Programmable Adaptive Microstep Table

Valid for TMC50xx, TMC5130, TMC2130, TMC429, TMC457, TMC4331 and TMC4361A

This application note is meant to be a practical guideline for parameterization of the TRINAMIC ICs with programmable microstep table. Part 2 focusses on the incremental table.

In order to understand where to find the parameters mentioned, and how to set them, please refer the specific product documentation.

Table of Contents

1 Microstepping

While stepper motors conventionally have been operated in audible and tangible (half- and full-) steps, they have been loud and prone to resonance failure. Thus, the first aim of microstepping is the reduction of resonance and operation noise. Aside from this, microstepping drastically improves the position resolution. A sine wave is a good solution for reaching an excellent microstepping in many respects: sine wave and cosine wave cause constant power dissipation in the motor. So, the motor can be operated at its maximum thermally limited power, independently of the position within the waves.

FINDING THE BEST WAVEFORM FOR A GIVEN MOTOR

Normally, there is no specific data available for the stepper motor series. A motor can be optimized for best microstepping or for highest torque, or for a certain form factor or tooling. The specific waveform can be best optimized when using a high resolution encoder or a laser pointer attached to your motor and moving the motor at very low velocity.

AIMS OF THE OPTIMIZATION

- even distribution of microsteps
- constant velocity at slow speeds
- constant torque independent of position

1.1 Motor Dependence

As a first step, you should understand which parameters have a direct or indirect influence on the microstep performance.

Parameter	Description	Optimization
Motor type	Each motor type has unique characteristics of its microstep behavior. The form of the pole shoes has a major influence on the back-EMF of the motor and hence on the required microstep wave.	Choose a motor fitting your requirements based on the motor torque curve, cost, current, etc. The motor should be strong when compared to mechanical friction or ripple torque (which could be caused for example by a gearing or by a belt drive) in the application, as friction will cause position offset and ripple torque will cause position failure.

TRINAMIC Motion Control GmbH & Co. KG
Hamburg, Germany

Parameter	Description	Optimization
Production tolerance	The manufacturer's tolerance when assembling the motor, especially the exact angle of the rotor magnets has an influence on the microstep quality.	You should test with several motors to get an idea of production stray.
Motor coil current	Normally, stepper motors work best at their nominal current, as they provide the highest torque and lowest relative torque ripple. However, factors which might lead to operation at reduced current levels are 1. reduction of power dissipation 2. standby operation	As a guideline operate a stepper at 50% to 100% of nominal current. Optimize the microstep curve for the motor current, where precision or smooth operation is most critical.
Waveform	For most stepper motors a sinusoidal waveform is a good approach.	As a first test, the motor should be operated with sinusoidal microstepping. When the motor shows a pumping effect (e.g. getting slower and faster within each fullstep), an adaptation of the microstep wave will bring improvements.

Table 1.1 Parameters which should be considered

1.2 Simple Approach for Microstep Wave Optimization

We will optimize the microstep wave table for equidistant microstepping using a simple interactive approach. Therefore, expensive measuring equipment is not required and in-depth data of motor physics is not needed. Torque variation of the motor is also not considered. This approach just compresses and drags the sine wave to yield an evenly distribution of microsteps. With the next step, the amplitude can be optimized in order to give a constant torque independently of the position.

TUNING THE MOTOR POSITION

Take your motor into operation at nominal conditions. In case your appliance does not directly allow assessment of the microstepping equidistance, you can attach a needle to the axis. A very good means is a tiny laser pointer, because of the optical amplification to a near wall. If available, a high resolution encoder can be used even for automatic tuning of the microstep wave.

1. Be sure to first tune the chopper parameters and motor current setting. Bring the motor into very slow rotation, e.g. a few microsteps per second. Check the quality of the microstepping using the needle or the laser pointer. You will probably see deviations from the optimum, equidistant stepping. Start with a sine wave.

2. If you use a laser pointer pointing to a distant wall, attach a scale to the wall. You can design the scale in a way, that it divides the distance of two fullsteps into a number of equidistant steps. Position the first fullstep corresponding to the 0° position at table position 0, and the next fullstep to the 90° position at table position 256. You do not need to use each microstep position in between for checking in case you work with high resolutions like 256 microsteps. A good result will already be achieved when you optimize the positions for 8 or 16 evenly distributed microstep positions and later on evenly distribute the remaining microsteps in between. The first and last positions are fixed to the original values at 0° and 90°, as they mark the original fullstep borders. You can do the same using a high resolution encoder.

