

Determining Quadrature Angle for DC motor operation

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ECE 480 Application Note

Executive Summary

Electric motors are used in a variety of applications, with a large focus in the automotive industry. The emergence of electric vehicles in recent years has been due to the desire for energy efficient machines. DC motors in current applications can approach efficiencies above 90%. This is largely a direct result of efficient design for maximizing the power usage going toward motion as opposed to heat. To plan and design for this efficiency, there must be a method for determining the most efficient way to apply current to the motor and minimize losses. In any motor, there is a specific angle the rotor shaft can be with respect to the stator that will be the most efficient place to apply current to energize the magnetic fields. The angle is called the quadrature point, and to optimize the efficiency of an electric motor, this angle needs to be determined precisely for each phase.

Objective

Throughout history, improving efficiency of machines has become more and more of a concern for engineers. One of the main fields where improving efficiency is strongly emphasized is in motor design. Motor efficiency can always be slightly improved through the use of more expensive and accurate parts. But, this efficiency increase eventually has diminishing returns. The main area where efficiency of motors can be improved is in upgrading the way in which power is applied to the motor. With any motor, there is a point on the rotor shaft where applying power is the most beneficial. This point is called the quadrature point and accurately measuring this point is a vital step in improving and maximizing the efficiency of a DC motor.

Procedure

Theory

To begin the process of measuring the quadrature point, we must first have a conceptual idea of what we are trying to measure. An analogy to consider helping visualize the concept is to imagine the task of pushing a car. Now, no matter what angle the car is pushed on from behind, the car will move. But, there is an angle that will require the least amount of work to move the car the same distance. If we examine Figure 1, we see a simple diagram of a 3-pole motor sequence.

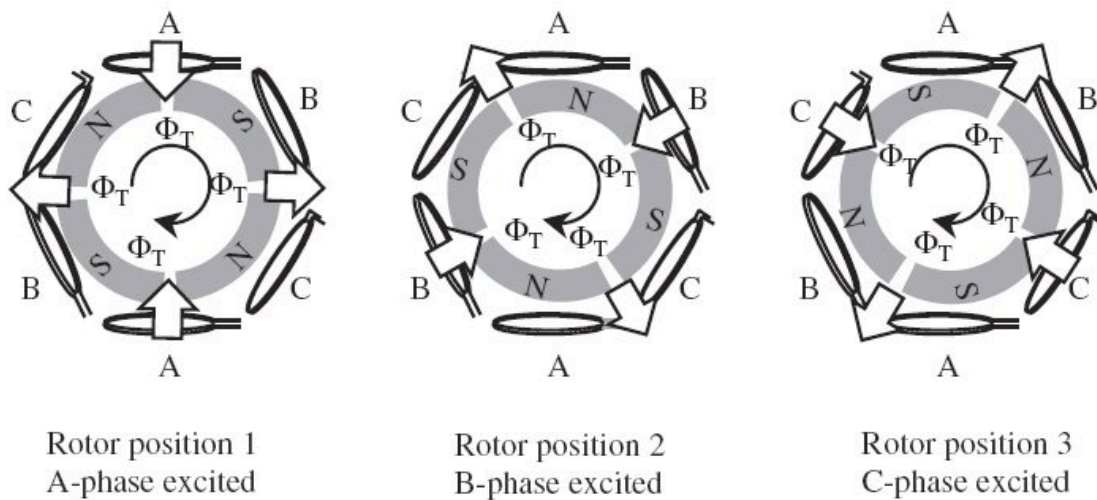


Figure 1: 3-pole Motor Sequence

This image shows that as each iteration of the coil sequence is excited, the rotor shaft generates torque. But by honing in and specifically calculating the time when each successive coil initiates our power losses minimize and our efficiency is greatly

increased. In theory, this point would be at an angle about halfway between two neighboring poles, as per the definition of quadrature, which is used to describe two signals with a 90-degree phase shift.

Steps

To start the measurement of a quadrature point there are a few pieces of equipment required. The required pieces of equipment are the motor and a stable power source (e.g. battery with a power resistor). To measure the quadrature point we will also need some sort of mechanical contraption that will allow us to measure the force exerted by the motor when the rotor and the stator coils are magnetized. The device we will use to measure the force exerted by the motor is shown in Figure 2.

