STSPIN820: Microstepping Management

Introduction

The STSPIN820 is a compact stepper motor driver, in a QFN 4 x 4 mm package, suitable for a wide range of motion control applications. The integrated controller implements a PWM current control and it can support a microstepping resolution up to $1/256^{th}$ of the step.

The first part of this document gives a basic overview on the stepper motor operation, describing the relation between the currents driven in the motor windings and the movement of the motor shaft.

The second part explains how to select the microstepping mode in the STSPIN820 and how to change it dynamically, in order to optimize the tradeoff between precision and speed.

1 Overview on the stepper motors

The basic concept behind a stepper motor, as the name suggests, is the discretization of the movement in equally-spaced intervals called steps. Therefore, the motor shaft can be positioned with a controlled and precise angle.

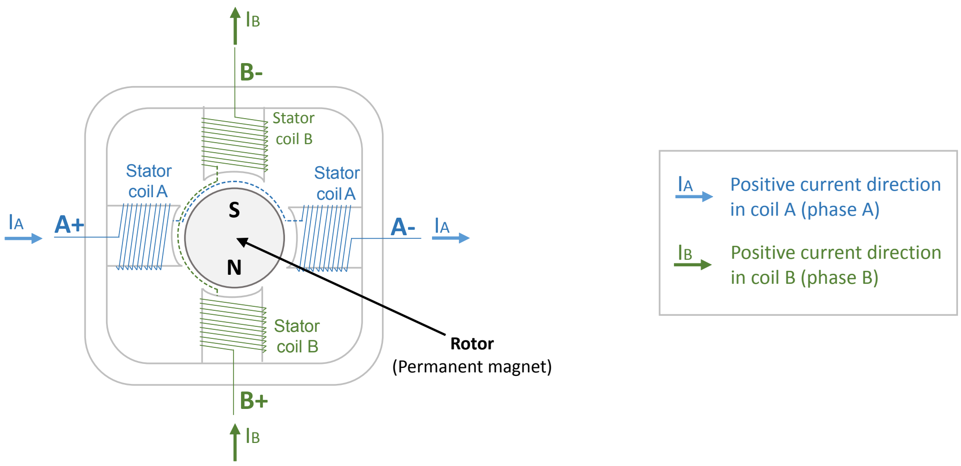
Stepper motors are brushless motors: the windings are positioned on the stator, while the rotor can be a permanent magnet, a variable reluctance structure or a mix of both, as in the case of hybrid stepper motors. The windings of the stator can be grouped and driven by the same current: each group is named phase. According to the direction of the current in each phase, stepper motors are classified as:

- *Unipolar:* the current in the phase is always in the same direction;
- *Bipolar:* the current in each phase can flow in both directions.

By energizing the phases of the motor (i.e. forcing a current in them) it is possible to generate a magnetic field, named stator magnetic field (B_{sta}). This field attracts the magnetic field of the rotor (B_{rot}), thus aligning the motor shaft in one defined step position. Using a proper driving sequence, it is possible to move the motor shaft step by step controlling its angle precisely.

The STSPIN820 is designed to drive two-phase bipolar stepper motors. A simplified model of a bipolar stepper motor is represented in Figure 1: the windings are grouped in two phases (named *A* and *B*), positioned every 90° on the stator; the rotor is a simple permanent magnet, with one pole pair.

Figure 1. Simplified diagram of a two-phase bipolar stepper motor



The current flowing in one phase generates a magnetic field. If both phases are energized, the stator magnetic field is the combination of the two perpendicular fields generated by the two phases, as in Figure 2. The rotor moves in order to align its own magnetic field with the stator one.

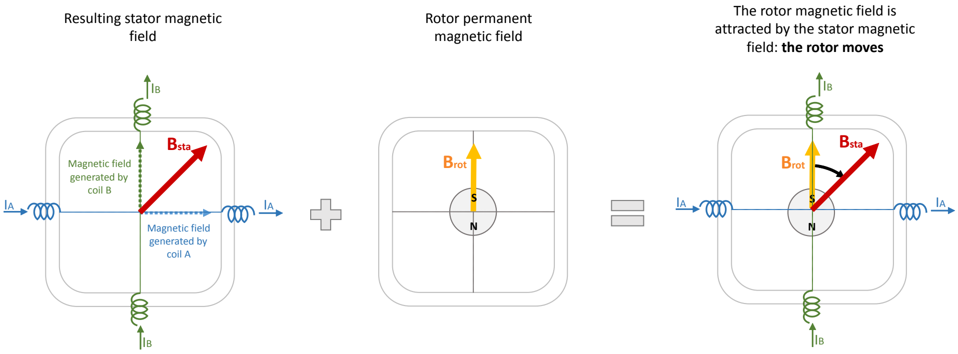


Figure 2. Representation of the stator and rotor magnetic fields

Changing the direction of the currents in the phases, it is possible to align the rotor along the different steps. Therefore, driving the phase currents with a proper sequence, it is possible to move the motor shaft step by step.

