dcStep™ Basics and Wizard

Valid for TMC5062, TMC2130 and TMC5130

The TMC5062 dual driver/controller family as well as the TMC5130 single driver & controller IC and the TMC2130 stepper driver offer a powerful feature to extend the usage range of a stepper motor: dcStep. dcStep is a load dependent speed control. The motor moves as fast as possible and never loses a step. dcStep basically requires tuning of a single parameter and setting of a lower operating velocity. The application note and the Wizard intend to give you a feeling for the parameters and their effect.

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1 What is dcStep

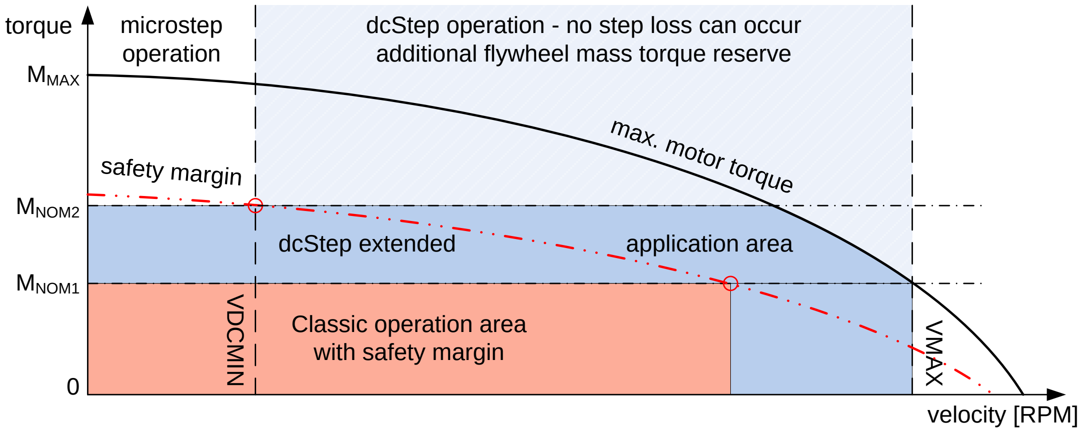
Stepper motors are typically used below their maximum pull-out torque with a safety margin of 40-50%. A safety margin of up to 50% torque is required in order to compensate unforeseen load peaks, torque loss due to resonance, and aging of mechanical components in an open loop system. Furthermore, stepper motors lose torque at higher speeds due to the specific dependency of rotor velocity and back EMF.
If load becomes too high, stepper motors lose steps and may even stall completely. This requires provisions to monitor motor movement and to recognize/prevent motor stall. Typically, various types of position encoders are used each with their specific pros and cons and costs.

dcStep is a new efficient stepper motor commutation scheme that focusses on utilizing most of the available output torque (ca. 80%) of the stepper motor. With dcStep, a stepper motor behaves like a DC motor if the load exceeds the motor output torque for the actual working point. It automatically adapts the motor velocity to the actual load by moving along the shape of the stepper motor torque curve. Due to this automatic load dependent deceleration and acceleration, the stepper motor does not lose any steps or stalls with the tradeoff of having a varying velocity. Nevertheless, it will arrive at the target position in any case without step loss. That is, dcStep keeps load and torque in balance.

dcStep is sensorless and thereby cost-neutral.

dcStep is based on full step excitation and is most efficient at middle to high speeds. When analyzing typical stepper motor torque curves, the maximum output torque does not increase significantly in the lower speed regions when decelerating but is more or less constant and further deceleration does not provide additional advantage. Thus, dcStep is used in the middle and higher speed regions where the back EMF impacts motor coil current and maximum output torque significantly.

For a given setup and application, dcStep extends the stepper motor's functional area by either allowing for more torque output in the same working point (same velocity) or by increasing the maximum velocity. In some cases and depending on the application a smaller and cheaper motor may do the same job.



M_{NOM}: Nominal torque required by application

M_{MAX}: Motor pull-out torque at v=0

Safety margin: Classical application operation area is limited by a certain percentage of motor pull-out torque

1.1 dcStep Operating Modes

dcStep can be used in different ways:

1. Speed limited: If the target velocity is limited by a motion controller, the motor is not necessarily operated at its torque limit. It still has some torque reserves left. In combination with coolStep (not possible with the TMC5062), the motor current can be reduced to the actually required value in order to save energy.
   With increasing load it does not decelerate immediately. Only when the load exceeds the output torque it starts deceleration to keep load and torque in balance.

