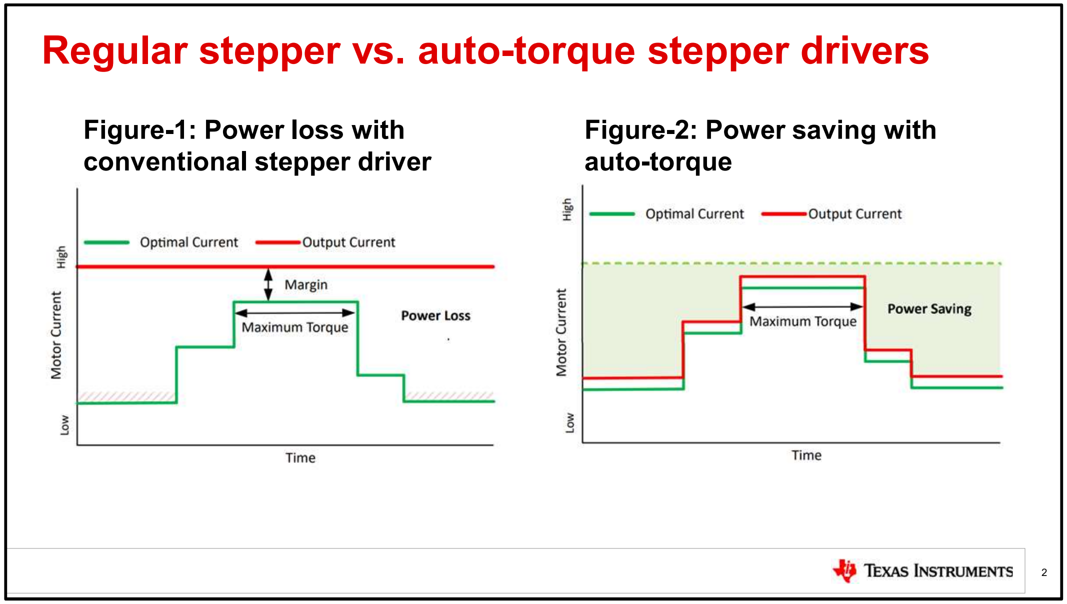
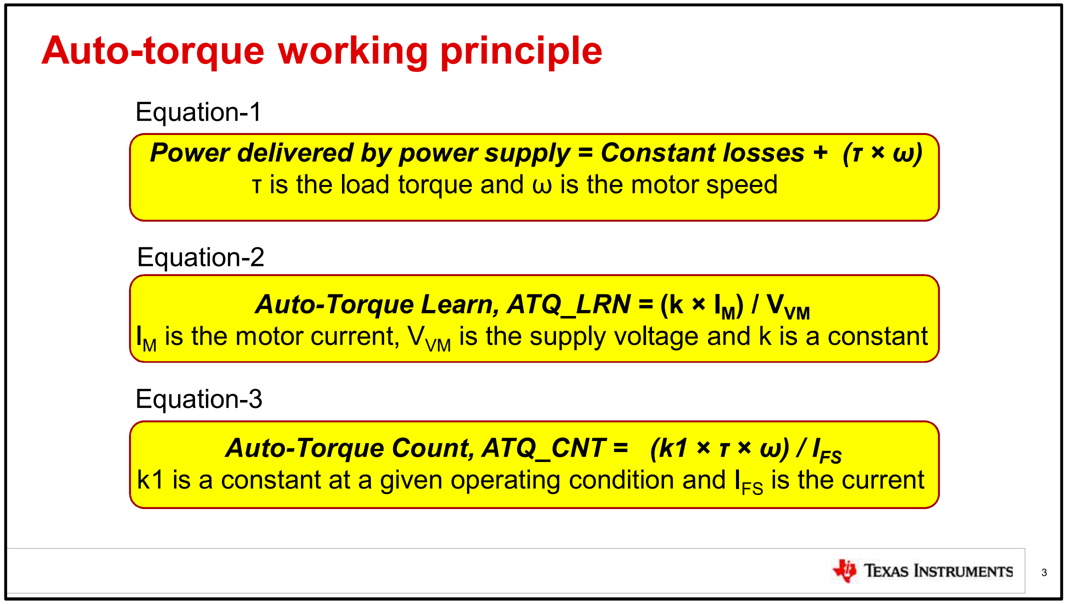
Welcome to the eleventh chapter in the TI Precision Labs series on stepper motors. My name is Murugavel Raju, and today I will discuss the auto-torque feature of the DRV846x/DRV8452 family of integrated stepper drivers. [Click]