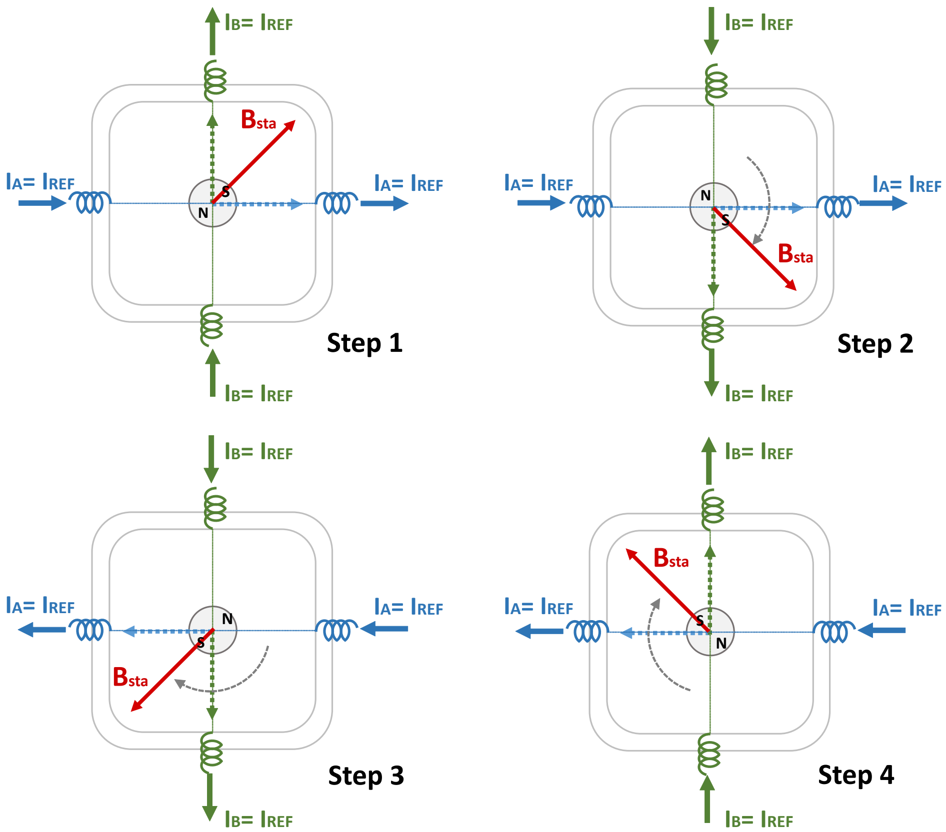
1.1 Full step operation

A simple way to drive a stepper motor is the full step mode: only the current direction in each phase is changed, while its value (I_{REF}) is kept constant. Four possible combinations are allowed and each one corresponds to a step, as depicted in Figure 3.

The STSPIN820 uses the approach to energize both the phases, in order to have a bigger magnetic field, thus a bigger torque, compared to a single phase approach. Since the currents flowing in the two phases have the same value (I_{REF}), the fields generated (directly proportional to the current) have the same magnitude. Referring to Figure 3 the two fields are perpendicular, so the resulting magnetic field is $\sqrt{2}$ greater than the two magnetic fields taken individually.

The magnitude of the resulting magnetic field determines the attraction of the rotor, thus the torque generated.

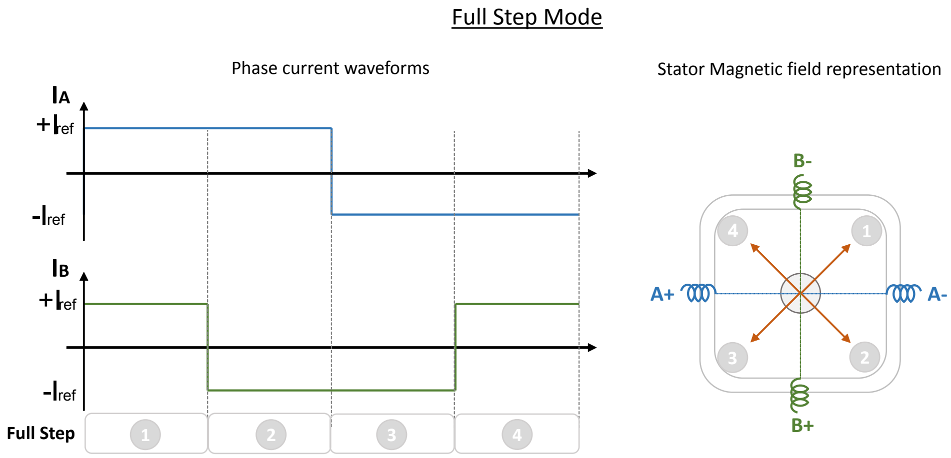
Figure 3. **Currents sequence in full step mode**