2. Load limited: If the target velocity is not limited (or very high) the motor is always operated at its limit and every load change is visible in a changing motor speed. Output torque and load are always balanced here.

3. Minimum allowed velocity is > 0.
   dcStep is tuned for highest torque output (at high velocities). In this case, the motor cannot decelerate down to zero but only to VDCMIN. This is the natural use case of dcStep because the torque does not significantly increase any further below this minimum velocity. Focus is on exploiting the maximum torque in the higher speed regions.

4. Minimum velocity is = 0.
   Here, the focus is not primarily on maximum torque output but on deceleration down to zero and automatic ramp up when load will decrease.

   - Using the dcStep stall/stop detection in the TMC5130, a stall/stop condition can be detected, and the motor stops automatically.
   - When tuning the setting for a very low operation velocity, higher velocities cannot be reached.

1.2 Limitations of dcStep™

- Actually, the dcStep slogan is "as fast as possible". Nevertheless, this does not mean that a stepper motor can be used at very high speeds comparable to a brushless DC motor (BLDC, PMSM). "As fast as possible" means that the stepper motor can run at the maximum speed that is possible according to the load applied to the motor shaft and according to the parameter settings and motor supply voltage.

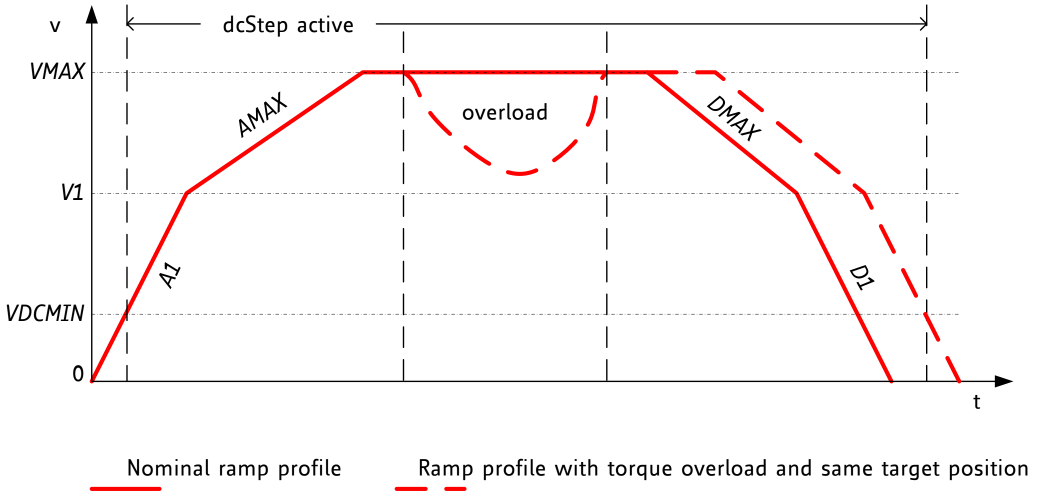
- dcStep does not replace an encoder. dcStep is still an open loop mode.
  If load is just too high and the speed falls below the minimum speed *VDCMIN*, the motor may stall and lose steps. However, stallGuard detects and reports this situation reliably.
  With an optional encoder, one could additionally track the position.

- dcStep allows for efficient utilization of the maximum stepper motor pull out torque without providing a safety margin. This again may allow replacing the original motor with a smaller and cheaper motor for the same application to safe costs. This cannot be guaranteed for every application and strongly depends on the application and the original motor type. A NEMA34 motor cannot be replaced with a NEMA17 motor for example because the difference between these two motors is just too big.

- dcStep cannot use 100% of the motor's maximum output torque but approximately 80% to 90% before slowing down the motor to a lower speed. This results from the necessity of some safety margin, to compensate for tolerances. However, this is still much more than the torque which may safely be used in an open loop system.

1.3 Supported Products

Trinamic stepper motor driver ICs allow for automatic and seamless switching from microstepping excitation during ramp up and ramp down to dcStep mode when exceeding the configured velocity limit VDCMIN. This still allows positioning moves with highest microstep precision (256 µSteps per full step) while exploiting the motor torque during constant speed phase.
Another reason for doing so is that especially in the lower speed regions microstep operation is superior to full step operation because of resonance dampening and slightly higher torque output. Whereas full step operation allows for slightly higher torque output in the high speed region compared to microstep operation.