In a typical stepper motor driver design, the motor current is set at a fixed full-scale current, IFS, aimed at driving the maximum load torque expected in an application, with some safety margin included. This is shown by the red line graph in Figure-1. This strategy works well from a power efficiency standpoint, only if the load torque is constant and close to the expected maximum torque, 100% of the time. However, in real-world applications, the motor may see a variable load torque, for example, with a load torque profile resembling the green line graph shown in Figure-1. Notice the motor is driven to output peak current all the time? This results with unwanted power loss during the durations the load torque is much lower than the peak torque. This power loss is translated to heat in the stepper motor and the driver, and could lead to premature aging and failure of the components in the system.

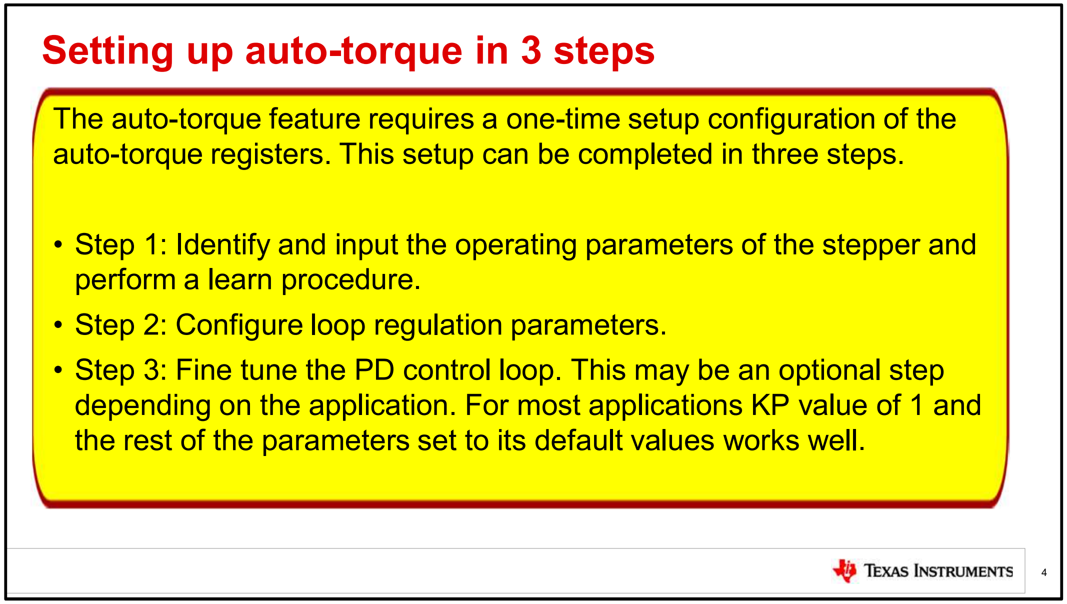
The auto-torque feature in the DRV8462, DRV8461 and DRV8452 is a sensorless integrated solution, that tracks the load torque profile and modifies the full-scale current, IFS, to automatically track the load torque profile, as shown by the red line graph in Figure-2. In this example, the auto-torque feature, eliminates the power loss region and increases the efficiency of the system. In applications where the peak demand for load torque is only for short durations the efficiency improvement could be as high as 75%. The integrated Auto-torque feature does not require any external sensor. Instead, by monitoring the power delivered to the motor, it generates an internal signal which linearly varies with the load torque. [Click]



In a stepper motor drive system, the total power delivered by the power supply is equal to the sum of the torque delivered to the load by the motor and the power losses in the electrical system, such as the resistive losses in the motor windings and the driver output stage. This is represented by the equation-1. The auto-torque algorithm obtains information about the load-torque by monitoring the power delivered to the motor using V and I values of the motor windings.