Repeating the full-step sequence results in a continuous rotation of the motor. In the STSPIN820, every pulse on the step clock pin (STCK) triggers a change from one step to another. The direction in which the sequence is performed (so the direction of the rotation) is selected by the DIR pin.

The phase currents diagram of the full step sequence is reported in Figure 4: the current waveforms are ideally two square waves with a delay of 90°.

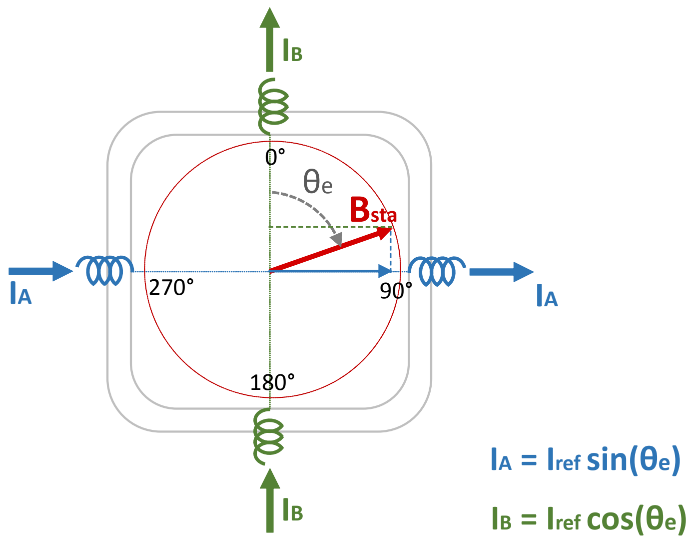
Figure 4. Phase currents representation in full step mode



1.2 Microstepping operation

According to the full step mode driving, the position of the stator magnetic field can assume four different positions. In order to define the position of the stator magnetic field, it is useful to define the electrical angle θ_e as the angle of the stator magnetic field with respect to one axis. Referring to Figure 5, the y-axis is used as a 0° reference so the electrical angles allowed in full step mode are 45°, 135°, 225°and 315°.

Figure 5. Representation of the electrical angle using two quadrature currents



In order to increase the resolution in the movement, the electrical angle of a single full step, that is 90°, can be divided into a number of microsteps equally spaced. The different microsteps are obtained by adjusting the levels of the currents according to the sine and the cosine of the target electrical angle to be obtained, as depicted in Figure 5. The number of intervals dividing the single full step, defines the resolution of the microstepping and are indicated as *M.* The STSPIN820 allows eight different resolutions, from full step mode to 1/256th microstepping mode. According to the previous definition, *M*=2 corresponds to half step mode, *M*=4 is for quarter step mode and so on, up to *M*=256 for the maximum resolution. Refer to Section 2.1 , Table 1 for the complete list.

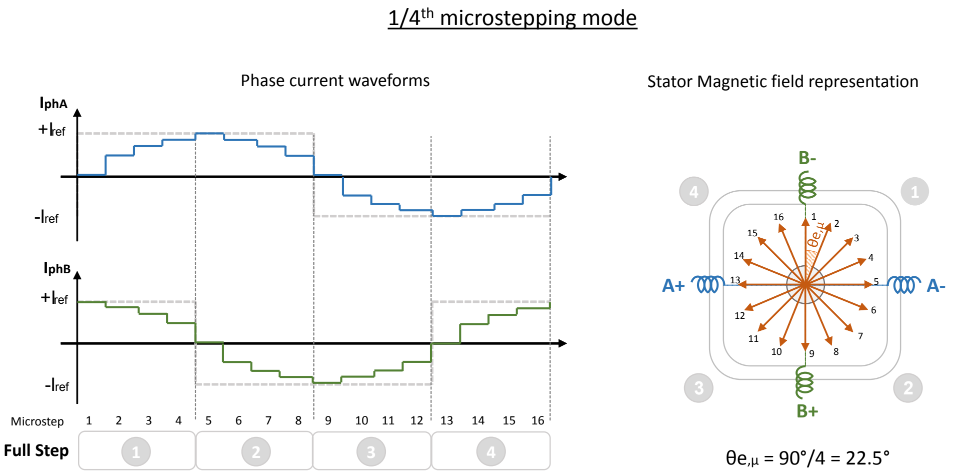
The electrical angle corresponding to a single microstep ($\theta_{e,\mu}$) is defined by:

Equation 1

$$\theta_{e,\mu} = \frac{90°}{M} \qquad (1)$$

An example of microstepping using M=4, quarter step resolution, is reported in Figure 6. The electrical step angle is $\theta_{e,\mu}$ = 22.5°; the example shows the sequence of the currents and the corresponding position of the stator magnetic field.

Figure 6. Electrical angle and phase currents – example using 1/4th microstepping mode



The increasing of the microstepping mode allows to have smoother sinewaves and a small angle between the microsteps. A smooth and constant rotation of the stator magnetic field results in a smoother movement of the motor shaft. For lower microstepping modes, the quantization can be seen on the sinewaves; conversely, using the maximum resolution (256 microsteps), the current sinewaves are very smooth.

1.2.1 PWM current control

The STSPIN820 controls the different levels of the current needed using a PWM method. The maximum value of the current (i.e. the peak of the sinewave, named I_{REF}) is set by the voltage on the REF pin divided by the shunt resistor R_S connected to the SENSE pin on each phase.

In microstepping mode, the reference values are discretized according to the number of microsteps, i.e. the microstepping resolution *M*. Each phase has its dedicated PWM current control; the values are selected by scaling the I_{REF} value according to the following:

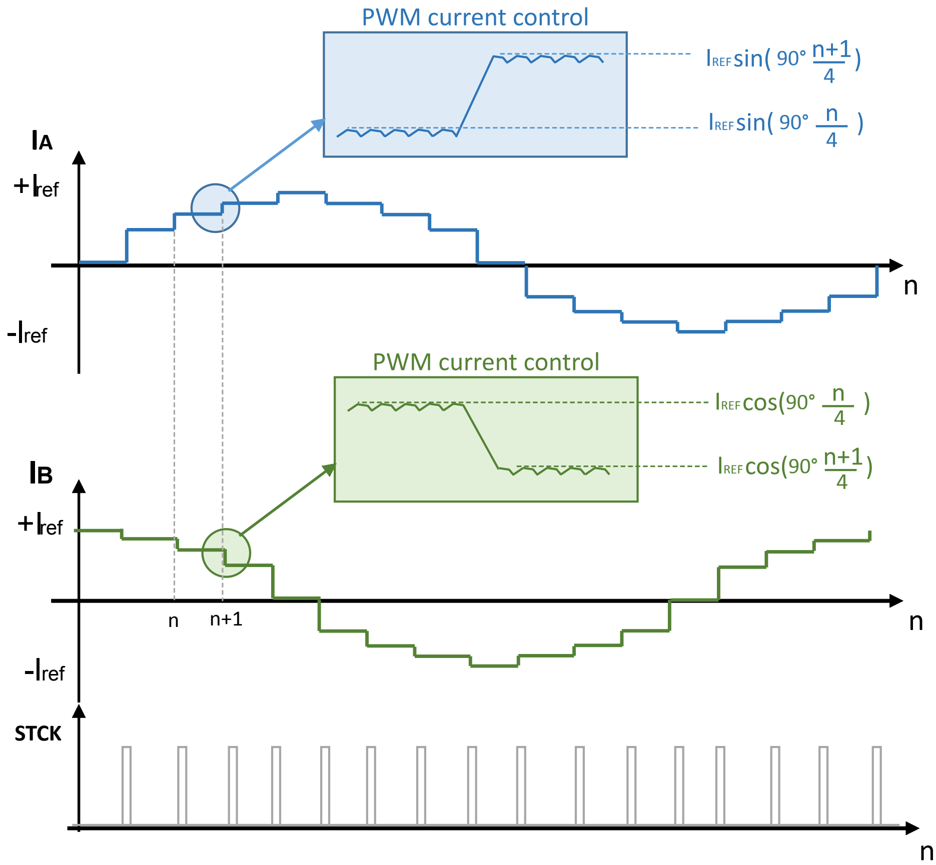
Equation 2

(2)

$$\begin{cases} I_A = I_{REF} \cdot \sin\left(90° \cdot \frac{n}{M}\right) = \frac{V_{REF}}{R_S} \cdot \sin\left(90° \cdot \frac{n}{M}\right) \\ I_B = I_{REF} \cdot \cos\left(90° \cdot \frac{n}{M}\right) = \frac{V_{REF}}{R_S} \cdot \cos\left(90° \cdot \frac{n}{M}\right) \end{cases}$$

Where *n* is the microstep in the sequence that is incremented on each pulse on the STCK pin. Figure 7 shows an example on how the PWM current control works; the resolution in this example is quarter step mode (*M*=4).