The following Trinamic products (integrated controller+driver) support dcStep with seamless switching to and from microstepping:

- TMC5062
- TMC5072

- TMC5130

The following Trinamic products (dedicated controller and dedicated driver/predriver) support dcStep in combination

- TMC4361 + TMC26x
- TMC4361 + TMC2130

2 Tuning Procedure

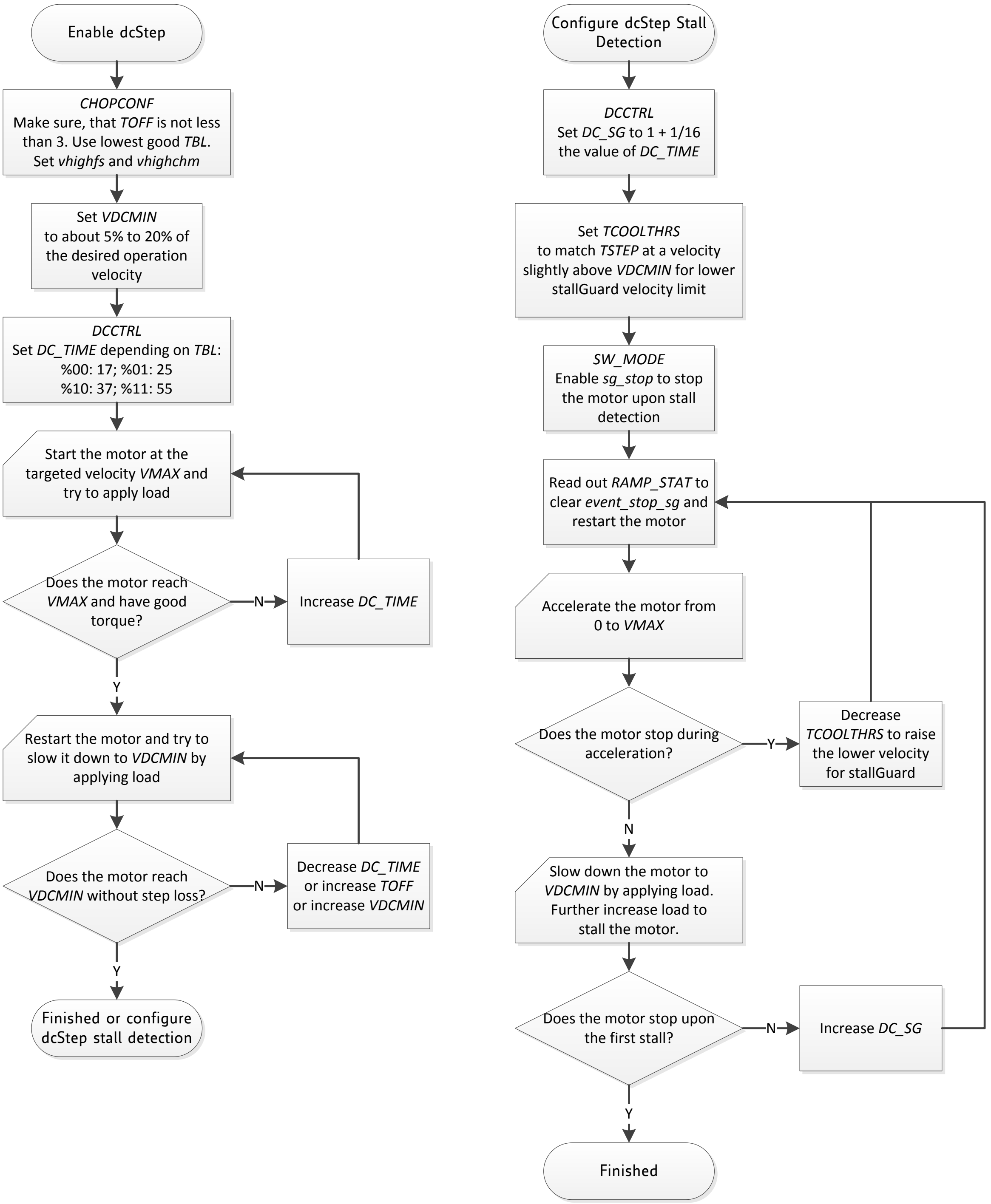
2.1 Parameters

A number of parameters are required to activate dcStep. Motor and supply voltage specific tuning is required for *DC_TIME* and *DC_SG*. Also, the clock frequency of the IC should not be changed after tuning, because the parameters internally are mapped to different timing constraints. As *DC_TIME* influences the lower operation velocity limit of dcStep, *VDCMIN* must be tuned after each change done to *DC_TIME*.

