

Getting Smart about Tuning Your Stepper Motor



James Lockridge

When I first heard about stepper motor tuning, I was really confused. How can a motor be out of tune? I started reminiscing about warming up for band concerts in high school and wondered how system designers could do something similar for their motors.

After watching a video from my colleague [Matt Hein](#) I learned these three things about stepper motor tuning:

- Stepper motor tuning relates to how well the current regulation scheme maintains current in a stepper motor's coils. Poor tuning occurs when the stepper driver does not properly regulate the current in the coils to the appropriate level. A poorly tuned stepper motor will have a jerky motion and significant vibration. Poor tuning can also negatively impact the efficiency of the motor drive system.
- Tuning the stepper motor can be time-consuming because finding the optimal fixed decay settings for a given motor, voltage, current and speed is a trial-and-error process.
- Stepper motor tuning is especially important for [microstepping](#). Microstepping gives stepper motors fine positional control. The current waveform of a tuned stepper motor should approximate a sine wave, as shown in [Figure 1](#).

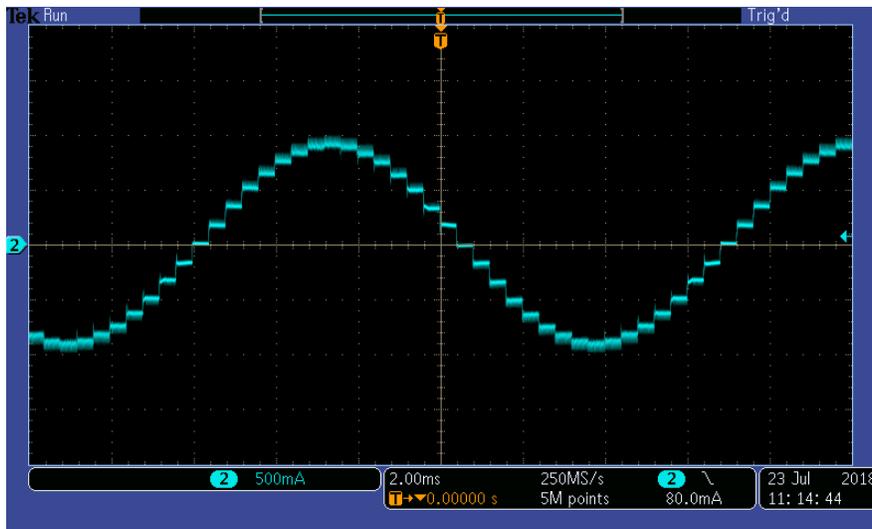


Figure 1. Stepper Motor Coil Current for a 25V Supply, 2,500 Pulses per Second (PPS) and One-eighth Microstepping Using Ripple Control on the TI DRV8886AT

However, engineers who work with stepper motors do not always see a waveform like [Figure 1](#) the first time they connect their motor. They may see waveforms like the ones shown in [Figure 2](#), [Figure 3](#), or [Figure 4](#). These figures are examples of poor stepper motor tuning, and will cause excessive vibration and noise from the stepper motor.