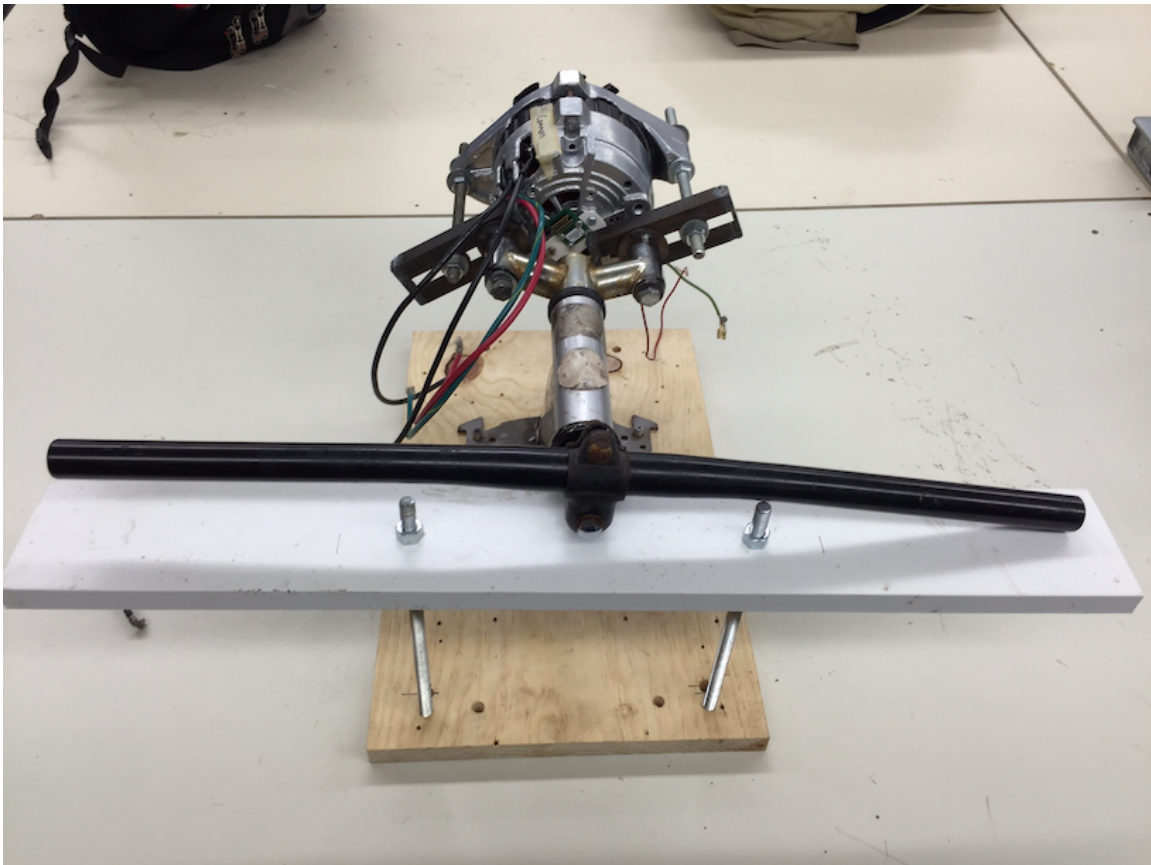


Figure 2: Motor Torque Measurement Device

To use this device, we must first attach the outer casing of the motor to the metal rods and adjust the position of the rods to ensure the AMS sensor located on the shaft of the rotor is in line with the rotating cylinder axis as shown in Figure 3.