Parameter	Description	Range	Comment
vhighfs *&* *vhighchm*	Activate to enable dcStep compatible chopper mode	0 / 1	set to 1 for dcStep
TOFF	dcStep requires a stable chopper for optimum operation. With a chopper not using fast decay, an increased slow decay time helps fulfilling this. Therefore, TOFF should be set to 8 initially. Later on, smaller values can be tried out.	2… 15	Settings 8…15 do not make any difference to setting 8 for dcStep operation.
VDCMIN	This is the lower threshold for dcStep operation when using internal ramp generator. Below this threshold, the motor operates in normal microstep mode. In dcStep operation, the motor operates at minimum *VDCMIN*, even when it is completely blocked. Tune together with *DC_TIME* setting. When DC_TIME is increased, typically a higher *VDCMIN* is required	0… 2^22	0: Disable dcStep Set to the lower velocity limit for dcStep operation.
DC_TIME	This setting should be optimized for robust operation with maximum motor torque. A higher value allows higher torque and higher velocity, a lower value allows operation down to a lower velocity as set by *VDCMIN*. Check best setting under nominal operation conditions, and re-check under extreme operating conditions (e.g. lowest operation supply voltage, highest motor temperature, and highest supply voltage, lowest motor temperature).	0… 255	Lower limit is t_{BLANK} (as defined by *TBL*) in clock cycles + 1
DC_SG	This setting controls stall detection in dcStep mode. Increase for higher sensitivity. A stall can be used as an error condition by issuing a hard stop for the motor. Enable *sg_stop* flag for stopping the motor upon a stall event. This way the motor will be stopped once it stalls. The stall detection should be enabled once the motor has exceeded a certain lower velocity. This will prevent the driver from detecting false stall events during acceleration in resonance areas.	0… 255	Set slightly higher than *DC_TIME* / 16

2.2 dcStep Tuning

The setup of dcStep requires some optimization. Please see the flow chart for the basic procedure. Additional loops may be required in order to get the best feeling for the parameters and the motor.


Enable dcStep
CHOPCONF
Make sure, that TOFF is not less than 3. Use lowest good TBL. Set vhighfs and vhighchm
Set VDCMIN to about 5% to 20% of the desired operation velocity
DCCTRL
Set DC_TIME depending on TBL: %00: 17; %01: 25 %10: 37; %11: 55
Start the motor at the targeted velocity VMAX and try to apply load
Does the motor reach VMAX and have good torque?
N
Increase DC_TIME
Y
Restart the motor and try to slow it down to VDCMIN by applying load
Does the motor reach VDCMIN without step loss?
N
Decrease DC_TIME or increase TOFF or increase VDCMIN
Y
Finished or configure dcStep stall detection
Configure dcStep Stall Detection
DCCTRL
Set DC_SG to 1 + 1/16 the value of DC_TIME
Set TCOOLTHRS to match TSTEP at a velocity slightly above VDCMIN for lower stallGuard velocity limit
SW_MODE
Enable sg_stop to stop the motor upon stall detection
Read out RAMP_STAT to clear event_stop_sg and restart the motor
Accelerate the motor from 0 to VMAX
Does the motor stop during acceleration?
Y
Decrease TCOOLTHRS to raise the lower velocity for stallGuard
N
Slow down the motor to VDCMIN by applying load. Further increase load to stall the motor.
Does the motor stop upon the first stall?
N
Increase DC_SG
Y
Finished

