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Servo Motor Test Equipment
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PM Brushless Servo Motor Feedback Commutation Series – Part 1
Commutation Alignment – Why It Is Important

INTRODUCTION

The main difference in servicing permanent magnet brushless (PMBL) motors versus other kinds of motors comes down to correctly aligning the position of the feedback devices relative to the rotor magnet and stator windings so that the drive system is able to correctly commutate the excitation currents to the armature winding. This note explains what commutation is and why this alignment is necessary for correct commutation.

HOW MAGNETS PRODUCE FORCE AND TORQUE

Magnets always have two poles, north and south, and lines of magnetic flux flow out of the north pole and eventually into the south pole. The flux will always take the shortest possible path and the path of least resistance. In fact, a force will be applied to the magnet and surrounding objects to move them into a position that reduces the flux path length or resistance. You see this happen when you move a permanent magnet close to an iron or steel object. Forces are applied to the magnet and the object to move them together to provide a shorter and lower resistance flux path. This force toward a path of least resistance is the force that allows motors to generate torque.

Torque is simply a force applied to a radius for a rotating object. When you tighten a bolt with a socket wrench, you apply torque to the bolt shaft by applying a force to the wrench handle. In fact, if you use a torque wrench, the wrench will show you how much torque you are applying. As you know, the more force you apply or the longer the handle, the more torque you generate because torque is the force multiplied by the length of the lever arm. The Figure 1 shows a compass needle pointing north and then shows it pointing in a new direction after it has a torque applied to it from the magnetic flux provided by the horse shoe magnet.

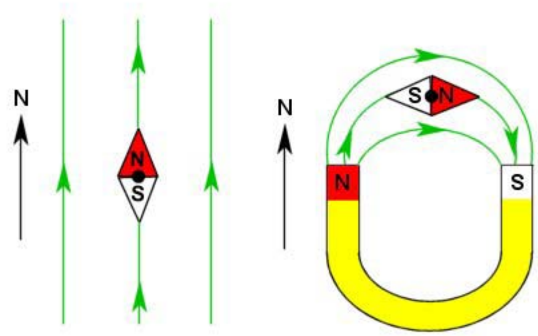

Figure 1 Alignment of Magnetic Flux Lines with Compass Needle

Electric motors rotate and produce torque to move rotating loads because of the torque produced by the interaction of magnetic fields within the motor. The compass pointer is similar to a motor rotor while the horse shoe magnet is similar to a motor stator field. This would represent a 2 pole motor because there are 2 magnetic poles on the compass pointer. Motors typically use electro magnets by winding coils around a soft iron core. Replacing the horse shoe permanent magnet with a stator winding and core makes the compass example more like a PMBL motor. For a PMBL motor, the fields are produced by windings in the stator and permanent magnets on the rotor. On the other hand, brush type DC motors will have windings on the rotor and either a permanent magnet or a field winding on the stator. Each layout has certain advantages that the motor designer takes into account for the particular application.

COMMUTATION

If we apply current to the winding in Figure 2, the rotor will move to the position which presents the path of least resistance to the magnetic flux and stay there. A device like this could be used as an actuator, but it does not remind us much of a motor. We expect a motor to start rotating and continue to rotate until we remove the current from the winding and not simply move to a position and lock up. In order to have a practical motor, we need a scheme to keep the rotor turning.

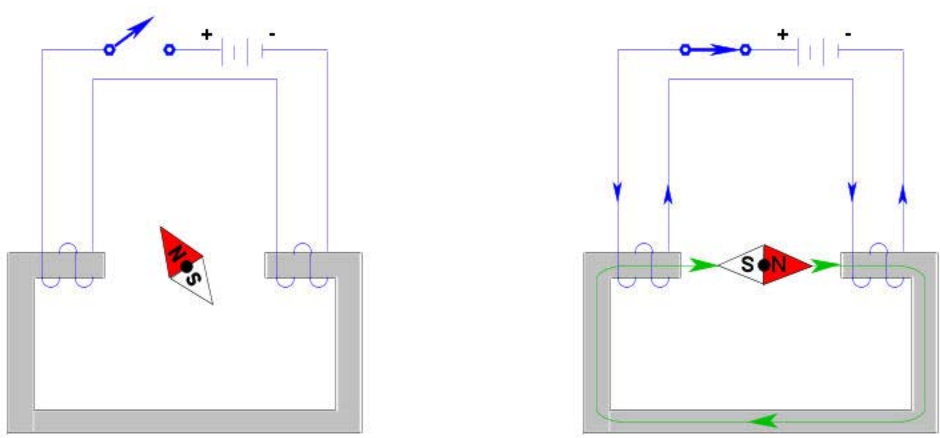

Figure 2 Torque from Flux Lines Aligning Compass Needle

If we add another phase to our stator winding, we can make some progress. In Figure 3 we can see how we might keep the rotation going. Figure 3A shows where the compass pointer will come to rest by applying a voltage to phase A. If we then apply a voltage to phase B, we see the pointer move 90 degrees clockwise (1/4 turn) in Figure 3B.