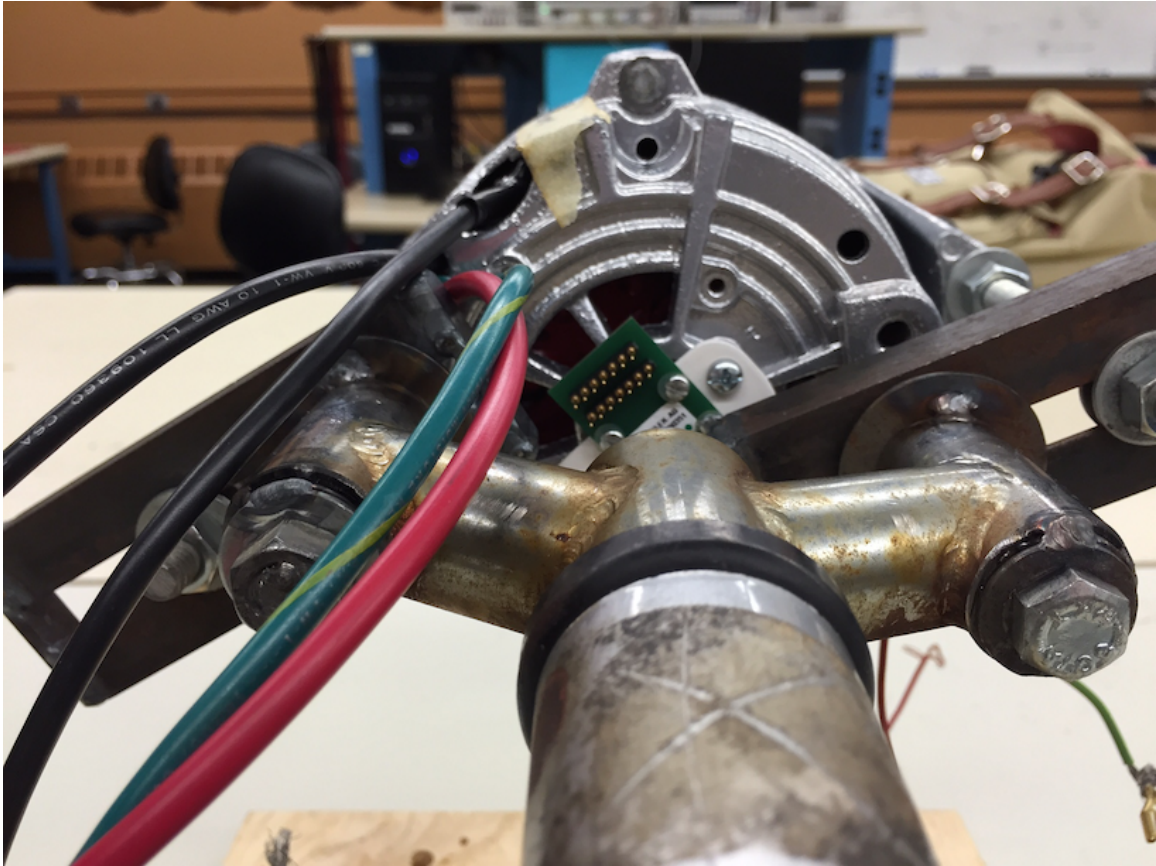


Figure 3: Position of AMS sensor

Once the motor is attached, operation and testing procedures should be approached with extreme caution. It is recommended to add circuit breakers to batteries if they are being utilized. Examples of batteries used are shown in Figure 4.