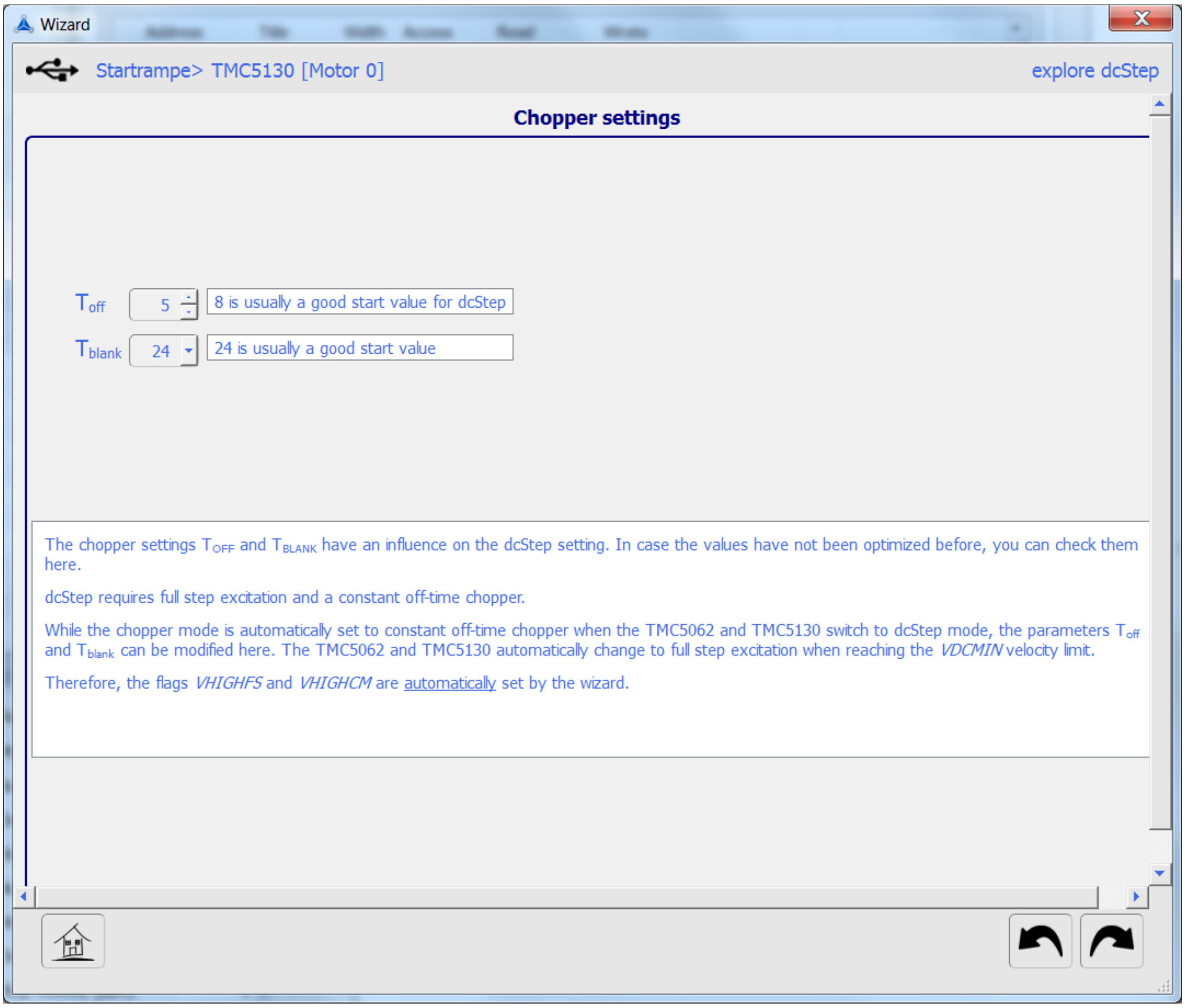
3 Using the Wizard

The TMCL-IDE brings a Wizard for tuning dcStep. The Wizard activates the required parameters in the right order and helps understanding dcStep and getting a feeling for its operation.

PREREQUISITES

Before launching the Wizard, the basic settings should have been made: Motor current (fitting to the motor) and initial settings for the spreadCycle™ chopper, which becomes activated during the first acceleration phase.

FIRST STEP: CHECK TBL AND TOFF



T_{off} 5 – 8 is usually a good start value for dcStep

T_{blank} 24 – 24 is usually a good start value

The chopper settings T_{OFF} and T_{BLANK} have an influence on the dcStep setting. In case the values have not been optimized before, you can check them here.