Figure 7. PWM current control – example using 1/4th microstepping



It can be seen from Figure 7 that the maximum reference current on one phase corresponds to the zero current in the other phase. The resulting current given by the combination of the two currents is equal to I_{REF}; this is true in all microstepping modes. While in full step mode, both currents are equal to I_{REF}, so their combination is $\sqrt{2}$ I_{REF} as described in the Section 1.1 .

1.3 Electrical angle and mechanical angle

The simplified model of the stepper motor described in Section 1 is used to explain the basic operating principles. However, it is not suitable in most applications because of the poor resolution in the movement: an entire mechanical revolution of the motor shaft is composed only by 4 full steps. Most applications require more full steps for a single mechanical revolution. In order to increase the movement resolution, the single full step must correspond to a smaller mechanical angle. The mechanical angle, so the physical angle covered by the movement of the motor shaft during a full step, is named step angle θ_m : it is expressed in degrees by the following:

Equation 3:

$$\theta_m = \frac{360°}{N_S} \tag{3}$$

Where N_S is the number of steps per revolution. Referring to a typical value of N_S = 200, the step angle θ_m is 1.8°.

The concepts of electrical angle θ_e, (described in Section 1) and mechanical angle θ_m (described here above) can be summarized by Figure 8:

- A sequence of 4 full steps corresponds to an entire period of the phase current waveforms, so 360° of the electrical angle.
- The same sequence of 4 full steps (by definition 4 times the θ_m) corresponds to a smaller angle on the motor shaft.
- A single full step always corresponds to an electrical angle θ_e = 90° and to a mechanical angle θ_m given by Eq. (3).

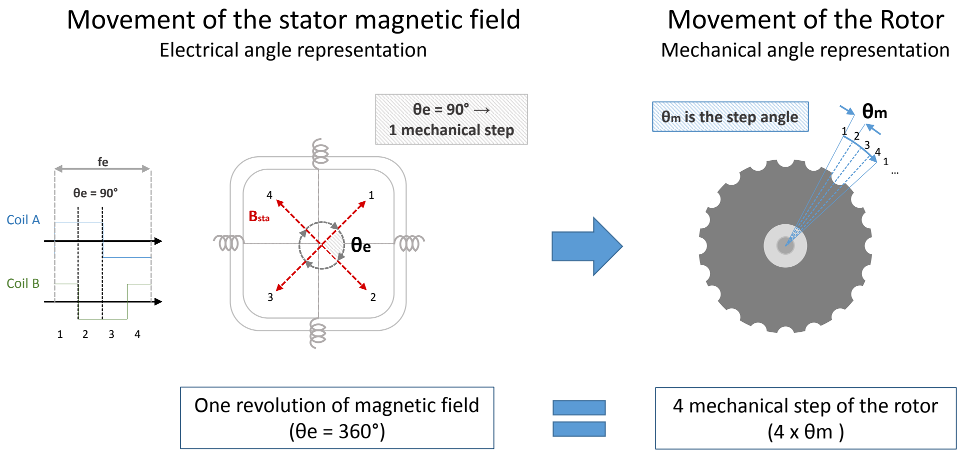
Eventually, there is a reduction between the frequency of the rotation of the stator magnetic field, i.e. the frequency of the current waveforms in the two phases f_e, and frequency of rotation of the motor shaft f_m, i.e. the speed of the motor in revolutions per second (Hz). The reduction ratio is expressed by

Equation 4:

$$\frac{f_e}{f_m} = \frac{90°}{\theta_m} = \frac{N_S}{4} \tag{4}$$

With a step angle of 1.8°, the reduction ratio between the electrical and mechanical angle is 50; so, considering an electrical frequency f_e= 100Hz, the mechanical frequency of rotation is f_m = 2Hz , so 2 revolutions per second or 120 rpm.