3. Now, position the motor as exactly as possible to each of the equidistant steps (P1, P2 …) using the highest available microstep resolution (256 microsteps). Take into account, that motor friction might influence the exact positioning. Multiple trials will help reducing errors caused by friction. Take a note of the microstep pointer (MSCNT) for best position match for each position (shift each position as required).

4. Now, you have a lookup-table (shifted positions for blue trace in Figure 1.2) which allows exact positioning to the determined values. The sine values at the noted MSCNT positions, which are required to exactly reach the desired microstep positions, are the optimized entries for these microstep positions. You can do an interpolation between each two entries to extend the microstep curve to the original table resolution, (e.g. to 256 microsteps). For this task a spread-sheet may be helpful.

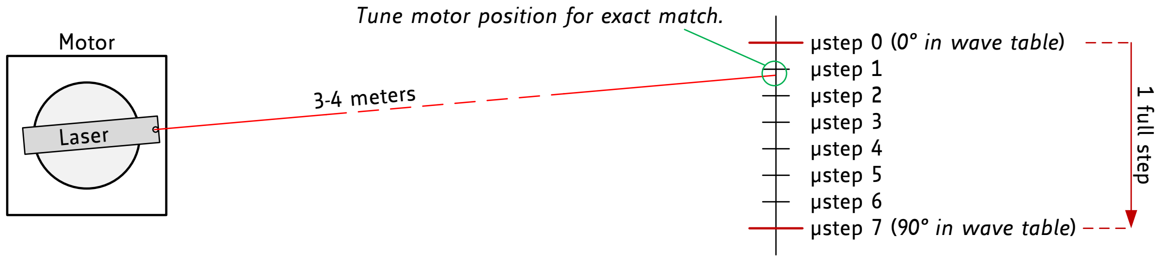

Figure 1.1 Tuning the motor position using a laser pointer (microstep resolution: 8 µsteps per full step)

Note: the angle between laser pointer and the scale on the wall can be neglected because of slightness except for very low resolution stepper motors.

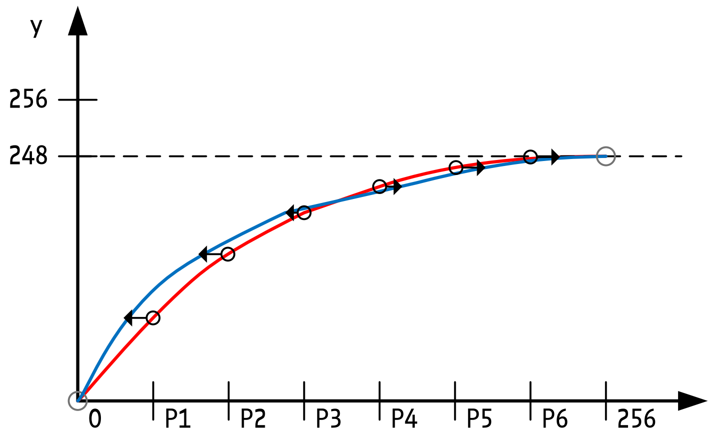

Figure 1.2 Modifying the wave for evenly distributed microsteps (example)

Optimization of the torque

Now, the optimization of the torque can be done. This will help the motor to keep equidistant positions when it is loaded with a certain torque. This optimization step requires more measuring equipment and can best be realized in an automatic setup. An encoder coupled to the motor can be used for torque measurement by superimposing a step (e.g. 90° electrical angle) on the motor and measuring the instant acceleration of the motor.