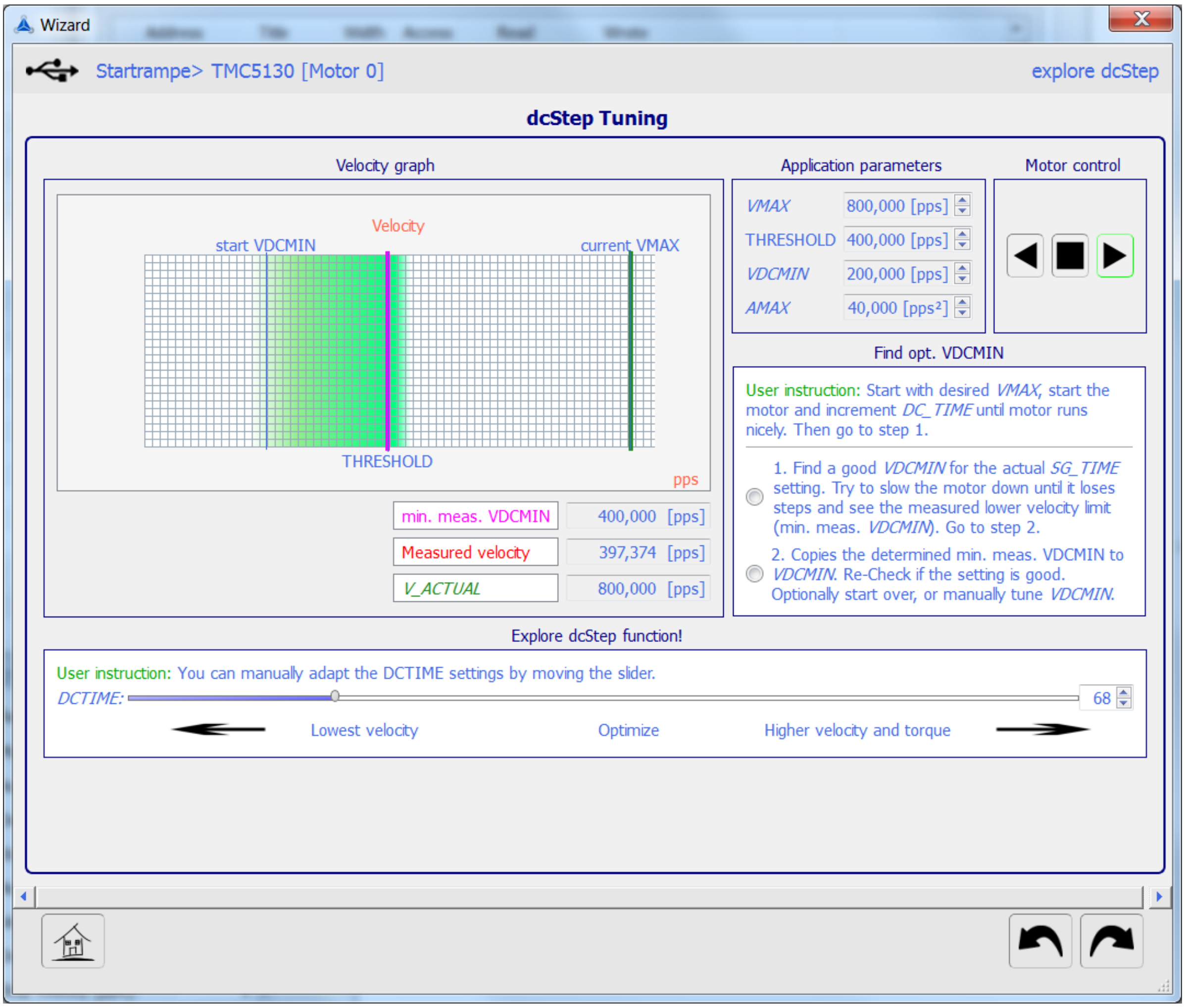
dcStep requires full step excitation and a constant off-time chopper.

While the chopper mode is automatically set to constant off-time chopper when the TMC5062 and TMC5130 switch to dcStep mode, the parameters T_{off} and T_{blank} can be modified here. The TMC5062 and TMC5130 automatically change to full step excitation when reaching the *VDCMIN* velocity limit.