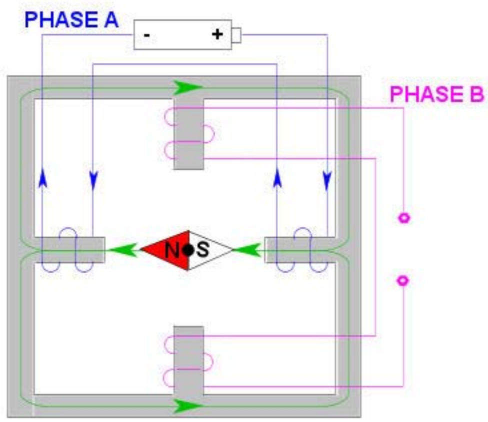

Figure 3A Phase A+ Compass Position

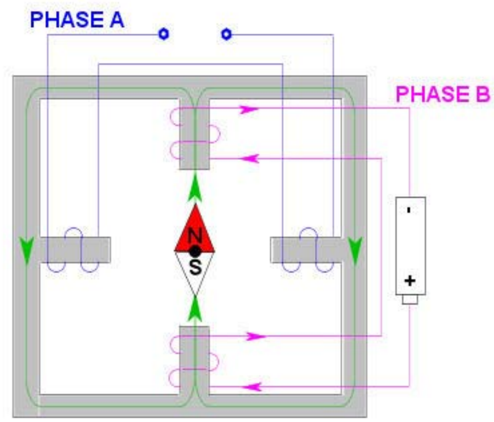

Figure 3B Phase B+ Compass Position

Figure 3C shows that if we then apply an opposite voltage to phase A, we move another 90 degrees clockwise. Finally by applying an opposite voltage to phase B we move another 90 degrees clockwise as shown in Figure 3D. Applying the original voltage again to phase A would move the pointer another 90 degrees clockwise back to the original position in Figure 3A. We could keep repeating this sequence and keep our 2 phase motor rotating.

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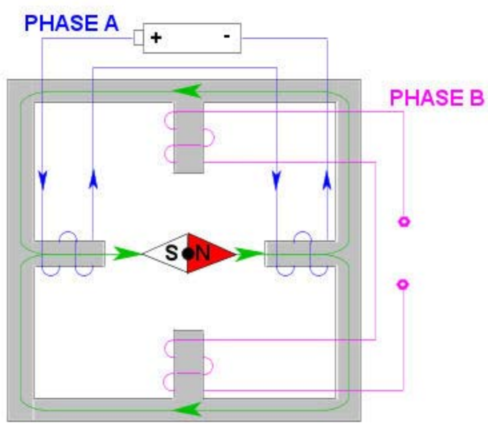

Figure 3C Phase A- Compass Position

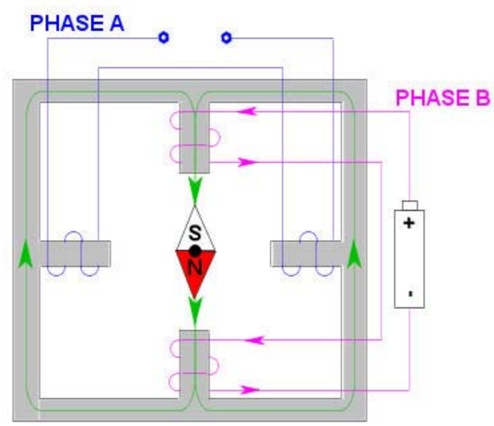

Figure 3D Phase B- Compass Position

We actually have designed a 2 pole 2 phase stepper motor which we can position at 4 different locations or keep rotating by switching the voltage in sequence. Commercial stepper motors typically have 50 poles instead of 2, and they can be positioned in any of 200 locations in one revolution.

Differences in servo motors and stepper motors are beyond the scope of this note, but in general servo motors need to run smoothly at high rotational speeds (RPM readings) and provide considerable torque over their speed range. This means that servo motors should not wait until the rotor stops moving before the voltage switches to a new phase. The voltage must switch while the rotor is in certain positions such that the magnetic fields are providing the maximum torque. This switching is called commutation.

