How to Set the Sensor Position Bias Angle

Application Note

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ABSTRACT

The MP6570 is an FOC controller with an integrated, high-accuracy angular sensor. To detect the rotor position, a magnet should be attached at the shaft of the motor (see Figure 1). The MP6570 detects the in-plane magnetic field components to obtain the rotor position. The magnetic angular sensor embedded in the MP6570 works as an absolute rotor position sensor. In the FOC algorithm, the electrical angle must be used for Park and inverse Park transformations. Therefore, the sensor position bias angle when the rotor is aligning with Phase A must be set first.

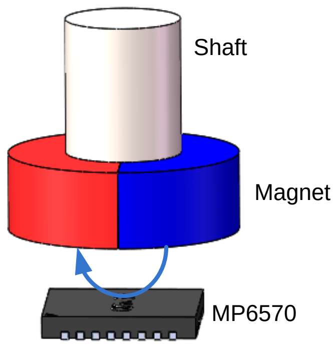

Figure1: How the MP6570 Senses Rotor Position

GETTING THE ELECTRICAL ANGLE FROM THE SENSOR ANGLE

A 3-phase PMSM/BLDC motor is composed of two parts: the stator and the rotor.

The stator is composed of three windings coiled on the stator core. The windings of the three phases are separately placed by the rule of 120°. When an AC current passes through the three phase windings, a circular rotating magnet field (Fs) in space is generated, and the rotating frequency is the same as the AC current frequency.

The rotor is composed of one or more pairs of permanent magnetic poles to offer a constant rotor magnetic field (Fr).

In steady-state operation, Fr follows the stator magnetic Fs with the same rotating speed. If we stand on the axis of rotor field Fr to see the stator magnetic Fs, the stator magnetic Fs becomes a DC component. This means that we can find a proper coordinate transformation to switch the three-phase AC components to 2-phase DC components for easy control. The 2-phase DC components, called the d axis (rotor flux axis) component and q axis (leading d axis 90°) component, can be decoupled and controlled separately. This is called field-oriented control (FOC).Normally, the d axis current ID is zero, so that the stator flux is perpendicular with the rotor flux to achieve better efficiency and larger torque.

If the angle theta between the rotor flux d axis and Phase A axis is known, 3-to-2 transformation can be done easily (see Figure 2). The angle between the rotor flux and stator phase vector A is defined as the electrical angle.

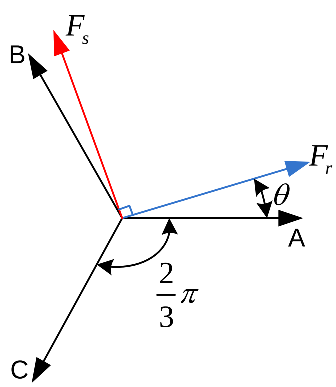

Figure 2:Electrical Angle

During manufacturing, the magnet maybe mounted arbitrarily on the motor shaft with no fixed relationship between the rotor pole and magnet pole alignment. For different sets of motors, the angle obtained from the MP6570 angle sensor differs from the rotor electrical angle by some offset (see Figure 3).

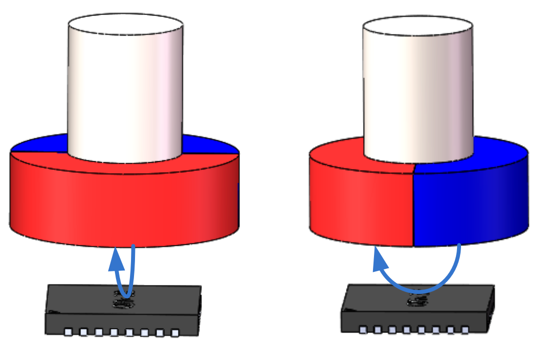

Figure 3: Magnet Mounting on Different Motors

If we know the sensor angle when the rotor flux is aligned with the stator phase A(θ_{bias}), the electrical angle can be obtained with Equation (1):

$$\theta = p(\theta_{sensor} - \theta_{bias}) \tag{1}$$

Where θ is the electrical angle, θ_{sensor} is the angle detected by the MP6570, and p is the motor pole pair number.