Therefore, the flags *VHIGHFS* and *VHIGHCM* are automatically set by the wizard.

As dcStep generally requires higher *TOFF* settings, while it benefits from lower *TBLANK* settings, a first step is to check if the settings applied should be modified. In case they have been optimized before, revert to the desired settings.

SECOND STEP: OPTIMIZE SGT TOGETHER WITH VDCMIN



Startrampe> TMC5130 [Motor 0]

explore dcStep

dcStep Tuning

Velocity graph

Application parameters

Motor control

min. meas. VDCMIN	400,000 [pps]
Measured velocity	397,374 [pps]
V_ACTUAL	800,000 [pps]

VMAX	800,000 [pps]
THRESHOLD	400,000 [pps]
VDCMIN	200,000 [pps]
AMAX	40,000 [pps²]

Find opt. VDCMIN

User instruction: Start with desired *VMAX*, start the motor and increment *DC_TIME* until motor runs nicely. Then go to step 1.

○ 1. Find a good *VDCMIN* for the actual *SG_TIME* setting. Try to slow the motor down until it loses steps and see the measured lower velocity limit (min. meas. *VDCMIN*). Go to step 2.

○ 2. Copies the determined min. meas. VDCMIN to *VDCMIN*. Re-Check if the setting is good. Optionally start over, or manually tune *VDCMIN*.

Explore dcStep function!

User instruction: You can manually adapt the DCTIME settings by moving the slider.

DCTIME: 68

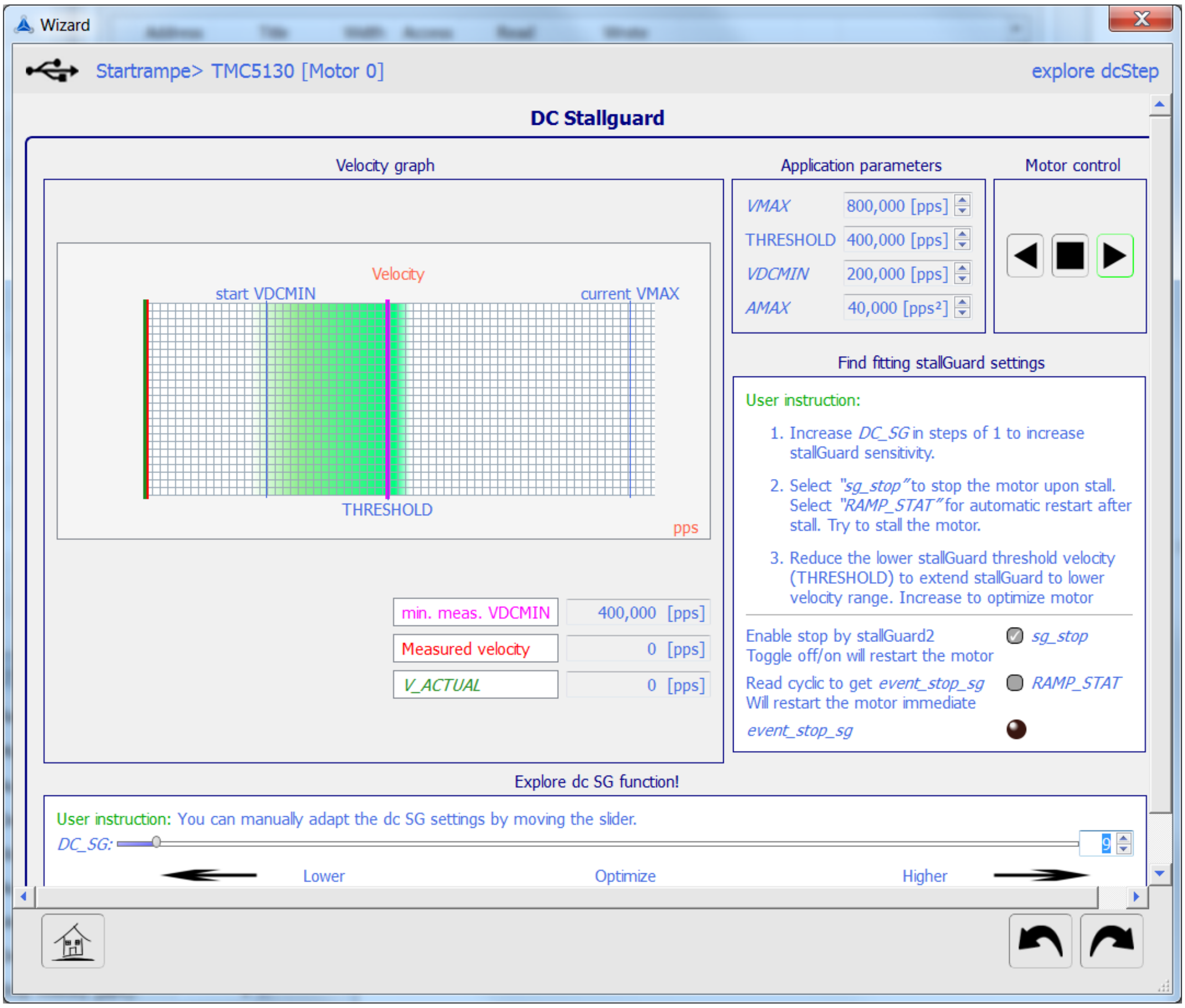
Lowest velocity   Optimize   Higher velocity and torque

