BRUSHLESS MOTOR KV CONSTANT EXPLAINED

JULY 29, 2015 ERIC TUTORIALS 15

The most common description of a motor's Kv constant is that it is the ratio of the unloaded speed to the applied voltage of a motor. Or RPM per volt, as many people say.

The main problem with that description is that it is wrong. The other problem with that description is that it *seems* right.

And when something seems right but is actually wrong, it tends to cause a lot of confusion.

Why is it wrong? That's a long story (which I'm about to tell). But first, we need to know a little bit about brushed motors and back-emf.

Brushed Motor Model

I've explained the very basics of what a brushed motor is ***in another post***. One concept I didn't explain was the back-emf. In a motor, whenever there is relative motion between the magnets and the coils, a voltage is induced in the coils.

This voltage is called the back-emf. The back-emf is proportional to the rotational speed of the motor.

$$E = K_e * \omega$$

In this equation E is the back-emf, K_e is the back-emf constant and ω is the speed. K_e is often given in units of Volts/RPM.

Given this, we can make a simple model of a DC brushed motor. It consists of a …tor, an inductor, and a back-emf in series with an applied voltage. If we

Search

NEWSLETTER SIGNUP

Be the first to see new posts:

Email address

Sign me up!

RECENT POSTS

The Best Solder to Use for RC Electronics
Number of Drones Registered with FAA – State/County Maps
Drone (Quadcopter) Frame Sizes – Mini, Micro, Nano
Portable Lipo Charging Station: How to Charge in the Field
Top 10 Best Drone Books for 2017

RECENT COMMENTS

Eric on Brushless Motor Kv Constant Explained
Umar on How Do Brushless RC Motors Work
M on Brushless Motor Kv Constant Explained
John Hendry on The Best Solder to Use for RC Electronics
matt on Puffed Lipo Battery: Why they swell and what to do about it

CATEGORIES

Legal
Multicopter Community
Reviews
Tutorials

me that the current through the uit is a constant DC current, we can re the inductor in the model and we eft with a resistor and a back-emf in es. This is shown in Figure 1.

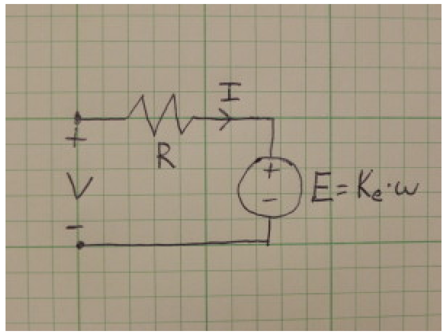

Figure 1 – DC Motor Model

g basic circuit analysis, we can e: $V = R * I + E = R * I + K_e * \omega$

n this simple model we can learn a bout a motor. For example, if we w the applied voltage, V, the motor stance, R, and the no-load current, I_0, we can determine the maximum speed of th notor:

$$\omega = \frac{V - R * I_0}{K_e}$$

In general, we can say that the speed of a DC motor is equal to the applied voltage minus the voltage drop due to the resistance and the current in the motor, all divided by the back-emf constant.

So as the current in the motor increases, the speed of the motor decreases. And because current is proportional to torque, we can also say that as the torque of the motor increases, the speed decreases.

Another thing we can do is see what happens if the motor speed is 0 and full voltage is applied. This situation occurs the motor can't rotate. For example, if you crash your quadcopter and the prop of one of the motors can't spin because the ground is preventing it from turning.

In this case the back-emf reduces to zero and the current is equal to the applied voltage divided by the resistance: $I = \frac{V}{R}$. Because the resistance can easily be measured and the applied voltage is known, the current when the rotor is locked can be found easily.

But that doesn't really answer the question of what Kv is or why it is misunderstood.

What about Motor Kv?

As I mentioned above, Kv is often taken to be the RPM/Volt of an unloaded motor.

In other words, if you apply 1 Volt to an unloaded motor, the Kv constant tells you how fast the motor will rotate. Then if you apply 2 Volts, the motor will rotate twice the value of Kv.

And, to be honest, this will get you pretty close. It's not a bad estimate.

But thinking about it this way will prevent you from understanding what is really going on in a motor.

So what is wrong?

Motor Kv has nothing to do with the applied voltage. Instead, Kv has to do with the back-emf I talked about above.

The motor Kv constant is the reciprocal of the back-emf constant:

$$K_v = \frac{1}{K_e}$$

So Kv tells us the relationship between motor speed and generated back-emf.

A 2300 Kv motor will generate a 1 V back-emf when the motor is rotating at 2300 RPM. At 23,000 RPM that motor will generate 10 V.

Brushless Motor Kv "Rating"

The model I described above was for a brushed DC motor. It turns out that everything above also applies to the type of brushless motors and ESC's that are used in RC quadcopters.

Even though brushless motors are a type of AC motor, the assumptions made allow us to use Kv in a similar way as with brushed DC motors.