The constant losses are modelled by ATQ_LRN, the auto-torque learn parameter. The auto-torque learn parameter is directly proportional to the coil current. This is represented by the equation-2. This equation describes a linear relationship between the auto-torque learn parameter and the motor current I_M. Using a learning routine, the auto-torque algorithm learns the ATQ_LRN values for the system, by taking measurements at any two output currents while the stepper motor is spinning with the target velocity with no load. The algorithm then uses this information to interpolate the ATQ_LRN values at any other output current within the operating range.

The auto-torque count parameter represents the component of the delivered power that supports the load torque. This is represented by the equation-3. This equation defines the basic working principle of the auto-torque algorithm. The auto-torque count parameter, determines motor coil current regulation target value, based on applied load torque on the stepper motor. When the auto-torque count decreases the I_{FS} increases and vice versa. The auto-torque count is also an indirect measure of the load torque. [Click]



I will walk you through a live demo of setting up the auto-torque using a DRV8462EVM and its GUI app. A NEMA17 stepper motor with 2 A current specification and a 24 V VM supply will be used for this demo.

Step 1: Let’s identify and input the operating parameters of the stepper and perform a learn procedure.

- Change the IFS setting to 2 A and use the default settings in the GUI to the spin stepper motor. Move to the “AUTO TORQUE” tab and enable “Auto-torque Mode”.
- “Maximum Current Limit” setting: This can be 100% of the IFS

current setting or a lower current value depending on the application requirement. In this example, we will use 100% IFS current setting. This value will be 255 (the default value).

- “Minimum Current Limit” setting: This is the minimum stepper current required, to support the minimum load torque of the application. In this example it is 0.5 A. For 0.5 A this value will be, (0.5/2) * 255 = 64.
- Set the “Initial Learning Current” to 8, just so x8 of this value is greater than or equal to 64, the “Minimum Current Limit” setting.
- The “Current Steps for Learn” can be at the default value of 128 for this setup. (because 128 + 64 is less 255)
- Start the “Auto Torque Learn” by pressing the button. Completion of the learning procedure is indicated by a “Learn Completed” check mark and message.

Note:
The ATQ_LRN values at these two currents are saved in the **ATQ_LRN_CONST1** and **ATQ_LRN_CONST2** registers. These two values are used by the algorithm to interpolate the ATQ_LRN values for all other

currents within the operating range of the application. These **ATQ_LRN_CONST1** and **ATQ_LRN_CONST2** values can be saved and re-used in mass production programming. There is no need to perform a learning procedure every time the auto-torque is enabled as long as the operating conditions are the same. Learning can also be performed for multiple operating conditions and saved. This can be used to load to the registers at any time for use with the corresponding operating conditions.

Step 2: In order to complete the configuration of the loop regulation parameters, the "Auto Torque Count Upper Limit" value for the ATQ_UL register and the "Auto Torque Count Lower Limit" value for the ATQ_LL register must be setup. The ATQ_UL and the ATQ_LL registers are the upper and lower boundaries of the hysteretic band, within which the auto-torque count "ATQ_CNT" is controlled by the auto-torque algorithm. To identify and setup these parameters the auto-torque closed loop control, must be enabled first. Setting KP to 1 in the PD CONTROL LOOP SETTINGS, will close the control loop.

Observe the maximum range of the “Auto Torque Count” values while loading the motor close to its maximum load torque in the application. Input this value to the “Auto Torque Count Upper Limit”. The “Auto Torque Count Lower Limit” can be the same value (no hysteresis) or a value lesser than the upper limit based on the desired hysteretic band of operation. In this example, we will use a hysteretic band of 10.