Now, start the motor by pressing the rotate right or rotate left button. Adapt *AMAX* if the motor cannot start up. If the motor does not accelerate when increasing *DCTIME*, decrease *VDCMIN*. In this case probably the motor already has reached the maximum dcStep velocity with the given current setting.

Now, activate the first round button. This will set a very low *VDCMIN*, allowing tests within the full motor velocity range. Manually apply force to the motor and try braking it. You will experience a lower velocity, below which the motor does not run smoothly anymore. This lower velocity shifts up with higher *DCTIME*. At the same time, also the upper velocity limit shifts up, and torque available at higher velocity. Find a good trade-off between lower velocity limit and torque at the desired *VMAX*.

In step 2, the lower measured velocity becomes copied to *VDCMIN*. In case it is too low, you can go back to step 1, or manually increase it.

Third Step: Optimize SGT together with VDCMIN



DC Stallguard

Application parameters

VMAX	800,000 [pps]
THRESHOLD	400,000 [pps]
VDCMIN	200,000 [pps]
AMAX	40,000 [pps²]

min. meas. VDCMIN	400,000 [pps]
Measured velocity	0 [pps]
V_ACTUAL	0 [pps]

Find fitting stallGuard settings

User instruction:

1. Increase *DC_SG* in steps of 1 to increase stallGuard sensitivity.
2. Select *"sg_stop"* to stop the motor upon stall. Select *"RAMP_STAT"* for automatic restart after stall. Try to stall the motor.
3. Reduce the lower stallGuard threshold velocity (THRESHOLD) to extend stallGuard to lower velocity range. Increase to optimize motor

Enable stop by stallGuard2 Toggle off/on will restart the motor ☑ *sg_stop*

Read cyclic to get *event_stop_sg* Will restart the motor immediate □ *RAMP_STAT*

event_stop_sg ●

Explore dc SG function!

User instruction: You can manually adapt the dc SG settings by moving the slider.

DC_SG: 9

Lower Optimize Higher

In this step, dcStep stallGuard becomes tuned to fit the determined settings. Hook *sg_stop* and try to stall the motor. The driver now will stop the motor in case it detects a complete stall. In case it stops too early, decrease *DC_SG*. In case it does not stop, or only after losing several steps, increase *DC_SG*. To reset the stop condition, either remove *sg_stop*, or check *RAMP_STAT*. This will read out *RAMP_STAT* and signal when a stop was detected, while at the same moment restarting the motor.

In case the motor cannot restart safely with the actual settings, reduce *DC_SG* or increase the stallGuard threshold velocity (THRESHOLD).

Go to the last step to see the results screen and copy them to your application.

4 Disclaimer

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5 Revision History

Document Revision

Version	Date	Author BD – Bernhard Dwersteg SK – Stephan Kubisch	Description
0.5	2014-MAI-27	SK	Started to rework the document for TMC5062, TMC5130 and the parameterization wizard in the TMCL IDE 3.0
1.00	2015-MAR-12	BD	Update, new style, some rewording & shortening, added flowchart and integration of new wizard

6 References

TMC5130 datasheet, www.trinamic.com
TMC50XX family datasheets, www.trinamic.com