As defined, the theta bias (θ_{bias}) is the sensor angle value when the rotor flux is aligned with phase vector A.

FIND THETA BIAS USING THE MP6570

Figure 4 shows a space vector diagram.

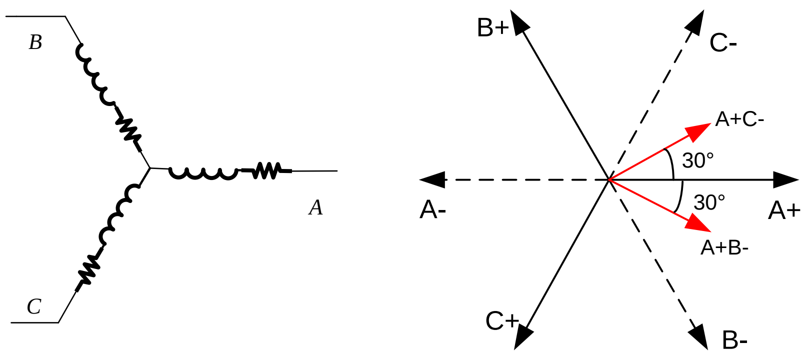

Figure 4: Finding Theta Bias in a Star-Connected Motor

When there is a positive current in motor winding A, the vector is shown as A+. When the current is negative, the vector is shown as A-. The six basic vectors are shown above.

To get the position when the electrical angle is zero, a current should be applied to the motor winding A. However, in a real motor, there is no way to apply current to phase winding A only. The current must flow via either phase winding B or C. The vector sum of A+B- and A+C- is also aligned with vector A. In the MP6570, to get the initial theta bias, the A/B/C switching logic is as below Fig 5:

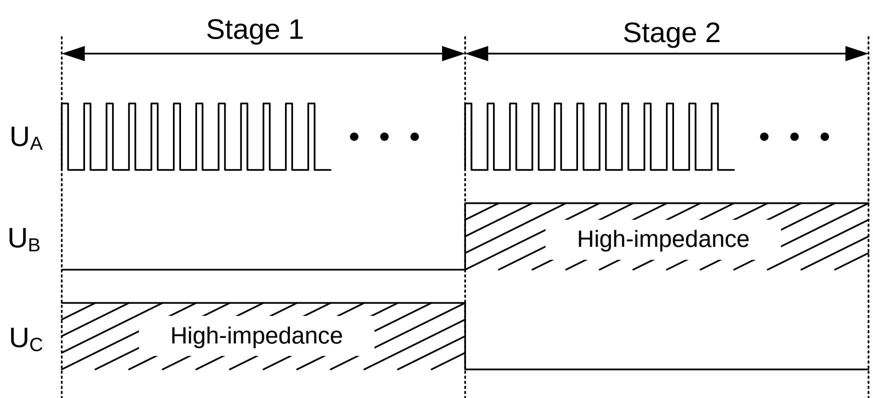

Figure 5: Switching Logic during the Auto-Theta Bias Period

During stage 1, Phase A is switching, the phase B low-side switch is on, and phase C is at high impedance. The rotor aligns to the A+B- vector position. During stage 2, Phase A is switching, phase B is at high impedance, and the phase C low-side switch is on. The rotor aligns to the A+C- vector position. By setting different Phase A duty cycles and time intervals, the torque current aligning the rotor can be controlled to match the characteristics of the motor used. This operation can be done automatically by setting the duty and time interval to corresponding registers. This is can be done easily by following this guide or using the *e*Motion Virtual Bench, the GUI software developed by MPS.

Please see Appendix 1 for details for getting the theta bias using the MP6570.

STAR AND DELTA CONNECTED MOTORS

The stator windings of three-phase BLDC/PMSM motors are made of three coils. There are two common electrical winding configurations: star and delta. The star configuration connects all of the windings to a central point, and power is applied to the remaining end of each winding (see Figure 6a).The delta configuration connects three windings to each other in a triangular circuit and power is applied at each of the connections (see Figure 6b).