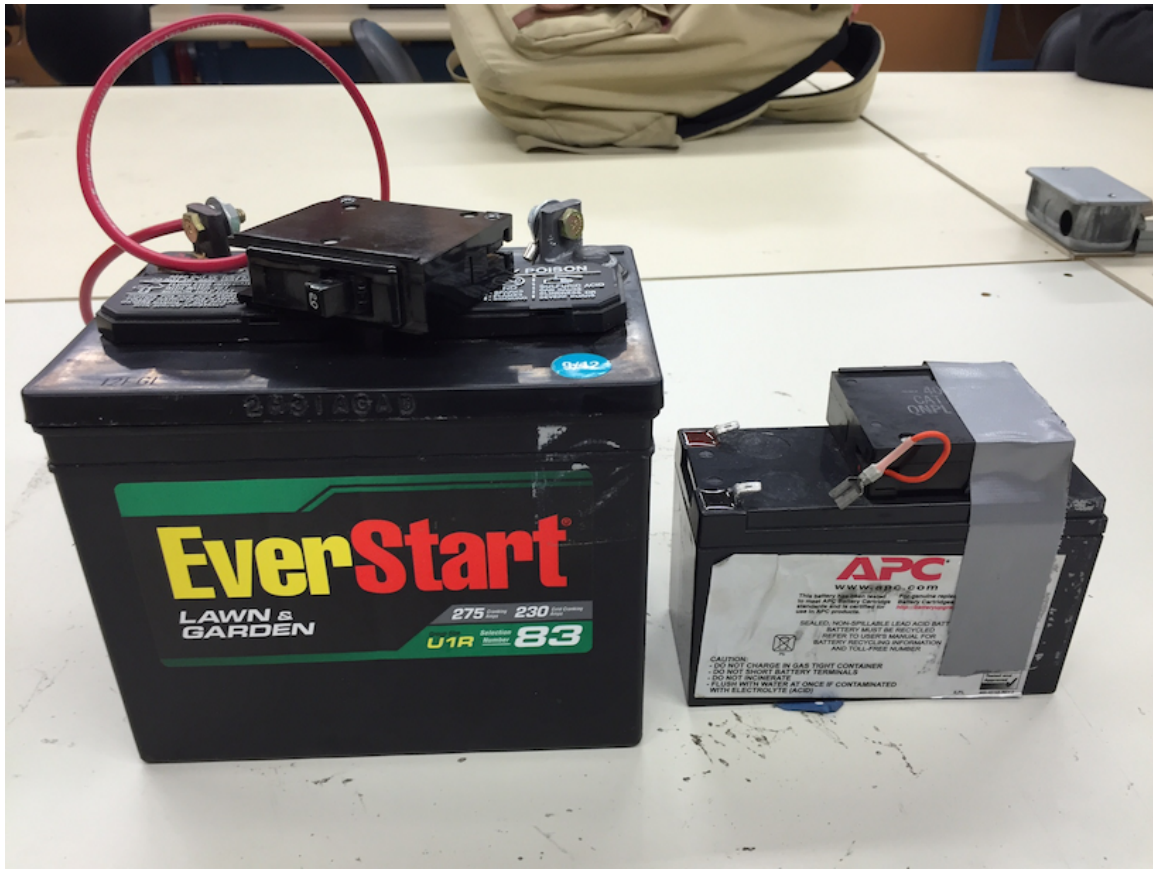


Figure 4: Batteries used for powering Rotor and Stator Coils

The batteries can now be attached to the rotor and stator if circuit breakers are attached. In addition to the torque measurement device, a small, precise scale will be used to measure the force the motor can exert. An example scale used is shown in Figure 5.



Figure 5: Example scale to measure force

The scale can now be placed on the device in the configuration shown in Figure 6.