Figure 8. Representation of the electrical angle and the rotor mechanical angle



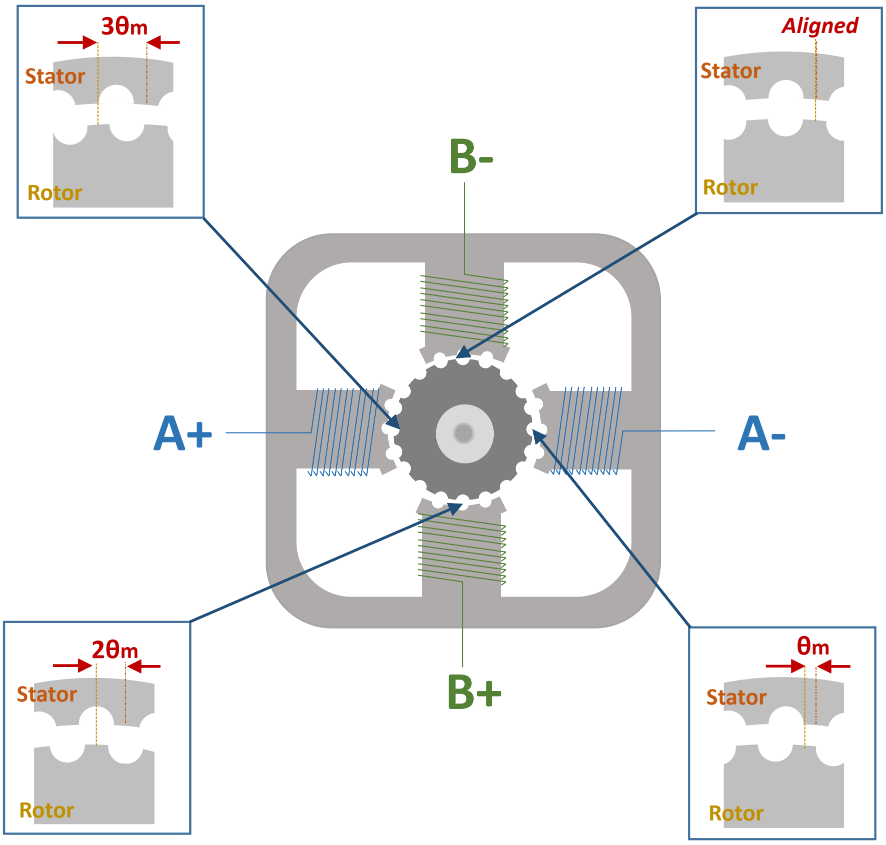
1.3.1 Hybrid stepper motor example

Let’s consider a typology of stepper motor commonly used in many applications: the hybrid stepper motor. The reduction between electrical and mechanical angle is achieved by properly shaping the rotor and the stator. The rotor is shaped by teeth, which actually increases the number of poles pairs and creates a variable reluctance structure. Each tooth of the rotor is actually a pole pair, since there is a permanent magnet inside the rotor; moreover, the teeth shape changes the reluctance of the structure, thus favoring the alignment of the rotor in well-defined positions. By exploiting the advantages of permanent magnet motors and variable reluctance motors, hybrid motors can increase their performance in terms of step resolution, torque and speed.

The displacement between teeth of the rotor and the stator poles determines the movement, according to the sequence of the phase currents. Referring to Figure 9, it is possible to basically understand how a hybrid stepper motor works. Figure 9 represents the stator and rotor teeth and how they are aligned: when the teeth of one stator pole are aligned with the rotor teeth, the teeth of all the other stator poles are shifted. The mechanical shift between stator and rotor teeth is incremented by θ_m for two consecutive stator poles. In this way at each change of the electrical angle θ_e of 90°, the rotor moves of one step angle θ_m in order to align its teeth with the ones of the energized stator.

By construction, an entire rotation of 360° of electrical angle corresponds to a movement equivalent to the pitch between two adjacent teeth of the stepper motor. Consequently, the number of teeth of the rotor is equal to Ns/4 or in other words, each step angle corresponds to ¼ of the angular pitch between teeth.

Figure 9. Schematic representation of a hybrid stepper motor and teeth displacement



2 Microstepping mode selection

2.1 Step mode selection in STSPIN820

The STSPIN820 can be easily configured in one of the eight possible microstepping modes. The step mode depends on the value present on three digital pins of the device: MODE3, MODE2 and MODE1. Refer to Table 1 for details about mode selection. The internal logic manages the pins asynchronously, so the step mode can be changed dynamically during operation. This allows to optimize the performance of the motor driver.