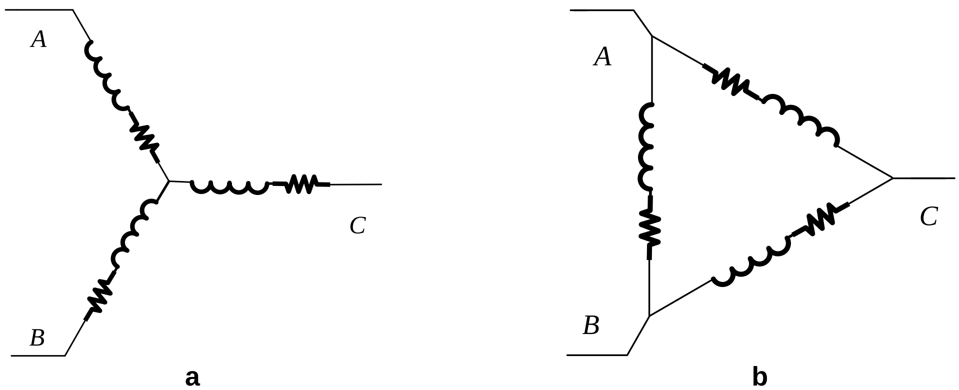

Figure 6: Star and Delta Connection Circuit

The MP6570can be used on both star- and delta-connected motors using the same aligning method to find the theta bias.

Please see Appendix 2 for details on the MP6570's use in delta-connected motors.

DESIGN SUMMARY

When the rotor is aligning to Phase A, the sensor angle, called theta bias, should be found first to operate FOC control. This is can be done easily by following this guide or using the *e*Motion Virtual Bench.

The MP6570 can be used in a delta-connected motor. There is no need to change the theta bias.

APPENDIX 1: AUTO THETA BIAS FUNCTION IN THE MP6570

To find the theta bias easily and quickly, the MP6570 provides an auto-theta bias function. After setting the register bits THETA_BIAS_EN, THETA_BIAS_TIME, and CMPA_SET and enabling the IC, the MP6570 apply current to the motor windings automatically to pull the rotor to position 1 and position 2.