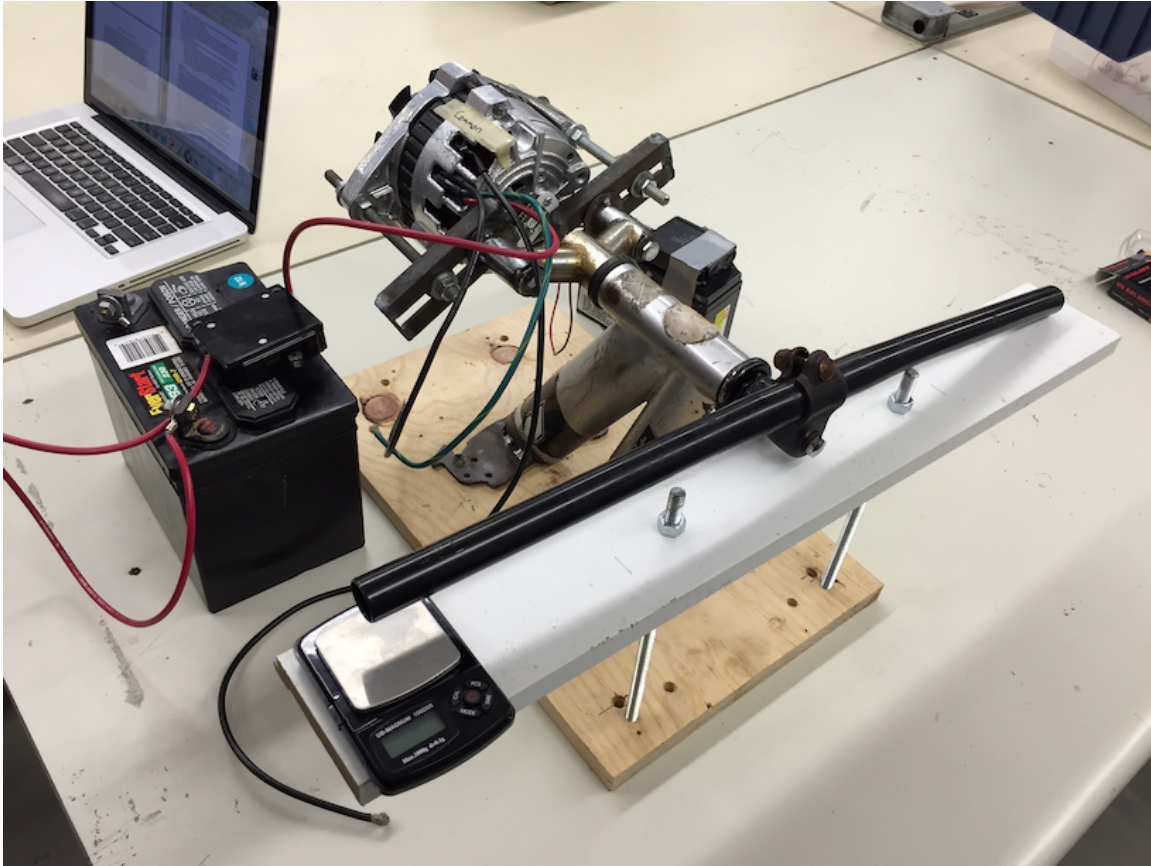


Figure 6: Setup to measure force

The final step in the setup of this test method is to attach the LCD screen that will display the angle of the rotor to the motor. Once the setup is complete, the measurement process can take place. The initial measurement to be made is to determine the angle that each coil is at, which will provide the reference frame. This measurement is done by energizing one phase at a time and allowing the stator and rotor to magnetize and lock into place. Once this happens, we know the angle displayed on the LCD screen is the angle of the pole. Once the angles are determined to each pole we are able to measure the quadrature points for each pole. The quadrature measurement is made by first energizing the pole in which you want to determine the quadrature angle. Once the rotor locks into place at the desired pole, the engineer is to then manually rotate the rotor against the magnetic field, which will cause the device to exert force on the scale. At some point during the rotation, the scale will read a maximum value. This maximum value will be the indicator that the motor pole is at its quadrature point. The angle displayed on the LCD, is the quadrature angle and can be used in further calculations involving the current application from the microcontroller.

Conclusion

Once measured, the pole and quadrature angle points on the rotor are very useful for programming the motor controller. Since these values are measured points on the device, they are static and are able to be hard-coded into the software. This simplifies programming the motor controller immensely, as these static data points can be referenced and changed easily without affecting the rest of the algorithm. Since the starting angle of the rotor varies from motor to motor, the general assumption can be made that on a 12-pole motor, the coils are about 30-degrees apart. This is simply calculated for any motor by taking 360-degrees and dividing by the number of poles. By knowing the pole locations, we are able to estimate the quadrature point for each pole to be about 15-degrees from each pole. This assumption is not accurate enough and needs to be precisely measured using the resolution of the microcontroller, not the LCD. From using the components above, the approximate angle of quadrature turned out to be around 16-degrees from each pole.

Recommendation

When measuring the quadrature angles, the force exerted when the rotor is turned may not have exactly one peak. There could be a very small distance between the two peaks, and it is to the team on how the motor controller should be programmed. For example, the team could use the middle point between the two peaks, or decrease the resolution of the angle calculation to eliminate the peaks.

References

Ways to measure force on a rotating shaft:

https://measurementsensors.honeywell.com/techresources/appnotes/Pages/Ways_to_Measure_the_Force_Acting_on_a_Rotating_Shaft.aspx

Measuring Torque and Horsepower:

<http://craig.backfire.ca/pages/autos/horsepower>