What Does “Stall” Mean, and Why You Should Use the 775pro

By Anand Rajamani

How does a DC motor work?

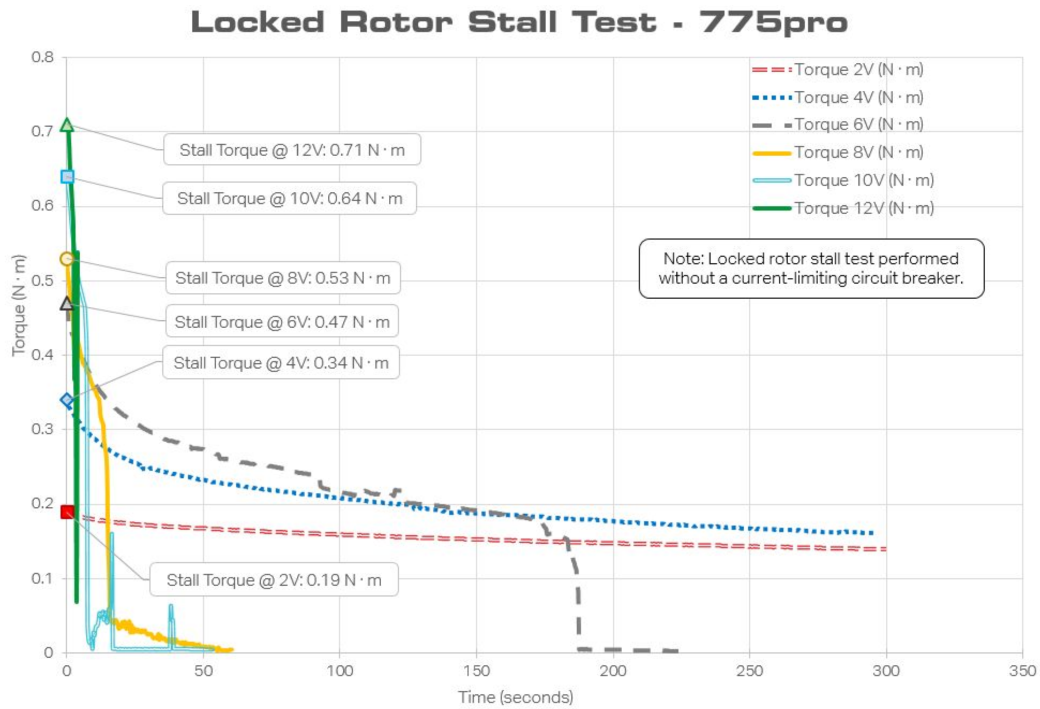
So first off, let’s talk about what happens to a DC brushed motor under normal operating conditions (e.g. while your lift is moving up or down). When your motor is running given a constant voltage input like 12V, the amount of current it draws decreases with its speed. Theoretically at “free speed”, the max speed of the motor, it draws 0A (or close to it), and at 0 RPM it draws “stall current”. These are the rated specs of a motor that you find on Vex or AM or what-have-you. Under these conditions, the motor acts as a sort of generator as it spins, so that part of the 12V is counteracted by the spinning of the motor to generate voltage, and the rest of it is just burned off in the resistance of the coils of wire. So for a motor with a free speed of 12,000 RPM at 12V, and a stall current of 120A, if it’s spinning at 10,000 RPM it will be drawing 20A (spinning at 5/6th of free speed means it draws 1/6th of stall current). This relationship is true for all motors used in FRC, excepting the Nidec Dynamo.

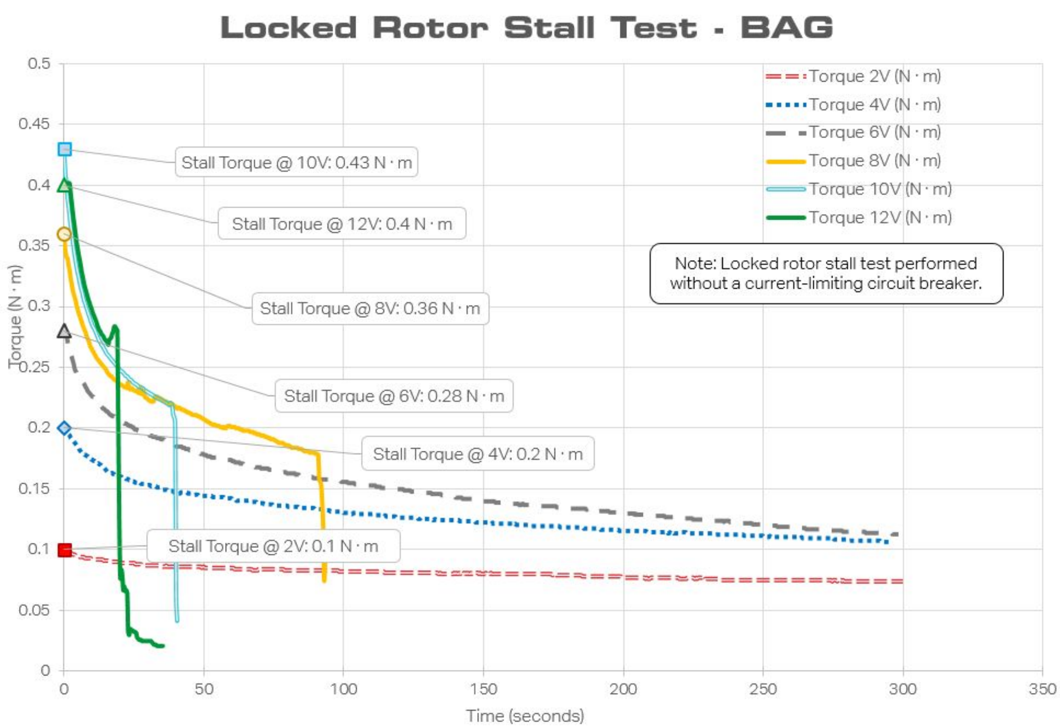
What makes the motor hot?

