Torque relationship to speed in a DC motor

I have a conceptual doubt about torque-speed relation in a DC motors. It's probably a gap in my thinking but I'm posting this question anyway.

Torque and speed in a DC motor are said to be inversely proportional. But doesn't an increase in torque result in increase in Angular Acceleration and consequently, angular speed?

I know that back EMF/counter-EMF is responsible for the inverse relation but it seems counter intuitive to me. What happens to the angular acceleration, angular speed when the torque is increased and where does all that work go?

dc-motor speed torque back-emf

edited Nov 17 '13 at 18:04
JYelton
15.7k 27 84 181

asked Nov 17 '13 at 15:32
Vineet Kaushik
432 2 10 16

7 Answers

Conceptually, you have to think about this slightly differently. The way I *think* you are thinking about this is kind of like torque in a vehicle. A car with more torque is going to accelerate more quickly and is associated with an increase in speed. In other words, you press on the gas pedal to increase the speed and you need torque to do that.

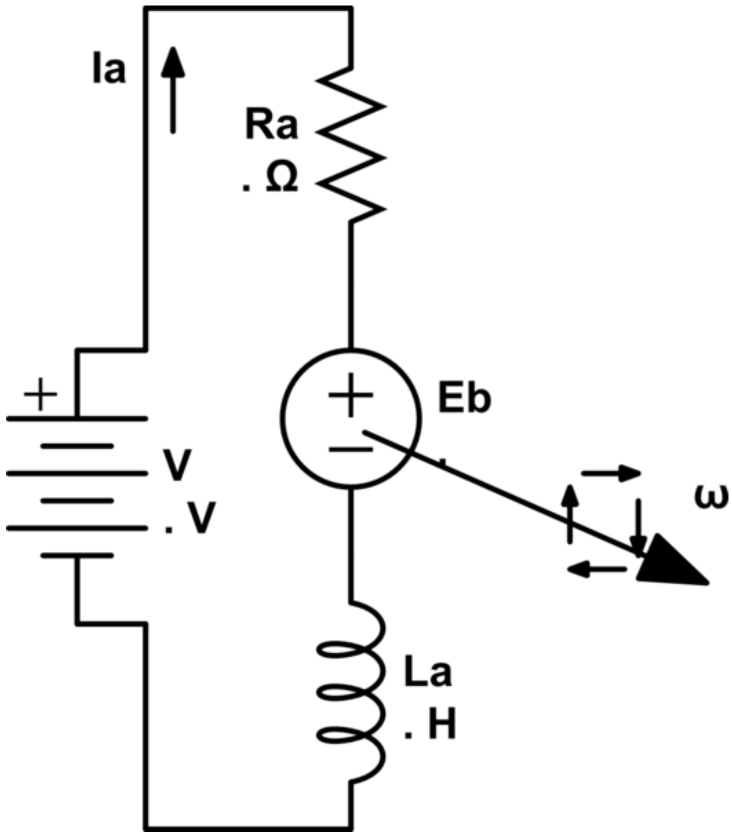
However, when you are talking about the relationship between speed and torque of a DC motor, then you have to think about it differently. For a given motor with a constant input voltage, the speed of the motor is going to be determined by the load on the motor shaft. For a given load, the only way to increase the speed is to increase the voltage. And this increase in speed will require some more torque to accelerate but after it reaches its new speed, the torque will back off to its original torque (unless, of course, the load is dependent on speed - like in a fan).

So maybe a better way for you to think about it is instead of saying "Torque and speed in a DC motor are said to be inversely proportional" you say "***For a given voltage***, torque and speed in a DC motor are said to be inversely proportional." A speed-torque curve that you see on data sheets is *only* valid for the rated voltage and the motor will operate on that curve. So if torque goes up, the speed will follow that curve and go down.

answered Nov 19 '13 at 17:08
Eric
2,555 9 18

1 Just a quick example. Think of a DC motor driving a belt conveyer in a constant voltage. What it can carry faster, 1kg load or 100kg load? Ofcourse 1kg, because it requires less torque, it is easy for the motor, and it can go with higher rpm. When carrying 100kg load it needs more torque, it is harder for the motor and it goes with lower rpm. So torque is not increasing by input voltage, but it is increased because the load requires that minimum torque, so DC motor sacrifices the speed in order to obtain that torque. – Farrukh Nov 13 '17 at 19:20