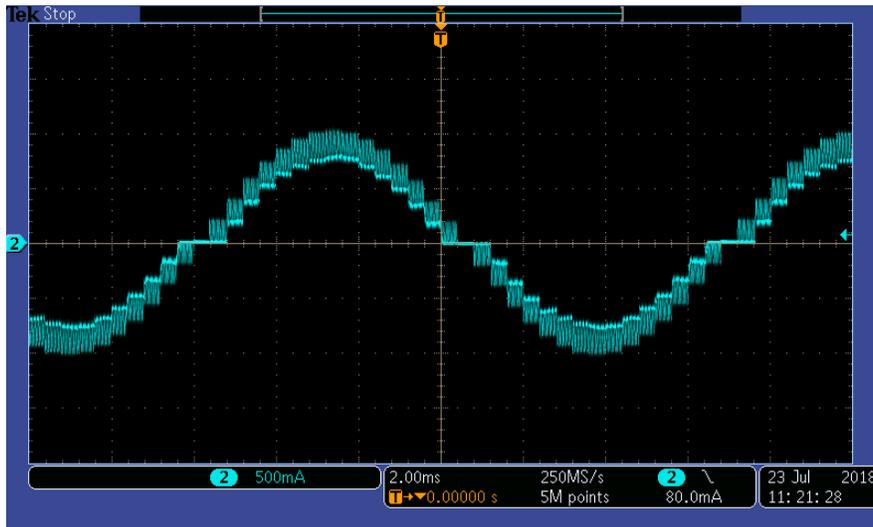


Figure 2. Stepper Motor Waveform with 60% Fast Decay

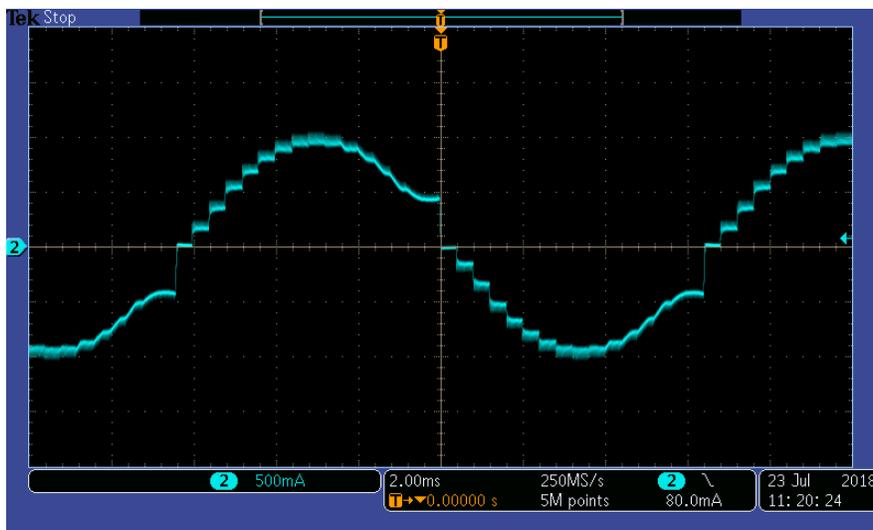


Figure 3. Stepper Motor Waveform with Slow Decay

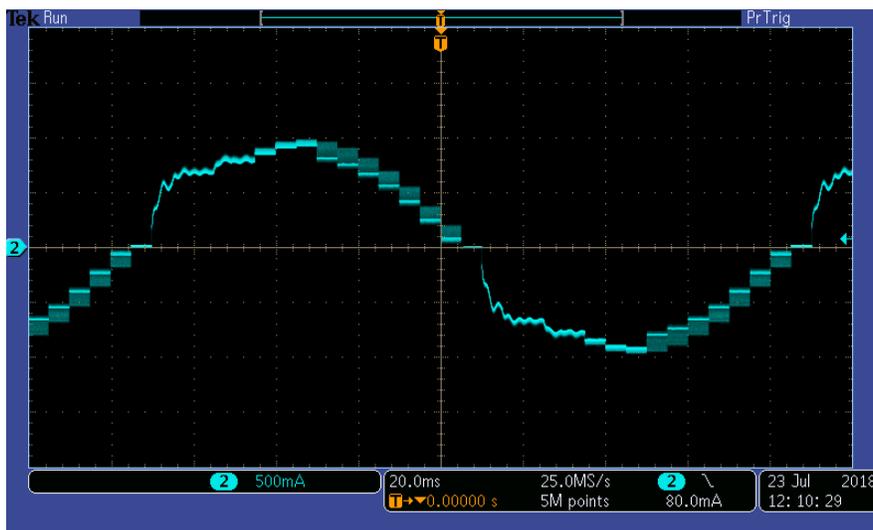


Figure 4. Stepper Motor Waveform at a Slow Speed (200PPS) with Slow Decay/50% Mixed Decay

In each of these cases, the decay setting chosen for the current regulation scheme (also called current chopping) was not appropriate for the chosen motor, supply voltage, full-scale current, and speed.

Stepper motor tuning is the process of choosing the proper decay setting during the off time of the PWM current chopping cycle (t_{OFF}). Figure 5 shows the different ways that current can flow through the H-bridges of a stepper driver. During fast decay, the field-effect transistors (FETs) opposite from the driving FETs turn on, and the current flows from the motor back to the power supply. For this condition, the current decreases quickly. During slow decay, the two low-side FETs turn on, and the current recirculates through these FETs. For this condition, the current decays much more slowly.