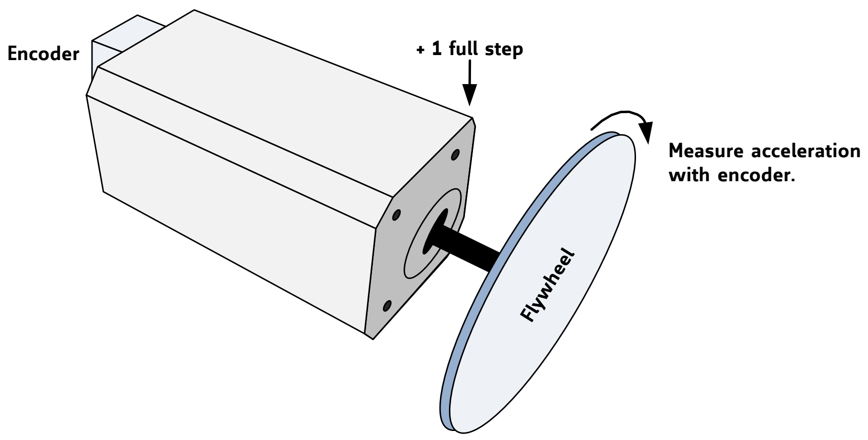

Figure 1.3 Setup for torque optimization

The positions have been compressed and dragged in the previous step (horizontal arrows in Figure 1.2). Now, the amplitudes become scaled in the same way (vertical arrows in Figure 1.4). While scaling the wave, keep in mind that the drivers optimally work when sustaining the peak amplitude at the maximum permissible level (248). A second iteration of both steps might still give improvements, as there is a small dependence of the position from the absolute current level, due to the motors' residual torque.

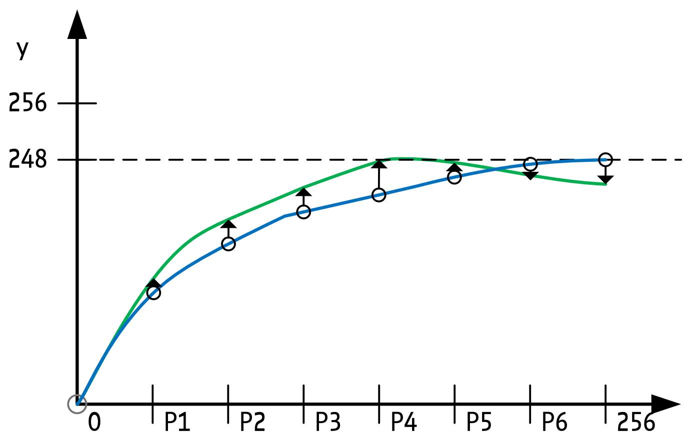

Figure 1.4 Modifying the wave for constant torque (example)

2 Programming the Incremental Microstep Table

For understanding the background of the incremental coding of the microstep table, it is good to have an idea of the characteristics of the microstep wave.

A MICROSTEP TABLE FOR A TWO PHASE MOTOR HAS CERTAIN CHARACTERISTICS:

1. It is in principle a reverse characteristic of the motor pole behavior.
2. It is a smoothened wave to provide a smooth motor behavior. There are no jumps within the wave
3. The phase shift between both phases is exactly 90°, because this is the optimum angle of the poles within the motor.
4. The zero transition is at 0°. The curve is symmetrical within each quadrant (like a sine wave).
5. But it must not be strictly monotonic as the example in the previous chapter shows.

Due to these characteristics, the wave can be described by a one quarter period and there is only a certain change possible between two adjacent positions. Following point 4, the slope of the wave is normally positive, but due to torque variations it can also be (slightly) negative.

Considering these facts, it becomes clear that the wave table can be compressed. The incremental coding used in the TRINAMIC ICs uses a format which reduces the required information per entry of the 8 bit by 256 entry wave table to slightly more than a single bit.

2.1 Incremental Encoding

The principle of incremental encoding just stores the difference between the actual and the next table entry. To have an absolute start value, the first entry is directly stored (START_SIN). For the ease of use, also the first entry of the shifted table for the second motor phase is stored (START_SIN_90_120).
The TMC drivers provide four inclination segments (0, 1, 2, and 3) with the base inclinations (W0, W1, W2, and W3) and the segment borders (0, X1, X2, X3, and 255).

Inclination segments	Base inclinations	Segments
0	W0	0… X1
1	W1	X1… X2
2	W2	X2… X3
3	W3	X3… 255

Table 2.1 Inclination segments of TMC drivers

EXPLANATORY NOTES AND EXAMPLES:

Using a single bit per table entry would allow any inclination between 0 and 1. E.g., a *0-bit* could mean *do not add anything* and a *1-bit* could mean *add one*. This allows describing a digital slope of 0° (all bits zero) to 45° (all bits one).

It becomes clear, that higher inclinations are necessary. However, the inclination will not drastically change from point to point. Therefore, the wave can be divided into up to four segments with different base inclinations.

Using a base inclination of one, a *0-bit* would mean *add one* and a *1-bit* would mean *add two*. This way, a slope between 45° (all bits zero) and 77.5° is yielded (all bits one).