Flow Chart

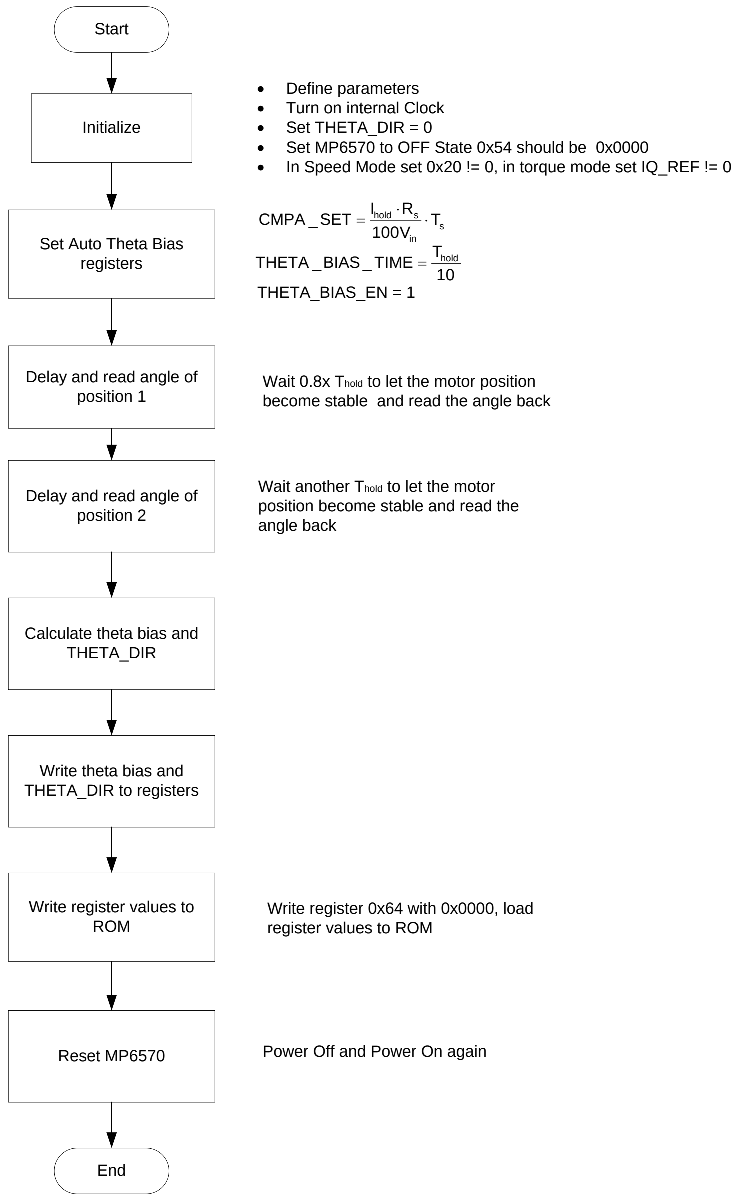

Figure 7: Flow Chart of Auto Theta Bias Determination

R_s(Ω) is the motor phase resistance, and I_{hold}(mA) is the winding current used for alignment. Choose a current according to the cogging torque and friction of the motor. A larger cogging torque and larger friction need a larger current to move the rotor to the correct position. T_{hold}(ms) is the stabilizing time for each positioning period. A longer time ensures that the rotor is stable before the angle is read. T_s(μs) is the switching period.

After getting the sensor angle in position 1 (A+B-) and position 2 (A+C-), the theta bias can be calculated by following the below procedure. A MCU code example is given to set the theta bias.

Calculate the Theta Bias

In manufacturing assembly, the motor's three windings maybe connected with the power stage OUTA/B/C arbitrarily. Since the three windings are symmetric, there are two possible connection formats. This connection method must be known by the MP6570 through setting THETA_DIR bit to provide the right sequence of phase A/B/C voltage.

The first connection format is OUTA - A, OUTB - B, OUTC - C (see Figure 8).

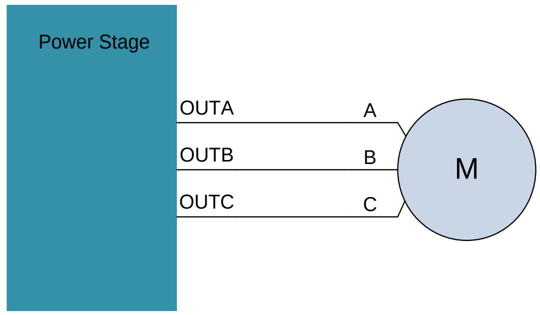

Figure 8: First Connection Format

The two angles can be obtained as shown as Figure 9.

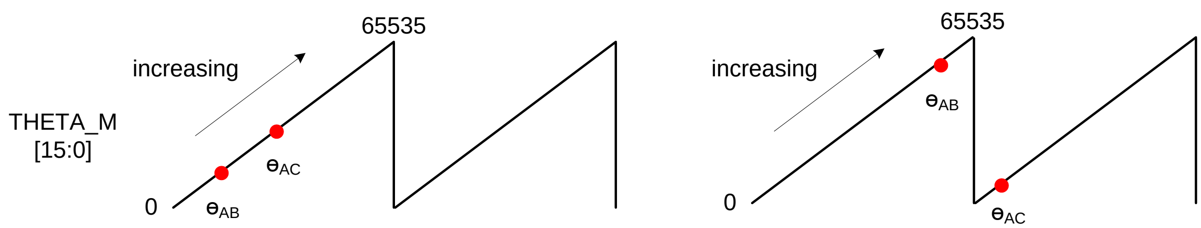

Figure 9: Two-Position Angle in First Connection Format (THETA_DIR = 0)

Another connection format is OUTA- A, OUTB - C, OUTC - B (see Figure 10).