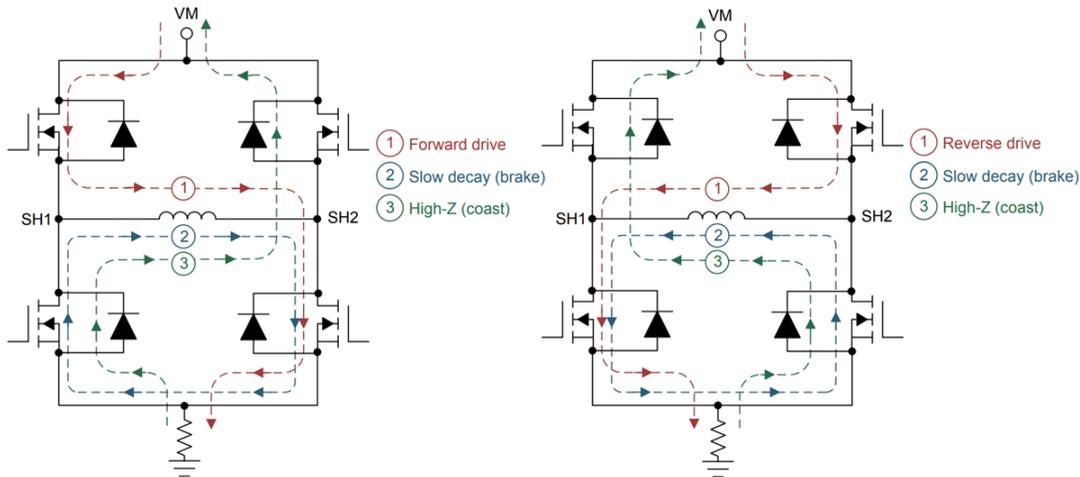


Figure 5. Current Paths through the H-bridge During Normal Operation (Driving), Dead Time (All FETs Are off), Fast Decay and Slow Decay

During stepper motor tuning, engineers search for the optimal “mixed” decay setting for the stepper. Mixed decay consists of a combination of fast and slow decay when the driver is not driving current into the coils. Choosing the mixed-decay settings means setting the percentage of fast decay versus slow decay for the off time.

Figure 6 shows how mixed decay helps regulate the current.

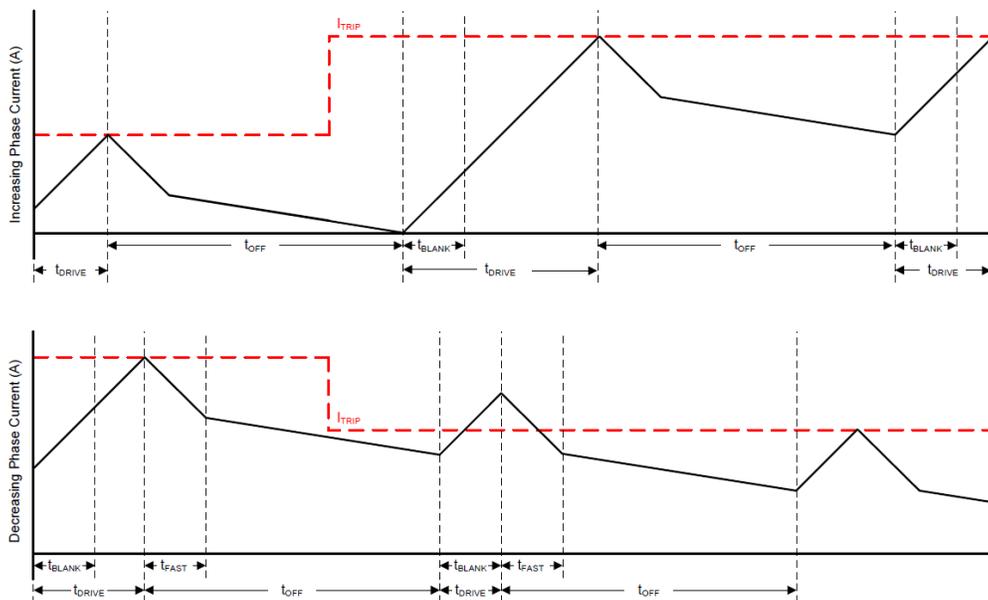


Figure 6. Using Mixed Decay to Regulate the Current at Each Microstep Level

Some customers have told us that it can take as long as a month to find the proper decay settings for their stepper motor. The combination of the supply voltage, back electromotive force (EMF) and microstepping current levels all impact the way the current in the stepper coils charges and discharges.