However, I want to stress that Kv is not a "rating," but rather it is a motor constant. It tells you how the generated back-emf in the motor relates to motor speed. But it doesn't tell you how powerful the motor is or how much current it can handle or how efficient the motor is.

You can have a large motor and a small motor with the same Kv constant. The large motor will be more powerful than the small power. So there is no way to use Kv to tell you how powerful your motor is.

However, Kv is related to another important motor constant – Kt, the torque constant.

Brushless Torque Constant, Kt

The motor torque constant for brushed DC motors and brushless motors tells you how current relates to torque.

$$T = K_t * I$$

In this equation, T is torque, Kt is the torque constant, and I is current. Kt has units of Newton-meters per Amp.

How does Kv relate to Kt? While it is beyond the scope of this post, Ke and Kt are actually the same constant. They are equivalent. This means that

$$K_t = \frac{1}{K_v}$$

Another way of writing this is:

$$K_t * K_v = 1$$

All of these equations assume SI units (Nm/A and V/(rad/sec) for Kt and Ke, respectively).

Wait … What? How Can Kt and Ke be Equal?

They have different units, after all. Nm/A is different than V/(rad/sec). Right?

No, they are the same actually.

$$1N = 1\frac{kg*m}{sec^2}$$

$$1V = 1\frac{kg*m^2}{A*sec^3}$$

This tells us:

$$1\frac{N*m}{A} = 1\frac{kg*m^2}{A*sec^2} = 1\frac{V}{rad/sec}$$

Which tells us that the units are at least equivalent.

How do you Measure Kv?

The typical way to measure Kv is to spin your motor at a known RPM and then measure the voltage generated on the motor leads. Many hobbyists use a drill press to spin the motor. You could also use another motor. You can measure the RPM with a tachometer or ***strobe***. You can measure the voltage using ***a digital multimeter***.

For brushed DC motors, you would measure the voltage between the two motor leads. For brushless motors, you would measure the RMS voltage between any two leads.

The formula to calculate Kv for brushless motors is:

$$K_v = \frac{Speed}{Volts*1.414*0.95}$$

This is just speed divided by voltage but the 1.414 term is to convert RMS voltage to peak voltage. The 0.95 term is "fudge factor" that has been found by hobbyists to give you the right answer.

The formula to calculate Kv for a brushed DC motor is to just divide the speed by the generated DC voltage that you measure using your multimeter.

Another option for brushless motors is to buy a BL motor tester that will calculate Kv for you. One example of this tester is ***here***, but there are other available out there.

Conclusion

The main thing I want you to take away from this post is that when a motor rotates it generates a back-emf. That back-emf is proportional to the motor speed and the Kv constant tells you how they relate to each other.

For rough calculations, you can treat Kv as the RPM/Volt (meaning, the speed the motor will turn per applied volt) but that will always be an approximation.

← **Previous article** **Next article** →

15 COMMENTS

Trevor Benjamin
MARCH 25, 2016 AT 12:03 PM

Reply

Thank you for your helpful and comprehensive note.

The problem is that Kv tells so little about the motor.

Before reading your note I wrote the following to encourage the publication of the Wattage data.

I too was confused.
Kv is the NO LOAD speed for 1V input. If you have 10 volts you will get 10 times the speed with no load.
But you want power as well as speed for your model, so the Kv rating is not much use as a guide.
As you may have already found you can get a 2500 Kv motor weighing 19g for £5 and also a 2500 Kv motor weighing 364g for £40. The first has a rated power of 235 W and the second 2 1/2 kW !
You do need more information but this seems to as much a mystery to distributors as it is to us.
Taking the kit manufacturers' recommendation is a reliable action but if the model is your own it is likely to be trial and error.
Increasing the Voltage will give you more power as will choosing a lower Kv but the motor might not fit.
Kv is a hangover from brushed motors whose speed is governed by the voltage and the load. Brushless motors are controlled by the frequency from the Electronic Speed Controller and the 'throttle' setting and like brushed motors there has to sufficient 'overhead' voltage to provide power to your propeller or drive chain.
The copper windings, the magnetic strength and the quality of the design limit the power you will get from a particular maker's motor. Without a chart (straighforward) of Volts/rpm/Watts you are in the dark. As an indication a high Kv motor runs fast and will be smaller, but you still do not know if the power is enough. I sympathise.

michael.szabo
JANUARY 16, 2017 AT 10:31 PM

Reply

I wish you were my variable speed drives professor. Thank you good sir!!