Exact. Also, one can think of DC motor as engine with built-in load governor, that is the significance of back emf, it changes with speed so that drawn current meets need of load torque, d dynamic changes in speed settles down to stable point on torque speed curve, so that motor torque equals load torque and then motor operates at corresponding speed. The operating speed point at this torque (for given voltage and other parameters) is fixed and can be changed by suitably modifying speed torque characteristics.So u r not putting in extra torque, instead u r driving extra load, hence less speed – Deep Apr 12 at 14:57



simulate this circuit – Schematic created using CircuitLab

This is a steady-state approximation of a dc motor that works fairly well with some types of dc motors(see comment by supercat). Since steady-state, the armature inductance L_a is neglected. We have the following:

$$\begin{aligned} V &= \text{input dc voltage} \\ R_a &= \text{armature resistance} \\ E_b &= \text{back-e.m.f} \\ \omega &= \text{angular rotational frequency of shaft } = \frac{2\pi \cdot \text{speed}}{60} \\ I_a &= \text{armature current} \\ K_e &= \text{back-e.m.f constant} \\ K_T &= \text{torque constant} \\ T &= \text{shaft torque} \end{aligned}$$

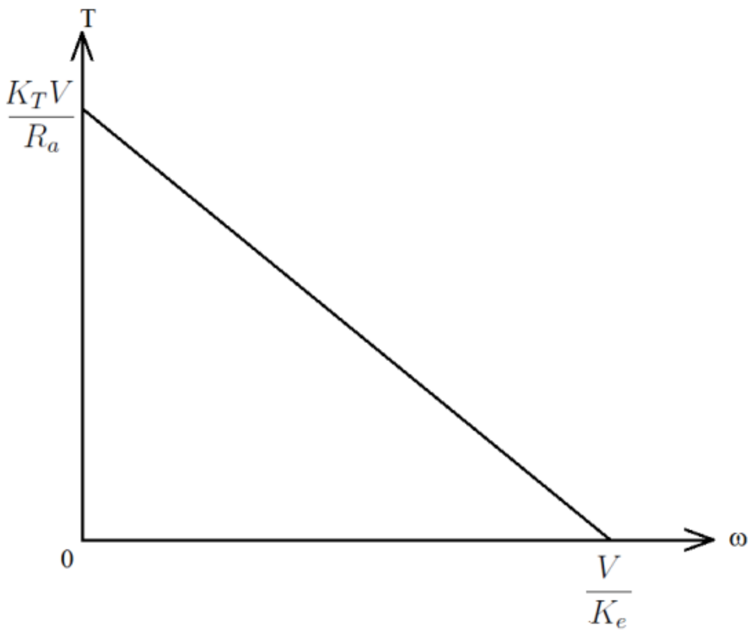
and the following equations apply:

$$\begin{aligned} E_b &= K_e \cdot \omega ...(1) \\ T &= K_T \cdot I_a ...(2) \\ E_b &= V - I_a R_a ...(3)(\text{obtained from equivalent circuit sl} \end{aligned}$$

from the above 3 equations,

$$T = \frac{K_T V}{R_a} - \frac{K_e K_T \ \omega}{R_a}$$

The equation relating torque and speed(or frequency) is graphed below , clearly showing torque is inversely proportional to speed:



edited Nov 19 '13 at 22:04

answered Nov 19 '13 at 21:44

K. Rmth
272 3 16

The other answers amply cater for your conceptual doubt. My answer focuses only on the torque-speed relation. – K. Rmth Nov 19 '13 at 21:45

I don't think it's a good approximation for series-wound motors only if current is fixed, or for shunt-wound motors only if the voltage is fixed. Otherwise the torque "constant" of the motor will depend upon the armature current, which will in turn depend upon the voltage drop of the rotor, which will in turn depend upon the torque [non]constant. Note that a series-wound motor driven with a constant voltage would run infinitely fast in the absence of *mechanical* friction or loading (despite the presence of electrical resistance!) – supercat Nov 19 '13 at 21:51

@supercat yes,my bad since i had the habit of working with this type of equivalent circuit and for the motors you mentioned,assuming the motor is operating in a range where the variations are negligible. I edited my answer following your comment. – K. Rmth Nov 19 '13 at 22:07

What happens if you power the motor from a constant current source instead of the usual voltage source? – richard1941 Feb 25 at 12:48

For a constant power delivered to the mechanical load torque and speed multiplied together is a constant. That's the basic definition of power ie

Power $= 2\pi nT$ where n is revs per second and T is torque.

