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1.) Some tests are performed on a permanent magnet electric motor. The motor is found to act nearly ideally with practically 100% efficiency. The locked-rotor torque is found to be 0.5 Nm when 12 V is applied and the locked rotor current is 32.7 A. The no-load speed is found to be 10 000 RPM, also at 12 V applied. The motor is used to drive a small fan. The torque needed to drive this fan is $T = [2.222\ \text{nNm/(RPM)}^2]S^2$ where $S$ is the speed of the fan in RPM. (The item in braces is 2.222 nano-newton-meters per revolution-per-minute-squared).

a.) If the fan is directly driven by this motor and, the motor is operated at 12 V, at what speed will the fan rotate?

The torque vs. speed equation (of the "curve"—actually a straight line) is

$$T = 0.5\ \text{N}\bullet\text{m} - [(0.5\ \text{N}\bullet\text{m})/(10\ 000\ \text{RPM})]S$$

Substitute the load equation for $T$ and solve for $S$

$$[2.222\ \text{nN}\bullet\text{m/(RPM)}^2]S^2 = 0.5\ \text{N}\bullet\text{m} - [(0.5\ \text{N}\bullet\text{m})/(10\ 000\ \text{RPM})]S$$

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$$[2.222 \times 10^{-9}]S^2 + [5 \times 10^{-5}]S - 0.5 = 0$$

$$S = 7\ 500 \text{ or } -30\ 000 \text{ RPM.}$$

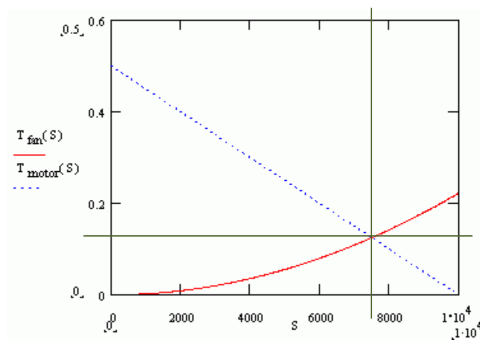
Assuming the fan is absorbing electrical power and forcing some air to move, the negative speed is illogical, thus choose

$\underline{S = 7\ 500\ \text{RPM}}$

$S := 0, 20 .. 10000$

$T_{fan}(S) := 2.222 \cdot 10^{-9} \cdot S^2$

$T_{motor}(S) := 0.5 - \dfrac{0.5 \cdot S}{10000}$




b.) For the conditions of part (a), how much electrical power will the motor draw?

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There are two approaches to solving this problem, find the current and multiply by voltage or find the torque and multiply by the speed (in radians/second) and divide by the efficiency (which is 100% in this case), being sure to answer in Watts. Current and torque are proportional, so either way, the torque must be found.

$T = [2.222\ \text{nN}\bullet\text{m/(RPM)}^2]S^2 = [2.222 \times 10^{-9}\ \text{N}\bullet\text{m/(RPM)}^2][7\ 500\ \text{RPM}]^2 = 0.125\ \text{N}\bullet\text{m}$

$I$ = (Locked rotor current)[(actual torque)/(locked rotor torque)] = (32.7 A)[0.125/0.5] = 8.175 A

$P = VI$ = (12 V)(8.175 A) = $\underline{98\ \text{W}}$

--OR—

If $\omega$ is the speed in radians/second, $\omega = S(1\ \text{min}/60\ \text{sec})(2\pi\ \text{rad/rev})$

$P = \omega T = = [(7\ 500\ \text{RPM})(1\ \text{min}/60\ \text{sec})(2\pi\ \text{rad/rev})](0.125\ \text{N}\bullet\text{m}) = 98\ \text{W}$

(continues on the next page)

c.) If the fan is operated at 10 V instead of 12 V, at what speed will the fan rotate?

The locked rotor current and torque, and the no-load speed are reduced proportionally.
The locked rotor torque will be (0.5 N•m)(10/12) = 0.4167 N•m
The no-load speed will be (10 000 RPM)(10/12) = 8333 RPM
The locked rotor current will be (32.7 A)(10/12) = 27.25 A
Now just repeat the calculations of part (a) with new numbers.

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$$[2.222 \text{ nN}\bullet\text{m}/(\text{RPM})^2]S^2 = 0.4167 \text{ N}\bullet\text{m} - [(0.4167 \text{ N}\bullet\text{m})/(8333 \text{ RPM})]S$$

$$[2.222 \times 10^{-9}]S^2 + [5 \times 10^{-5}]S - 0.4167 = 0$$

$$S = 6\,472 \text{ or } -28\,974 \text{ RPM.}$$

Assuming the fan is absorbing electrical power and forcing some air to move, the negative speed is illogical, thus choose

<u>$S$ = 6 472 RPM (or about 6500 RPM)</u>

d.) For the conditions of part (c), how much electrical power will the motor draw?