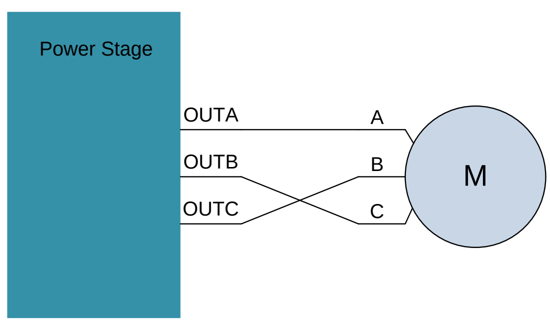

Figure 10: Second Connection Format

The two angles can be obtained as shown in Figure 11.

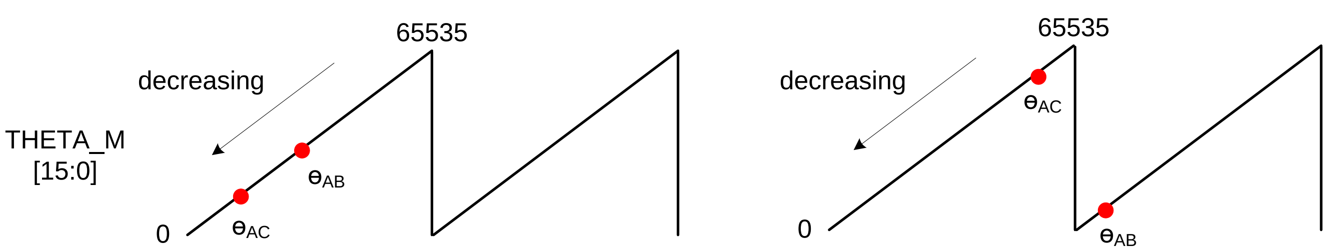

Figure 11: Two-Position Angle in Second Connection Format (THETA_DIR = 1)

It is necessary to consider the situation where the output sensor angle transitions through the zero degree point. The mechanical angle between the two positions can be determined with Equation (2):

$$\Delta\theta_M = \frac{360^\circ}{6p} \qquad (2)$$

Where p is the motor pole pairs. The maximum value of $\Delta\theta_M$ is 60°when the pole pair is 1.

If θ_{AB} and θ_{AC} occur on either side of the zero degree transition, $|\theta_{AB} - \theta_{AC}| = 360^\circ - \Delta\theta_M > 180^\circ$, we can divide the four situations as shown below.

Situation 1: Theta increasing not through the zero degree transition

$$(\theta_{AC} > \theta_{AB})\,\&\,(\theta_{AC} - \theta_{AB} < 180^\circ)$$

THETA_DIR = 0

$$\theta_{bias} = \frac{\theta_{AC} + \theta_{AB}}{2}$$

Situation 2: Theta increasing through the zero degree transition

$$(\theta_{AB} > \theta_{AC})\,\&\,(\theta_{AB} - \theta_{AC} > 180^\circ)$$

THETA_DIR = 0

$$\theta_{bias} = \begin{cases} \frac{\theta_{AC} + \theta_{AB}}{2} + 180^\circ & if\,(\theta_{AC} + \theta_{AB}) < 360^\circ \\ \frac{\theta_{AC} + \theta_{AB}}{2} - 180^\circ & if\,(\theta_{AC} + \theta_{AB}) > 360^\circ \end{cases}$$

Situation 3: Theta decreasing not through the zero degree transition

$$(\theta_{AB} > \theta_{AC})\,\&\,(\theta_{AB} - \theta_{AC} < 180^\circ)$$

THETA_DIR = 1

$$\theta_{bias} = \frac{\theta_{AC} + \theta_{AB}}{2}$$

Situation 4: Theta decreasing through the zero degree transition

$$(\theta_{AC} > \theta_{AB})\,\&\,(\theta_{AC} - \theta_{AB} > 180^\circ)$$

THETA_DIR = 1

$$\theta_{bias} = \begin{cases} \frac{\theta_{AC} + \theta_{AB}}{2} + 180^\circ & if\,(\theta_{AC} + \theta_{AB}) < 360^\circ \\ \frac{\theta_{AC} + \theta_{AB}}{2} - 180^\circ & if\,(\theta_{AC} + \theta_{AB}) > 360^\circ \end{cases}$$