Table 1. Step mode selection in STSPIN820

Step Mode	M	MODE3	MODE2	MODE1
Full step	1	0	0	0
Half step	2	0	0	1
Quarter step	4	0	1	0
1/8th step	8	0	1	1
1/16th step	16	1	0	0
1/32th step	32	1	0	1
1/128th step	128	1	1	0
1/256th step	256	1	1	1

The STSPIN820 drives the motor according to the step clock, a train of pulses applied on the STCK pin. The number of STCK pulses required to move by a single step depends on the microstepping mode selected. A pulse on STCK moves the motor by a single microstep, so the higher the microstepping mode, the higher the number of STCK pulses needed to move by a single full step. For example, consider the following cases:

- Using the Full Step Mode, a single full step movement is performed applying one STCK pulse
- Using the Half Step Mode, a full single step movement is performed applying two STCK pulses
- Using the 1/32th microstepping mode, a single full step movement is performed applying 32 STCK pulses

In other words, increasing the microstepping resolution results in a smaller angle in the movement, at each STCK pulse. The electrical frequency f_e of the current waveforms, can be expressed as a function of the step clock frequency f_{STCK} by

Equation 5:

$$f_e = \frac{f_{STCK}}{4 \cdot M} \quad (5)$$

Combining Eq. (4) and Eq. (5) it is possible to find the relation between the motor speed (the mechanical frequency f_m) and the step clock frequency, in relation to the microstepping mode.

Equation 6:

$$f_m = \frac{f_{STCK}}{N_S \cdot M} \quad (6)$$

It is clear that increasing the microstepping resolution requires higher frequency of the step clock in order to achieve the target speed: i.e. more step clock pulses are required to move the motor shaft by the same mechanical angle.

Table 2. **Parameters summary**

Definition	Symbol	Unit	Description
Step Angle	θ_m	°	It is the angle covered by a single step of the stepper motor. A typical value is 1.8°, meaning that 200 steps are necessary to perform a complete rotation.
Steps per revolution	N_S		It is the number of steps required to complete an entire mechanical revolution of the motor shaft
Microstepping mode	M		M represents in how many intervals a single step is divided. The higher the microstepping mode, the smoother is the movement and the sinusoidal profile of the current.
STCK frequency	f_{STCK}	Hz	The step clock frequency – the clock provided to the STSPIN820
Electrical frequency	f_e	Hz	It is the frequency of the current waveforms so the frequency of rotation of the stator magnetic field
Mechanical frequency	f_m	Hz	It is the frequency of the rotation of the rotor, therefore it corresponds to the speed in revolutions per second

2.2 Tradeoff between speed and resolution

Using high resolution microstepping modes improves precision in positioning and smoothness in the movement, avoiding unwanted vibration of the motor. Precision and smoothness are very useful when the motor is moving at low speed or it is performing an accurate positioning. On the other hand, there are some disadvantages in microstepping mode, when the motor is spinning at higher speeds:

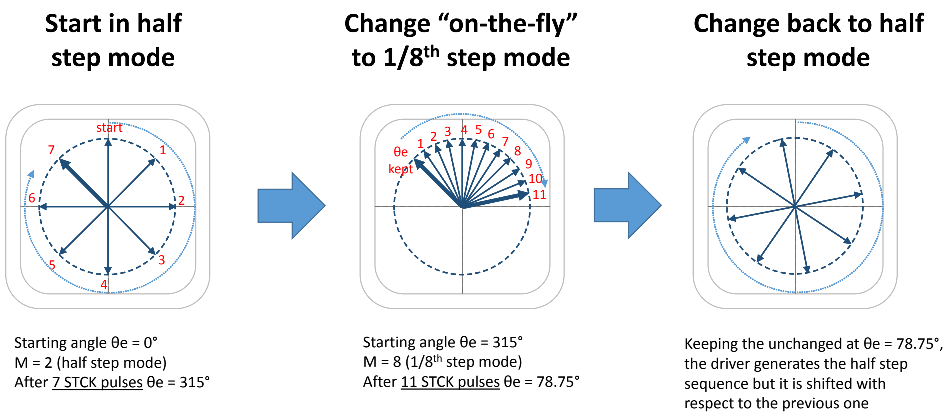
- the sinusoidal profiles of the current can be corrupted by the back electromotive force (BEMF) and the dI/dt limit imposed by the phase inductance and the supply voltage.
- the step clock has high frequency as stated in Eq. (5)
- the smoothness in the movement and the precision in the positioning are no longer required because the motor is moving at high speed and it is not pointing to a precise position.

Since there are acceleration and deceleration profiles to be computed, the higher the STCK frequency, the higher the effort required by the MCU. Although the STSPIN820 maintains step counting even at frequencies up to 4 MHz, decreasing the microstepping resolution could be an option to decrease the STCK frequency. As previously stated, when the motor rotates at high speeds, precision in the positioning is not as critical, and the microstepping resolution can be decreased, thus reducing the step clock frequency and the MCU overhead. Choosing the right microstepping resolution provides a way to limit the step clock frequency without losing performance. Eventually, at higher speed, it is suitable to operate in full step mode: this allows to increase the torque generated by the motor since both the phases of the motor are energized with the maximum reference current, as explained in Section 1.1 .