As in part (b), but with new numbers,

$T = [2.222 \text{ nN}\bullet\text{m}/(\text{RPM})^2]S^2 = [2.222 \times 10^{-9} \text{ N}\bullet\text{m}/(\text{RPM})^2][6\,472 \text{ RPM}]^2 = 0.0931 \text{ N}\bullet\text{m}$

$I$ = (Locked rotor current)[(actual torque)/(locked rotor torque)] = (27.25 A)[0.0931/0.4167] = 6.087 A

$P = VI$ = (10 V)(6.087 A) = <u>60.87 W</u>

--OR—

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If $\omega$ is the speed in radians/second, $\omega$ = S(1 min/60 sec)($2\pi$ rad/rev)

$P = \omega T$ = [(6 472 RPM)(1 min/60 sec)($2\pi$ rad/rev)](0.0931 N•m) = <u>63 W</u>

(There must be some roundoff error.)

2. Lin Engineering makes stepper motors. Use the Web to look up the specifications and "torque curve" for a NEMA size 11 stepper motor with a step angle of 1.8 degrees, and choose specifically model number 211-13-01. On the top of the torque curve you will find the operating voltage and current. The current specified there only applies when the rotor is stationary. In most stepper motor applications the rotor is stationary most of the time, but as speed increases current decreases due to speed voltage, as we discussed in class. The ratio of the voltage and current at the top of the torque curve gives you the winding resistance.

a.) Extrapolate the locked rotor torque (also known as "running torque") and no-load speed from the torque vs. speed curve. Compare to the "Holding Torque" specification. Why is the holding torque larger? (See Jones, Figure 2.6)

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The locked rotor torque is about 6.6 oz-in.
The no-load speed is about 28 000 half-steps/sec or 70 RPS or 4200 RPM
(A half-step = one pulse since half-stepping drive pulses are assumed for this motor.)

When the rotor is stopped and then torque is applied the rotor turns to the position of maximum torque, just ever so slightly ahead of a half-step out of phase with the driven pole face. However when the motor is running the pole face experiences an average torque as the rotor moves past the stator poles. Since the magnetic fields are not always aligned to the maximum torque position the average torque available for rotation is lower than the holding torque.

b.) For a frictional load of 3 oz-in, what is the maximum speed in RPM? (Note: in RPM).

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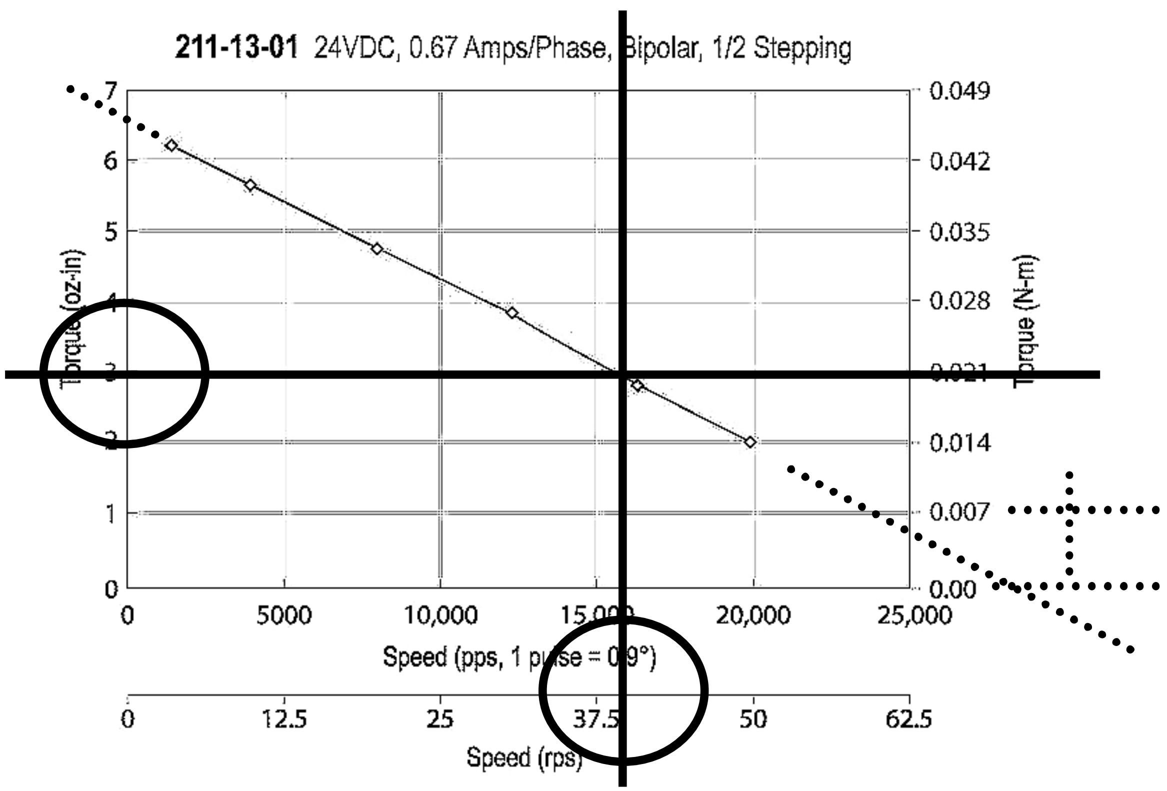


Interpolating from the given torque vs. speed curve, the speed is (40 RPS)(60 sec/min) = 2400 RPM