Now the voltage “generated” by the motor while it is spinning is not causing any power loss, it’s just dropping voltage. Power loss comes from the power dissipated in the coils as heat. Power loss is calculated as an extension of Ohm’s law using the equation $P = I^2 * R$, where P is the power in watts, I is the current in Amperes (amps), and R is the resistance in ohms. As a result, the slower your motor spins at a given voltage, the more current it draws, and the more heat it generates. The R for a motor is constant and is easily calculated using Ohm’s Law at stall current and rated voltage. For the 775pro, the R is 12V/133A = 0.090 ohms. For the BAG, it’s 12V/51A = 0.235 ohms.

Now when we’re talking about a motor at stall, all of the voltage is dissipated in the coils of the motor. That means that if we’re driving a 775pro at 12V, and the output isn’t spinning, it’s dissipating 133 amps into pure heat. Contrast with the BAG motor at a 12V stall and it’s dissipating only 51A. When, then, is the 775pro going to perform better than the BAG at stall?

The answer lies in the relationship between torque and current. The exact same current that creates heat also creates a proportional amount of torque. Brushed DC motors have a constant called “kt” which, when multiplied by the current passing through the motor, gives you its torque. See Appendix A for the calculations of kt for the BAG and 775pro, but for the purposes of keeping this concise we will assume they are the same. This means that if you need 20 amps with a BAG motor to keep your lift stuck in place, you will need 20 amps for a 775pro to keep your lift stuck in place as well. Now let's take a look at the "locked rotor stall test" for both the 775pro and the BAG.





Graphics and testing courtesy of motors.vex.com

When Vex says “Stall torque @ 4V” for the 775pro, what they are effectively saying is “stall torque at 44A” due to the I = V/R relationship between voltage and current at stall. The BAG motor at 4V, on the other hand, is only dissipating 4V/0.235ohm = 17A. As we discussed earlier, due to kt, the BAG motor at 17A is not going to have as much torque as the 775pro at 44A. If we use the BAG motor’s 10V stall curve we get 10/0.235 = 43A, which is a much closer comparison to the 775’s 44A stall. At 10V (43A) the BAG lasts around 30 seconds, while the 775 lasts over 300 seconds at the same current. This disparity in heat resistance could partially be due to factors such as the casing (polished steel versus the lacquer of the BAG) or the sealed vs. unsealed designs of the two motors. The 775pro weighs 0.1lb more, so it can store more heat before it fails. Furthermore, the 775’s integrated fan lets it cool down as it moves in non-stall conditions, unlike the BAG and its closed-case design, so for normal FRC operations the 775pro will last even longer. The bottom line is that at virtually any current draw, and therefore virtually any torque, the 775pro lasts longer than the BAG.

The Talon SRX motor controller allows you to control and limit the current draw of a motor directly, but designing your mechanisms to stay within the safe limits of the motor using the data at motors.vex.com is the best way to ensure that your mechanism puts out the maximum amount of work while remaining inside of safe operating limits. The Power Distribution Panel will also let you track your current draw to see if you are going over the safe limits, but that can be hard to program for many teams. In those applications where you want a safety from user error, a BAG motor can still be a useful option.

Appendix A: torque constants for the BAG and 775

The exact same current that causes heat also creates torque. These brushed DC motors have a constant called “kt” which, when multiplied by the current passing through the motor, gives you its torque. So for that 12k RPM 120A motor we talked about earlier, if we run it at 10,000 RPM and 20A and get an output torque of 2 inch-pounds, then the Kt is 0.1 in*lb/A (2 in*lb/20A = 0.1). It doesn’t matter what voltage we run the motor at; the kt will remain the same throughout its operating range. The BAG motor’s kt is 0.43 N-m / 53A (stall torque and current) = 0.00811 N-m/A, or 8.11 mN-m/A. The 775pro’s kt is 0.71 N-m / 134A = 5.30 mN-m/A. If a gear ratio is added to account for difference in free speeds (18,730 for the 775, 13,180 for the BAG) you get 7.53 mN-m/A for the 775 when you gear it down to 13,180 RPM free speed. These two kt are close enough that I’m going to pretend they are the same for the purposes of this writeup.

If you assume the adjusted kt are the same, then running a BAG motor and 20A and a 775pro at 20A will make the same amount of torque at the output. However, at 20A the 775 will be spinning a lot faster, approximately 1.2x as fast as the BAG, meaning it's also putting out 1.2x more power.