2.3 Electrical angle management in STSPIN820

The STSPIN820 supports the microstepping mode change “on the fly”: this means that, while the motor is moving, the resolution can be changed just by acting on the MODE pins, as explained in Section 2.1 . In order to avoid any position misalignment when changing from one mode to another, the electrical angle is always maintained between the different modes. This ensures that, even changing microstepping mode “on the fly”, the movement is as smooth as possible, avoiding any “jump” in the electrical angle. As a consequence, when switching from one higher resolution to the lower one, the electrical angles composing the driving sequence can be modified (see the example in Figure 10).

Figure 10. Example of the electrical angle sequence change in STSPIN820



In order to maintain the sequence unchanged when changing from one resolution to another, the mode switching must occur at one electrical angle available in the lower microstepping mode. In the example of Figure 10, when changing from 1/8th (M=8) to half step mode (M=2), the change must occur at θ_e multiple of 45° (that is 90°/M).

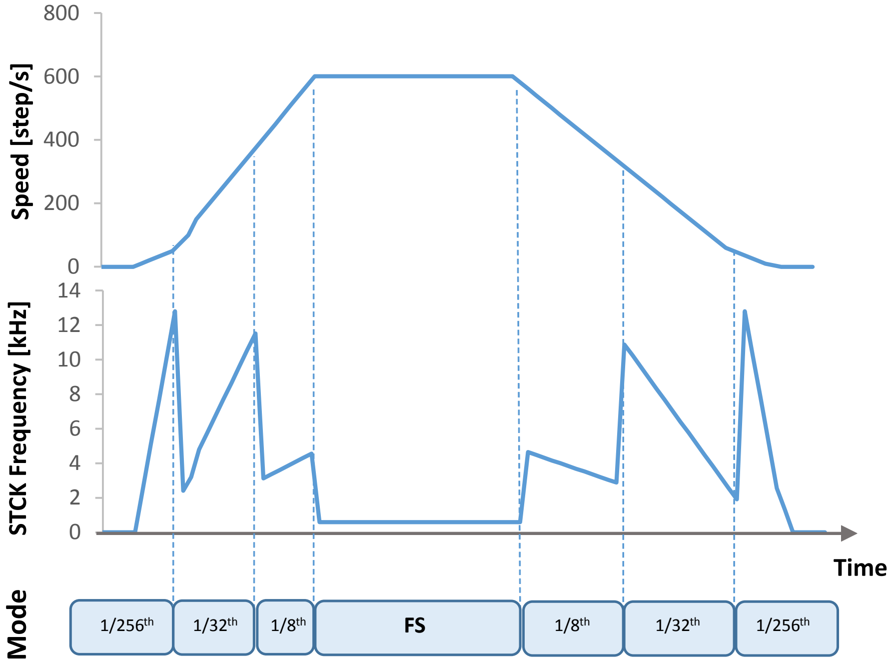
The only exception in the electrical angle conservation is the full step mode. The full step mode cannot use two different levels of current, so the electrical angle is always 45° + 90°•k (where k is an integer k =0, 1, 2, 3...) or in other words, when the phase currents are equal in the module. It is preferable, in order to keep the angle constant to switch in full step mode only when the magnetic field is in the above mentioned electrical angles.

Switching to full step mode, not only allows to decrease the STCK frequency, but also to increase the torque generated by the motor. The change to full step mode at the correct electrical angles cannot be managed by STSPIN820, so it must be managed by the control firmware of the MCU.

2.4 Example: speed profile and mode selection

An example of dynamic management of the microstepping mode is reported in Figure 11, showing a typical speed profile composed by three parts: acceleration, constant speed and deceleration. The microstepping mode is changed according to the speed: during the acceleration phase the movement is smooth using the maximum resolution of the STSPIN820, that is 1/256th of a microstep. As the speed increases the resolution is decreased, until the maximum target speed is reached (600 steps/s in this example). The constant speed movement is performed in full step mode in order to have a higher torque and a lower step clock frequency (600Hz in this example). If the 1/256th microstepping mode resolution were used at this maximum speed, a step clock of more than 153 kHz would be required. The change in the resolution can be done at any time without stopping the driver or losing the step, so any speed profile can be managed optimizing resolution and step clock frequency.

Figure 11. Speed profile example and related step clock, changing microstepping mode



Revision history

Table 3. **Document revision history**

Date	Version	Changes
01-Oct-2019	1	Initial release.

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