The base inclinations can be set between -1 (falling slope) and +2. This way, slopes between -45° and 78.75° can be described.
The default sine wave table in TRINAMIC drivers uses one segment with a base inclination of 1 and one segment with a base inclination of 0.

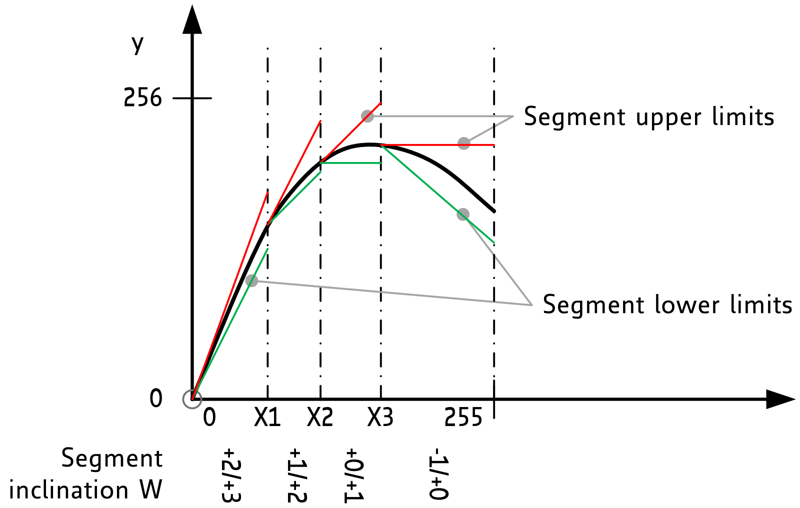

Figure 2.1 Wave showing segments with all possible base inclinations (highest inclination first)

Example (compare spread-sheet TMC562_TMC50XX_Calculations.xlsx)

CONSIDER THE GIVEN CONDITIONS:

The microstep table for the standard sine wave begins with the eight entries (0 to 7) {0, 1, 3, 4, 6, 7, 9, 10 …} etc.
The maximum inclination in this area is 2 (1+2=3).
The minimum inclination in these eight entries is 1.
The start value is 0.
Advancing in the table, the first time the inclination becomes lower than +1 is from position 153 to position 154. Both entries are identical.
The calculated value for position 256 (start of cosine wave) is 247.

THEREFORE, THE FOLLOWING SETTINGS NEED TO BE MADE:

- Set a starting value *START_SIN*=0 matching sine wave entry 0.
- Set a base inclination range of *W0*: +1 / +2 (*W0*=%10), valid from 0 to *X1*.
- Calculate the differences between each two entries: {+1, +2, +1, +2, +1, +2, +1,…}
- Set the microstep table entries *ofsxx* to 0 for the lower value (+1), 1 for the higher value (+2). Thus, the first seven microstep table entries *ofs00* to *ofs06* are: {0, 1, 0, 1, 0, 1, 0 …}
- Latest at position 153, the inclination must be lowered. Use the next inclination range 1 with *W1*: +0 / +1 (*W1*=%01). Therefore, *X1* becomes set to 153 in order to switch to the next inclination range. Thus, starting from position 153, an offset *ofsxx* of 0 means add nothing, 1 means add +1.
- *START_SIN90_120* becomes equal to the value at position 256, i.e. 247.
- As the wave does not more have segments with different inclinations, the remaining inclination ranges *W2* and *W3* shall be set to the same value as W1, and *X2* and *X3* can be set to 255. This way, only two inclination segments are effective.

OVERVIEW OF EXAMPLE												
Microstep number	0	1	2	3	4	5	6	7	…	153	154	…
Desired table entry	0	1	3	4	6	7	9	10	…	200	200	…
Difference to next entry	1	2	1	2	1	2	1	…	…	0	…	…
Required segment inclination	+1	+1	+1	+1	+1	+1	+1	…	…	+0	…	…
Offs bit entry	0	1	0	1	0	1	0	…	…	0	…	…

3 Revision History

3.1 Document Revision

Version	Date	Author BD – Bernhard Dwersteg SD – Sonja Dwersteg	Description
0.10	2012-DEC-03	BD	First preliminary version.
1.00	2013-JAN-08	SD	Changes related to wording and design.
1.00d	2016-FEB-09	BD	Updated list of related ICs

Table 3.1 Document revisions