Step 3: In this example we will leave KP to its initial setting of 1 and the rest of the control loop parameters to its default values.

Note:

The auto-torque feature is a closed loop control based design. It is a PD, proportional derivative controller. The PD control algorithm is expressed by the equation $u(t) = KP * e(t) + KD * de(t)/dt$, KP and KD are PD loop constants, $u(t)$ is the output of the loop controller, and $e(t)$ is the error signal.

The auto-torque PD control loop smoothens the response, to sudden load torque transients while minimizing the error. These values can be fine tuned, for the desired auto-torque response, specific to the application needs. Check out the “Stepper Motor System Power Loss Reduction Using AutoTorque” application note for guidelines to tune the PD loop parameters.

The Auto-Torque setup is completed.

To perform a quick check, let’s load the stepper with the maximum load torque of the application. The drive current will automatically change to the upper limit programmed. Now let’s load the stepper with the minimum load torque of the application. The drive current will quickly reduce to the lower limit programmed. This can be observed in the graph of the GUI. When the motor is loaded with nominal load torque, the drive current will be maintained within the defined hysteretic band.
[Click]

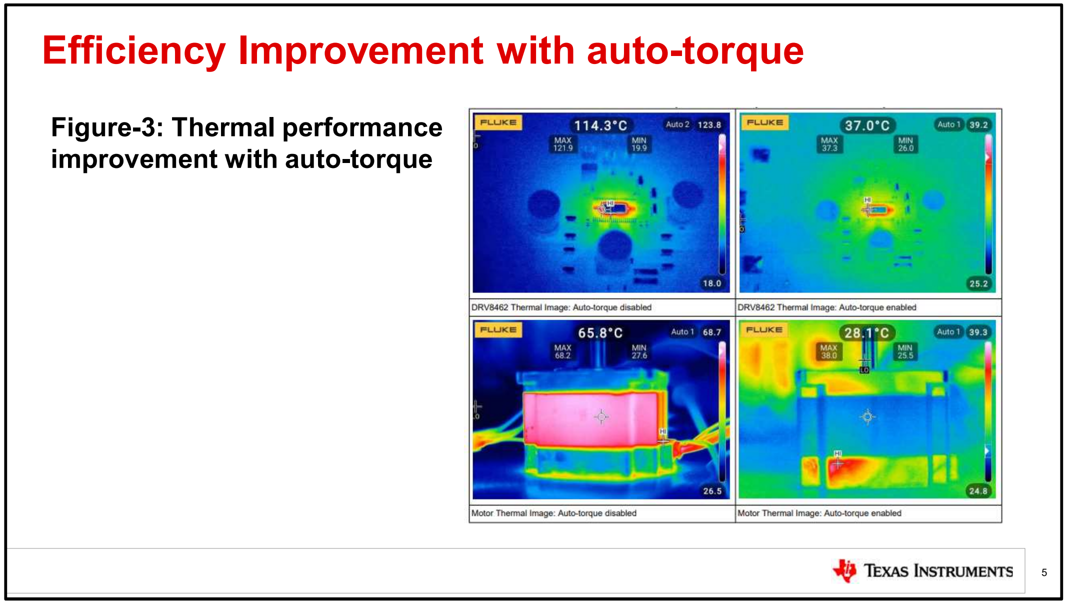


Figure-3 shows an example of the thermal performance improvements of a stepper motor system with auto-torque enabled vs. auto-torque disabled.

The thermal images were captured using the following conditions:
VM = 24 V, 1/16 Steps, 4A I_{FS}, 3000 PPS speed setting, idle load, and at room temperature ambient T_A = 25 ^{o}C,.

The driver IC temperature reduced to 37 ^{o}C with auto-torque enabled vs. a steaming hot 114.3 ^{o}C with auto-torque disabled. Likewise, the stepper motor temperature reduced to 28.1 ^{o}C with auto-torque enabled vs. a very hot 65.8 ^{o}C with auto-torque disabled. This improvement in the thermal performance of the system significantly improves long term reliability of the complete stepper motor system. [Click]

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