Conventional brush type motors incorporate an ingenious mechanical apparatus using brushes and a commutator to achieve this. As the rotor turns, the commutator turns, thereby changing the windings to which the voltage is applied. The brush and commutator positioning is such that the voltage is always applied to a winding that will provide torque and never to a winding that is already in the position of the path of least resistance for the magnetic flux. It is similar to a dog chasing its tail or the carrot held in front of the horse. The rotor is never allowed to get to the stable position or rest. The brushes and commutator mechanically accomplish the switching of the voltage to the different windings at the correct time to keep the rotor moving. Again, this act of switching is called commutation.

For many reasons, not the least of which that brushes and commutators are maintenance problems, PMBL motors are becoming more and more commonly used. However, even though we can eliminate the mechanical brushes and commutator, we still need the process of commutation in order to keep brushless motors moving. This process of brushless commutation

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is achieved by electronically switching the voltage from winding to winding just as we did manually with our example of the 2 phase winding and compass pointer. The drive system can easily perform this switching to keep the motor moving. However, we do not want our servo motor to cog along like a stepper motor. We want a smooth running motor with good torque like we are used to with a DC brush type motor. To accomplish that, we must make sure that we apply the voltage to the winding that is currently in the proper position to apply the maximum torque. That, of course, requires that the drive know the position of the rotor magnets relative to the stator windings at all times. Accomplishing this requires that we add a new device to our system. We need to add the feedback device.

Feedback devices commonly used with PMBL servo motors are Hall effect switches, resolvers, incremental encoders, and serial encoders. Often they can be used for positioning as well as for commutation, but they must be present for electronic commutation.

For simplicity in the drawings, this concept has been shown for a 2 phase motor. Most modern servo motors are 3 phase, but the principle is the same. The feedback device reports the position of the rotor magnets to the drive so that it can apply voltage to the winding that will provide maximum torque in its current position.

FEEDBACK ALIGNMENT IN GENERAL

With the addition of the switching drive system and the feedback device, we have substituted electronic devices for the mechanical brushes and commutator system. From the previous discussion, we can see that the job of the feedback device is to synchronize the voltage applied to the windings with the position of the rotor magnets. Exactly how these are synchronized is up to the motor designer, and will vary greatly among different manufacturers. The basic idea is always the same, but the details can differ considerably.

Our automobile engines use a distributor to synchronize the crankshaft position and the spark plug ignition voltage to each cylinder. Maximum torque results when the distributor provides ignition to a cylinder when the fuel mixture is fully compressed nearly in position for the down stroke. We know that the engine will perform poorly or not at all if this timing is not adjusted correctly.

We have a similar situation with PMBL motors. The position feedback device synchronizes the relative rotor magnet and stator winding positions to the current provided by the drive. Maximum torque results if the current is applied to the winding when the rotor magnets are in a particular position range relative to the stator windings. The motor will perform poorly or not at all if this timing is not adjusted correctly. Unlike the engine, improper feedback alignment on the motor can actually cause it to run backwards sometimes resulting in a hazardous run away condition. Correct alignment is absolutely essential to proper operation of PMBL servo motors.

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FEEDBACK ALIGNMENT FOR THE TECHNICIAN

We have been talking from the perspective of motor and drive designers up to this point, but we really are interested in this technology from the perspective of the servo motor repair technician or plant maintenance person. In a sense designers have an advantage because they are making up the rules. They know how the feedback device must be aligned because they set it up to work that way in the first place. The technician must discover these rules and be able to check and (if necessary) correct the feedback alignment so that the motor can run with peak performance.

It is not difficult to expand what we have discussed to see that the technician must be able to perform the following checks with regard to the servo motor system:

1. Is the feedback device functional?
2. Is the feedback device aligned per manufacturer specifications?
3. Is the feedback device wired correctly?
4. Are the armature leads wired correctly?

You can probably easily see how any of the above problems could prevent the drive from applying the correct voltage to the correct winding at the correct time. The technician must know how to deal with testing and alignment because the alignment can be lost during repair if the feedback is removed. The feedback may have been removed by maintenance personnel during trouble shooting, or it may have been replaced (due to failure) causing loss of alignment.

Of course feedback alignment is only one of many repair steps for the busy technician, but it is one that is absolutely crucial. Without the proper tools this essential task is difficult if not impossible. <u>With the best quality modern test equipment</u>, feedback alignment can be performed quickly and accurately to assure the proper commutation required for a good running motor.

PMBL servo motors and drives comprise a modern motor system, and servicing them properly requires using the best modern equipment and techniques. How this can be accomplished by service and maintenance technicians is the topic of a follow-on application note, “PM Brushless Servo Motor Feedback Series – Part 2, Commutation Alignment – How It Is Accomplished”.