Reading and understanding a torque curve

Introduction

Stepper motors must be carefully selected. Indeed, if the load exceeds the motor's torque specifications, the stepper motor will stall. Obviously, this can be detrimental to the application. In practice, working points of stepper motors cannot be calculated and one has to rely on the torque vs. speed curve published on the related datasheet. These torque vs. speed curves are plotted using several torque measurements made at different speeds.
The goal of this application note is to explain how to read a torque curve and show the important parameters that must be taken into account when choosing the most appropriate stepper motor.

Understanding a torque curve

A torque curve, as presented in the datasheet, is shown in Figure 1.

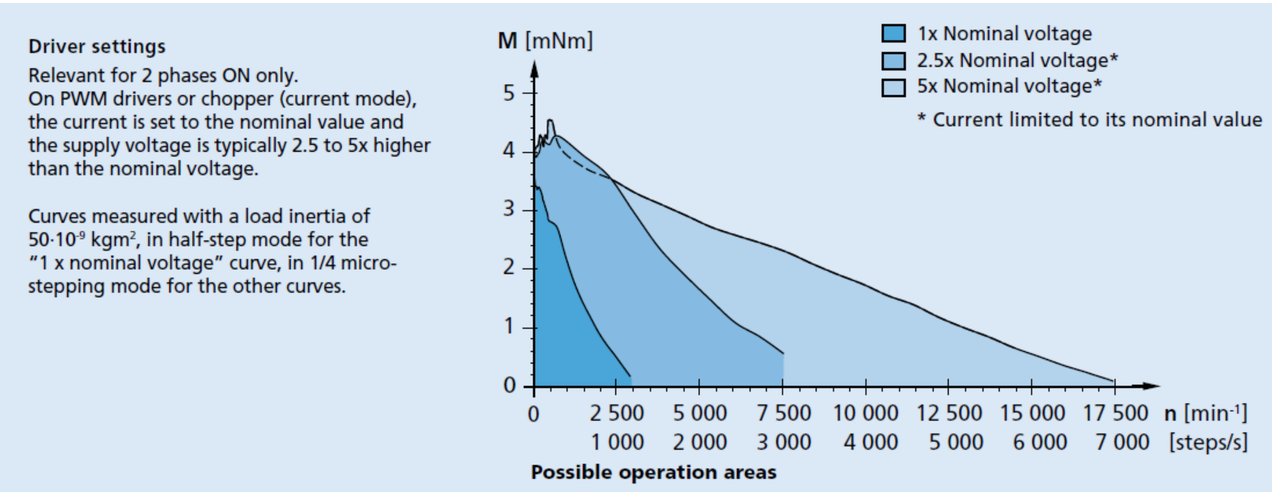

Figure 1 : Torque vs. speed curves for an AM1524 motor controlled by trinamic TMCM-110 driver. The three curves correspond to three different driver supply voltage (i.e. 1x, 2.5x and 5x the motor nominal voltage).

Stepper motors offer somehow what we can compare to a "torque reserve". Either the application requires less torque than available and it is fine, either the torque required exceeds the motor capacity, causing the rotor to lose synchronism and to stall. This maximum is defined as pull-out torque which curve can be seen on datasheet. The motor current consumption does not change even if the load is null.
Stepper motors can start/stop with an initial speed (without acceleration ramp). Its maximum is defined as the pull-in torque. Starting motors with conditions exceeding the pull-in curve will cause the motor to stall (loss of synchronism).

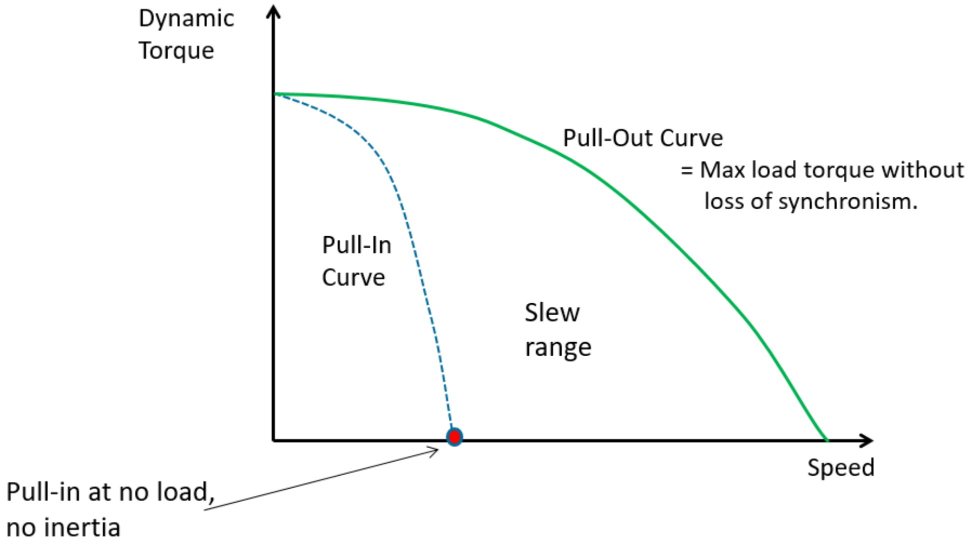

Figure 2 : Schematic of a torque vs. speed curves for stepper motor.