Code Example

Below is an example of the code in C language.

```
u8 MP6570_Positioning(u16 Ihold_mA , u16 Thold_ms)    //current(mA)、interval(ms)

{

        u16 CMPA_SET,x_theta_dir;

        MP6570_WriteReg(MP6570_ADDR, 0x62, 0);                          //turn internal clock on

        int i05 = MP6570_ReadReg(MP6570_ADDR, 0x05);                    //read register 0x05

        MP6570_WriteReg(MP6570_ADDR, 0x05, i05 & 0x7fff);       //set THETA_DIR = 0

        int i54 = MP6570_ReadReg(MP6570_ADDR, 0x54);            //read register 0x54 to determine if MP6570 is at ON or OFF state

        int i33 = MP6570_ReadReg(MP6570_ADDR, 0x33);            //read register 0x33 to determine standby or not-standby mode

        if (i54 != 0x00)

        {

                if ((i33 & 0x8000) == 0x8000)                   //set MP6570 to OFF state

                        MP6570_WriteReg(MP6570_ADDR, 0x61, 0);

                else

                        MP6570_WriteReg(MP6570_ADDR, 0x60, 0);

        }

        else

        {

                MP6570_WriteReg(MP6570_ADDR, 0x20, 100);        //set SPEED_CMD !=0

                CMPA_SET =Ihold_mA * Rs * Ts / 100 / Vin;

                MP6570_WriteReg(MP6570_ADDR, 0x51, CMPA_SET);   //write CMPA_SET to register 51H Bit0~Bit11

                u16 THETA_BIAS_TIME=(u16)(Thold_ms*0.1);        // calculate THETA_BIAS_TIME value

                MP6570_WriteReg(MP6570_ADDR, 0x52, ((THETA_BIAS_TIME<<1) + 1));        //write THETA_BIAS_TIME to register
0x52 and set the THETA_BIAS_EN bit

                if ((i33 & 0x8000) == 0x8000)                   // set MP6570 to ON state

                        MP6570_WriteReg(MP6570_ADDR, 0x60, 0);

                else

                        MP6570_WriteReg(MP6570_ADDR, 0x61, 0);

                delay_ms( Thold_ms * 0.8);                              //delay 0.8 x Thold_ms until the motor is steady at position 1

                int i55 = MP6570_ReadReg(MP6570_ADDR, 0x55);            //read the angle at position 1

                delay_ms( Thold_ms * 1);                                //delay Thold_ms until the motor is steady at position 2

                int i55_2 = MP6570_ReadReg(MP6570_ADDR, 0x55);          //read the angle at postion 2

                delay_ms( Thold_ms * 0.2 +100);                 //delay (Thold_ms * 0.2 +100) to let the auto-theta-bias procedure
finish.
```

```
int i07_temp;                                    //calculate the THETA_DIR and THETA_BIAS

if (((i55 > i55_2) && (i55 - i55_2 < 0X3FFF)))  // decrease and no zero degree transition
{
        x_theta_dir = 1;
        i07_temp = (i55 + i55_2)>>1;
}
else if ((i55 < i55_2) && (i55_2 - i55 > 0X3FFF))     // angle decrease and zero degree transition
{
        x_theta_dir = 1;
        i07_temp = (i55 + 65536 + i55_2)>>1;
        if (i07_temp > 65536)
        {
                i07_temp = i07_temp - 65535;
        }
}
else if ((i55 > i55_2) && (i55 - i55_2 > 0X3FFF))     //angle increase and zero degree transition
{
        x_theta_dir = 0;
        i07_temp = (i55 + 65536 + i55_2)>>1;
        if (i07_temp > 65535)
        {
        i07_temp = i07_temp - 65535;
        }
}
else
                                                    // angle increase and no zero degree transition
{
        x_theta_dir = 0;
        i07_temp = (i55 + i55_2)>>1;
}
if ((i33 & 0x8000) == 0x8000)                    //set MP6570 to OFF state
        MP6570_WriteReg(MP6570_ADDR, 0x61, 0);
else
        MP6570_WriteReg(MP6570_ADDR, 0x60, 0);
MP6570_WriteReg(MP6570_ADDR, 0x52, 0);              //exit auto-theta-bias procedure
```

```
        MP6570_WriteReg(MP6570_ADDR, 0x07, i07_temp>>5);    //set register 0x07 according to calculated value
        MP6570_WriteReg(MP6570_ADDR, 0x05, (i05 | (x_theta_dir<<15)));        //set THETA_DIR
        delay_ms(10);
        MP6570_WriteReg(MP6570_ADDR, 0x64, 0);                    //write register values to MTP
        delay_ms(1000);                                           // delay 1s
    }
}
```