An increase in torque (and by torque increase I mean the angular force produced when the mechanical load increases) naturally produces a slowing down of the armature if power in is constant.

However, "dc motor" could mean anything and quite a few motors will have field windings that exhibit "constant power" type effects whilst others (with different field windings) will work as constant speed regulators and thus for an increase in torque (due to the load), the speed stays almost constant.

Other type of dc motors can have electronic controllers that do the same; they sense the current and as it rises, they increase the dc voltage to the armature and this can achieve near constant speed.

I think you are confusing real torque with the ability (or potential) to deliver real torque. Without a mechanical load torque is meaningless except for the mechanical losses in the motor.

edited Nov 17 '13 at 16:22

answered Nov 17 '13 at 16:13

Andy aka

Current ~= Torque

Voltage ~= (angular) Velocity

(to be fair almost all machines kind of follow this as well but it becomes less and less proportional and more "in some way related", eg freq)

You have two constants (kind of constants) when it comes to electrical machines

Kt & Ke

Ke is the open-terminal voltage constant with units: Volts/w. This produces a BackEMF

Kt is the torque constant with units: Nm/A

in theory Ke == Kt, but Kt is effected by iron characteristics (hence why two exist).

The Reason that Torque and Speed are said to be inversely proportional is the ability to generate torque diminishes with increase speed.

The reason for this is because the BackEMF opposes the supply that is attempting to force current into the stator, that will generate EM-Torque.

You are right that for a certain application of Torque a certain amount of acceleration will be generated based upon the rotor inertia and load inertia, BUT this torque will be reduced with increased speed as well (windage, bearings etc...). So between a diminishing ability to force current into a machine at increase speed as well as increased losses at higher speed the rate of acceleration will diminish until finally noload-speed is reached (or some loaded speed when compared to the load torque and the generated torque)

edited Nov 17 '13 at 17:26

answered Nov 17 '13 at 17:20
JonRB
12.1k 2 18 38

I agree that increase in torque will definitely increase the angular acceleration , But it does not mean that speed will always increase by increasing torque or acceleration , For increasing speed torque should be positive(in direction of angular velocity) , not necessary increasing . suppose angular Velocity = + 50 rad/sec Eg1: torque1 = +5 N-m , torque2 = +10 speed increasing both cases . Eg2: torque1 =+5 N-m , torque2 = +3 speed is still increasing even after decreasing torque but definitely with a lesser rate .

Eg3: torque1 = -5 N-m , torque2 = -10 speed decreasing both cases . Eg4: torque1 =-5 N-m , torque2 = -3 speed is still decreasing even after increasing torque but definitely with a lesser rate .

In all examples angular velocity is assuming to be positive .

So I think you have doubt is in basic dynamics not in machine.

answered Jul 8 '17 at 18:09
user155331
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Any answer which seems to deny acceleration is proportional to torque or that power is not proportional to speed is just nonsense. There are answers here that seem to deny that but which are dressed up in sophisticated (=false wisdom) language. So let's be plain. If you increase the torque you increase the speed UNLESS you increase the load. The important thing to remember is that with electric motors there is a back-EMF (a motor is a generator too) which increases with speed and that limits the effective voltage and thereby the current and thereby the torque. But more torque? More speed. Ref Isaac Newton.

answered Sep 7 '17 at 14:43
Paul B
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More motor torque -> More speed. But More load torque and constant power - > Less speed. But hey, this is DC motor, it always "regulates" it's shaft torque to be equal to load torque! Unlike dieael engines in which you can "put in" more power (by controlling diesel spray) to get out more power, these DC machines works on principle which have sort of auto load governing mechanism hence you can not put in extra power well

The way i think is, as for steady state operation load torque must be equal to motor torque, now if load is increased for dc motor (shunt) , current will increase. Now in other way you can say if current drawn increases motor torque increases. Now as load increase, the motor speed will decrease and will stable at a speed lower then previous value, and hence you can say as load increase , current drawn increases but speed decreases. So you can conclude , as load(load torque) increases→motor torque increases but at the same time speed decreases as load torque is becoming more than motor torque.

answered Oct 17 '17 at 10:35

G93
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