Eddy
JUNE 18, 2017 AT 7:42 AM

Reply

It's a pity en confusing that every post i read about the Kv value indicates it's a rpm/volt value 🙁 for brushless motors only the frequency and the number of poles determine the rotation speed (rpm = f/pp)! Voltage is not in the formula! The only use of the Kv value for brusless motors is to get an idea about the torque… But that being said, this is however one of the best articles i read until now on this subject! 🙂 Grtz…

Kenny
JULY 19, 2016 AT 2:54 AM

Reply

One question …. if you wrote 1 Nm/A is 1 {(kg.m^2)/sec^3}.sec, which becomes 1 V.sec or 1V/(1/sec), then where did the 'unit' of rads spring out from?

Eric
JANUARY 12, 2017 AT 9:04 AM

Reply

Kenny,

Yeah, that's a bit confusing. The short answer is that even though the radian is a unit of measure, it is a dimensionless quantity. 1 radian is the angle you get when you take a circle's radius and sweep out an arc on that circle. 1 radian is just the ratio of the length of that arc divided by the length of the radius. length divided by length is a dimensionless quantity. So it's a bit of a trick but you can just add radians in without effecting the dimensions.

RC Roundup
NOVEMBER 22, 2016 AT 7:57 AM

Reply

Hey there, just wanted to let you know that we referenced this article in our latest post. Thanks for the great information on KV and motors. We were talking about boosting the speed of your RC car and how KV can have an effect on that. Cheers!

Peaky
MARCH 9, 2017 AT 2:50 PM

Reply

Hello all,
Not using a brushless motor for maximum thrust as in a quadcopter, but instead to drive a model locomotive at various realistic looking speeds, I am curious how I might reduce the slow running speed when the stick is nearly right back. Is it the ESC that needs attention to provide a lower frequency than normal for aircraft?

Paolo
APRIL 20, 2017 AT 4:10 PM

Reply

Hi,
that Ke and Kt have the same unit is clear. But why have them also the same value? I'm confused 🙂
Best regards.

Zak
JUNE 28, 2017 AT 2:09 PM

Reply

There is actually a fairly simple explanation which I am surprised wasn't put in the article. From definition in the article, $Kv = w/E$ where w is angular velocity and E is the back-emf generated (voltage effectively). $Kt = T/I$ where T is torque and I is current. $Kv * Kt = (w*T)/(E*I)$. $w*T$ = power output of the rotating shaft. $E*I$ = power due to electricity flow (ie electrical input power). Assuming no power losses, the power input is power output so $Kv*Kt$ = power/power = 1. Therefore in an ideal scenario $Kv * Kt = 1$, $Kt = Ke$. Realistically motors are up to 90% for brushless motors, so it's approximately correct for rough work.

Eric
JUNE 28, 2017 AT 3:37 PM

Reply

Yes, that's a very good explanation. We know that back-emf voltage is proportional to speed (that is, $E = k*w$, where k is some constant). We also know that the ideal power conversion in a motor is $E*I = T*w$

(back-emf times current equals torque times speed). When you plug in the first equation into the second you get k = E/w = T/I. We know that E/w is the back-emf constant, which is just the inverse of Kv and we know that T/I is the torque constant. So that value k above is really tells us how speed relates to back-emf and how current relates to torque. We just split them up in to 2 different constants for convenience.

M
NOVEMBER 5, 2017 AT 4:50 PM

Reply

I think there's a constant of (2*pi)/60 to correct for w being in rad/sec and Kv being in RPM. By my calculation:

RPM = Kv *V
Torque = Ki*I
Torque = Force*radius = F*r
Power = Voltage*Current = V*I
Power = Force*Distance = F*d
= F *(r*2*pi)*rps
= T*2*pi*rps
= T*2*pi*(V*Kv/60)
= (Ki*I) *2*pi*(V*Kv/60)
= Ki*2*pi*Kv/60
60/(2*pi) = Ki*Kv
60/(2*pi) = 9.54930

Eric
NOVEMBER 16, 2017 AT 3:35 PM

Note that my claim is that Ke = Kt. That is, the back-emf constant = the torque constant. And these are only equal when we are using Nm for torque and rad/sec for speed.

Kv, on the other hand, is usually measured in RPM / V, not rad/sec / V. It just so happens that the conversion from rad / sec to RPM requires you to multiply by 9.5493.

In other words, we started out with different assumptions about units, I think.

David Lewis
MAY 28, 2017 AT 3:09 PM

Reply

For a model locomotive, a high gear ratio is beneficial. Also I believe there are digital throttles that give realistic acceleration. The switching frequency of the ESC probably doesn't have much effect.

David Lewis
MAY 28, 2017 AT 3:12 PM

Reply

Also, the bit resolution of the ESC will have a huge influence on realism. Inexpensive aircraft ESCs might have only 8 steps.

Gregc
JUNE 30, 2017 AT 12:09 AM

Reply

I hope you meant 8bits of resolution(256 steps), not just 8 steps, which would be 3 bits. I think even a high end flight controller wouldn't be able to stabilize a quad flying with motors that had only 8 different speeds.

Leave a comment

Your email address will not be published.

Comment

Name *

Email *

Website

Post Comment