APPENDIX 2: INITIAL POSITIONING IN STAR AND DELTA CONNECTED MOTOR

If the motor is star-connected, there is a positive current in phase A and a negative current in phase B at stage 1, and the rotor is pulled to position 1.

During stage 2, the rotor is pulled to position 2. The MP6570 obtains the angle at these two positions and calculates the average angle. From the space vector diagram, we can see that the average angle is the theta bias when the rotor direct axis is aligned with stator phase A (see Figure12).

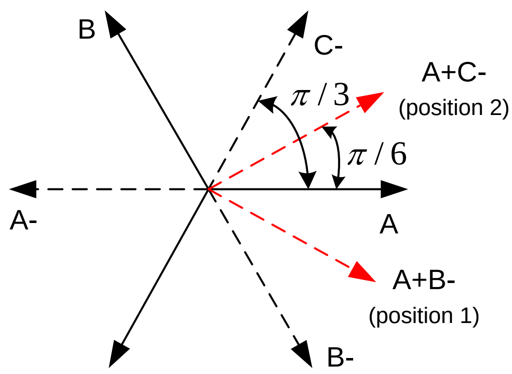

Figure 12: Space Vectors in Star-Connected Motor

If the motor is delta-connected, then there is a positive current in phase A during stage1. The currents in phase B and phase C are negative and have half of the amplitude of phase A due to phase B and phase C being in series (see Figure 13).

During stage 2, there is a negative current in phase C. The currents in phase A and phase B are positive and have half of the amplitude of phase C (see Figure 13).

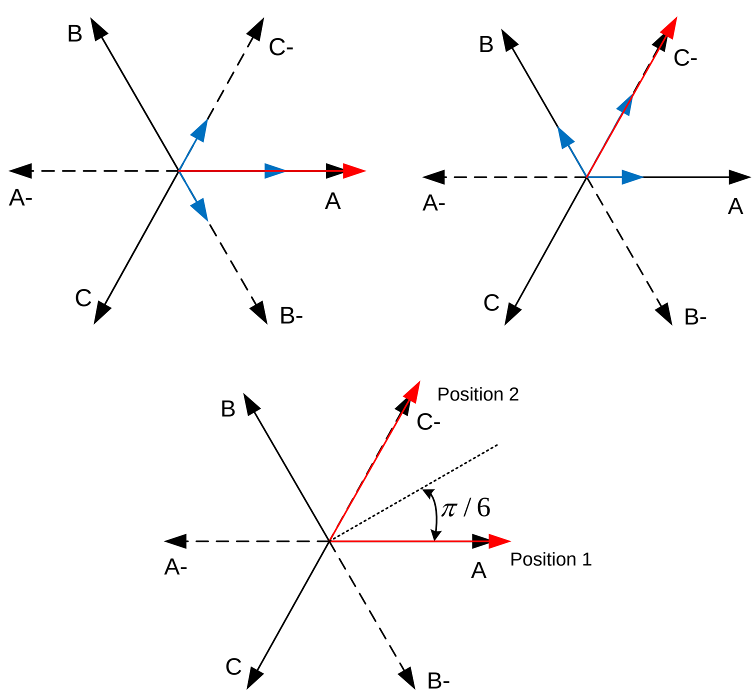

Figure 13: Space Vector in Delta-Connected Motor

The MP6570 takes the average of position 1 and position 2 as the initial theta bias, which causes a 30° lead of the phase vector A.