The following list provides some details as to why this is the case:

- Back EMF will change with speed and load torque. Back EMF opposes the supply voltage, so the effective voltage across the coil is smaller.
- The application may require the stepper motor to operate at a wide range of speeds.
- Each current level required for microstepping has a different I_{TRIP} threshold, which will impact the timing of the current charging and discharging in the coil. Because of this, choosing a fixed mixed-decay setting is difficult because it has to regulate the current under all of those conditions.

Table 1 provides explanations for why the decay modes chosen in Figure 2, Figure 3, and Figure 4 exhibit poor tuning.

Table 1. Explanations for examples of the poorly tuned stepper motor waveforms shown in Figure 2, Figure 3 and Figure 4

	Conditions	Tuning issue
Figure 2	25V supply, 2,500PPS, 1/8 microstepping, 60% fast decay for increasing and decreasing current	Too much fast decay percentage causes large ripple currents
Figure 3	25V supply, 2,500PPS, 1/8 microstepping, slow decay for increasing and decreasing current	Significant back EMF distorts the waveform when the current decreases using slow decay
Figure 4	25V supply, 200PPS, 1/8 microstepping, slow decay for increasing current and 50% fast decay for decreasing current	The blanking time for slow decay is too long, so the motor coils charge faster than the driver can regulate the current

At this point, you may be thinking, “Instead of manually testing all of the fixed mixed-decay settings to find the best one, what if the stepper driver had some kind of smart tuning feature to choose the best mixed-decay setting while driving the motor in real time?”

Devices like the DRV8880, DRV8881 and DRV8886AT have smart tuning features that can help eliminate the time-consuming effort of stepper motor tuning. All of these devices have the option to select dynamic decay, which is a smart tuning feature that automatically adjusts the percentage of fast decay used in the total off time. The DRV8886AT has an additional smart tuning feature called ripple control that regulates the current at each microstep level between the upper and lower thresholds. Ripple control only uses slow decay, but because the driver continually senses and adjusts the current, the current does not lose regulation.

Other than achieving nice sinusoidal current waveforms like Figure 1, these smart tuning features have other benefits as well. When the stepper motor has a well-tuned current waveform, it runs more quietly and more efficiently. Interestingly, the examples of poor tuning in Figure 2, Figure 3, and Figure 4 all result in currents larger than the targeted stepper motor current at certain microstep levels. This excess current increases the temperature of the motor and the driver. With dynamic decay and ripple control, the driver does not use excess current at each microstep level. Figure 7 shows how a stepper motor tuned with dynamic decay reduces thermal dissipation of the stepper driver chip.

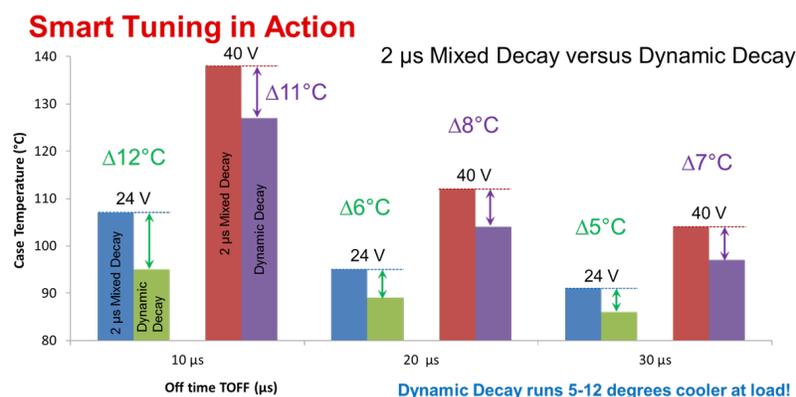


Figure 7. Dynamic Decay vs. Mixed Decay at Various T_{OFF} Times

Ultimately, smart tuning features like dynamic decay and ripple control can help you save time and reduce temperature and noise in your stepper motor applications.

Additional Resources

- For more information on dynamic decay and ripple control, check out the data sheets for the [DRV8880](#), [DRV8881](#), and [DRV8886AT](#)
- The application report [Current Recirculation and Decay Modes](#) explains the decay modes used in stepper driving in greater detail

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2023, Texas Instruments Incorporated