In FOC control, the stator flux is 90° ahead of the rotor flux to produce the largest torque for any given phase current. Figure 14 shows a block diagram of the FOC control system.

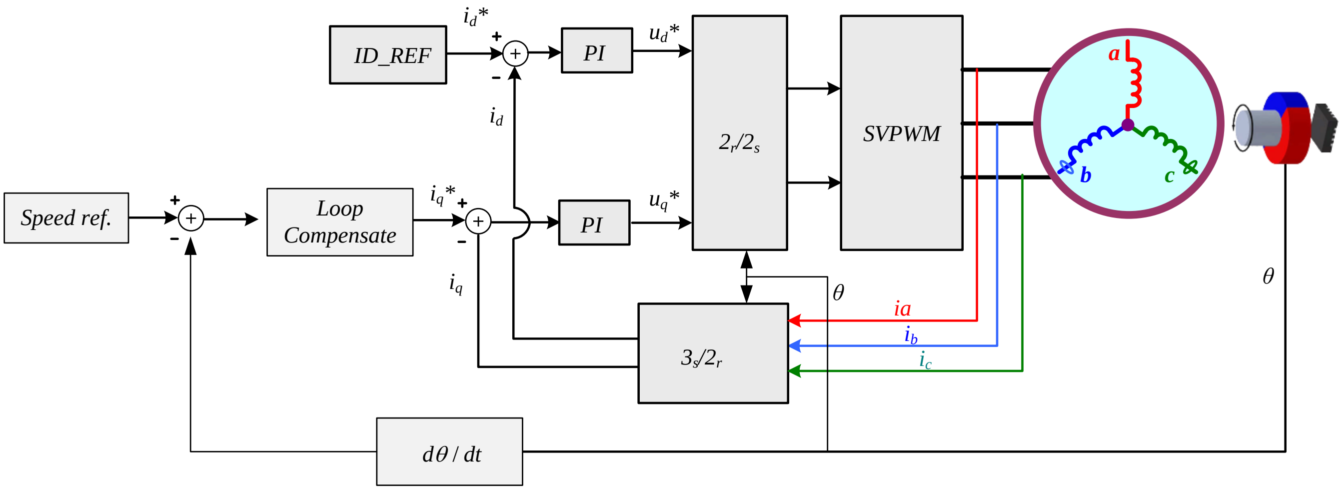

Figure 14: FOC Control Diagram

It is required to know the rotor position to perform a Park and inverse Park transformation. θ is the angle between the rotor's direct axis and the stator phase A vector. If using the MP6570 to drive a delta-connected motor, the angle used by the controller can be determined with Equation (3):

$$\theta = \theta_{\Delta} - \frac{\pi}{6} \tag{3}$$

Where θ_{Δ} is the real angle between the rotor and stator.

Because the MP6570 samples the line current, to achieve FOC control, the MP6570 generates a current, which can produce a flux 90°ahead of θ. Since the phase current is 30°ahead of the line current, the real flux is perpendicular with the rotor flux, and FOC achieved (see Figure 15).

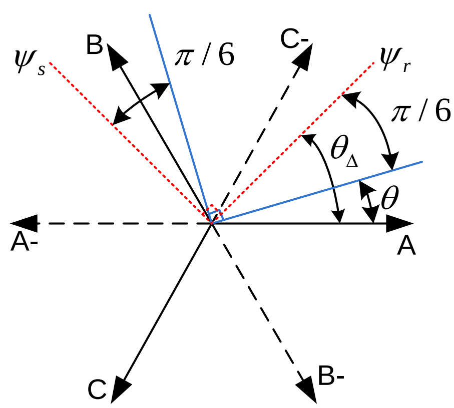

Figure 15: FOC in Delta-Connected Motors