The zone between the pull-in and pull-out curve is known as the slew range and the motor can enter (exit) this zone with acceleration (deceleration) ramp.
The maximal start/stop speed of a stepper motor at a given load is called the **pull-in speed** (or frequency). Its maximal value is achieved without load. The values of the pull-in speed at no load can be obtained on request since they are not represented on the FAULHABER catalogue. In practice, the addition of inertial and frictional loads significantly modify this limit and it must evaluated on a case to case basis directly in the application.

Pull out curve (sometimes referred as maximum slew rate)

Depending on the torque requirements, the pull-out curve defines the max. speed a stepper motor can reach without stalling. This curve can also be interpreted as the max. torque the stepper motor can provide at a given speed.
This curve also shows the performance limitations of a given stepper motor, as it is not possible to drive it to a point "over" this curve.
When selecting a stepper motor, it is recommended to use a 30% safety factor on the torque curves, by simply multiplying the torque curves by 0.7. This is to anticipate the effect of the overshoot on the position of the stepper and most of the manufacturers recommend it.
Increasing the driver supply voltage (for instance to about 5 times the nominal voltage) will help the motor to reach higher speeds. This is a direct effect of the inductance of the windings of the motor and the current can rise much faster when the voltage is higher[1]. For most applications, it is therefore recommended to use a driver with a supply voltage 2 to 5 times the nominal voltage specified in the datasheet. Note that increasing excessively the driver supply voltage leads to a defective current regulation (ripple) at low and medium speed and may results in a small decrease of the torque.

[1] Please refer to the application note "*Drivers and controllers : how to drive a stepper motor?*" for more information.

What happens if a load is applied?

When a load is applied to a stepper motor, the necessary torque has to be calculated taking into consideration its speed profile.

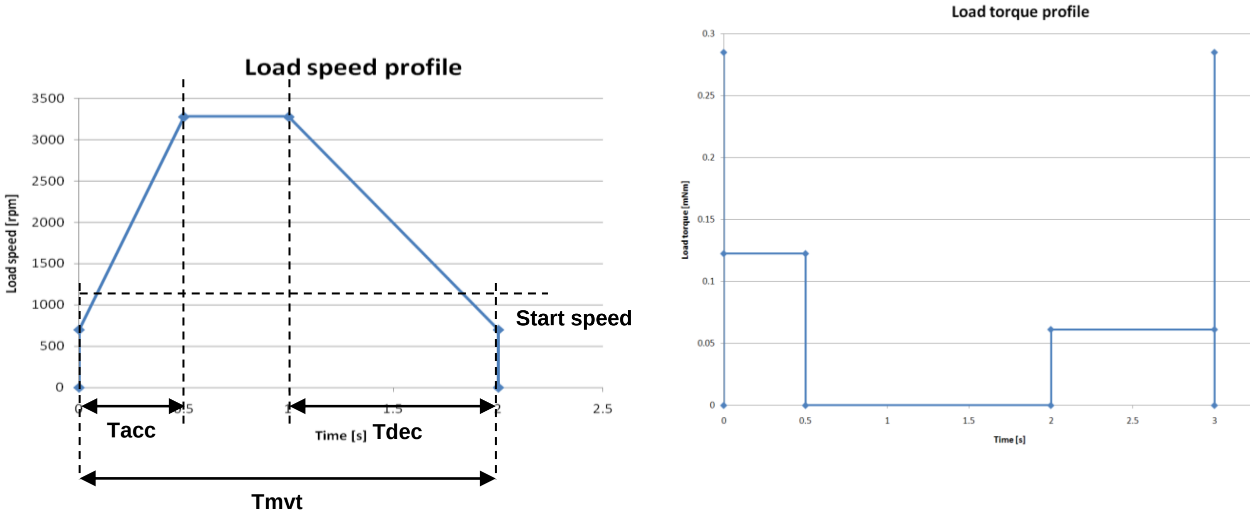

Figure 3 : Example of a speed profile with an inertial load (without friction or other losses). Profiles of the speed (left) and load torque (right) with an acceleration (Tacc) and deceleration (Tdec) ramp. Start speed is also displayed. The torque during acceleration is higher than during deceleration because there is less time to accelerate than to decelerate.

A tool to facilitate the calculation

The goal of this section is to quickly explain how to use the Dynamic torque calculator developed by FAULHABER PRECISTEP and available on the FAULHABER website. When opening the application, the window shown in Figure 4 appears.

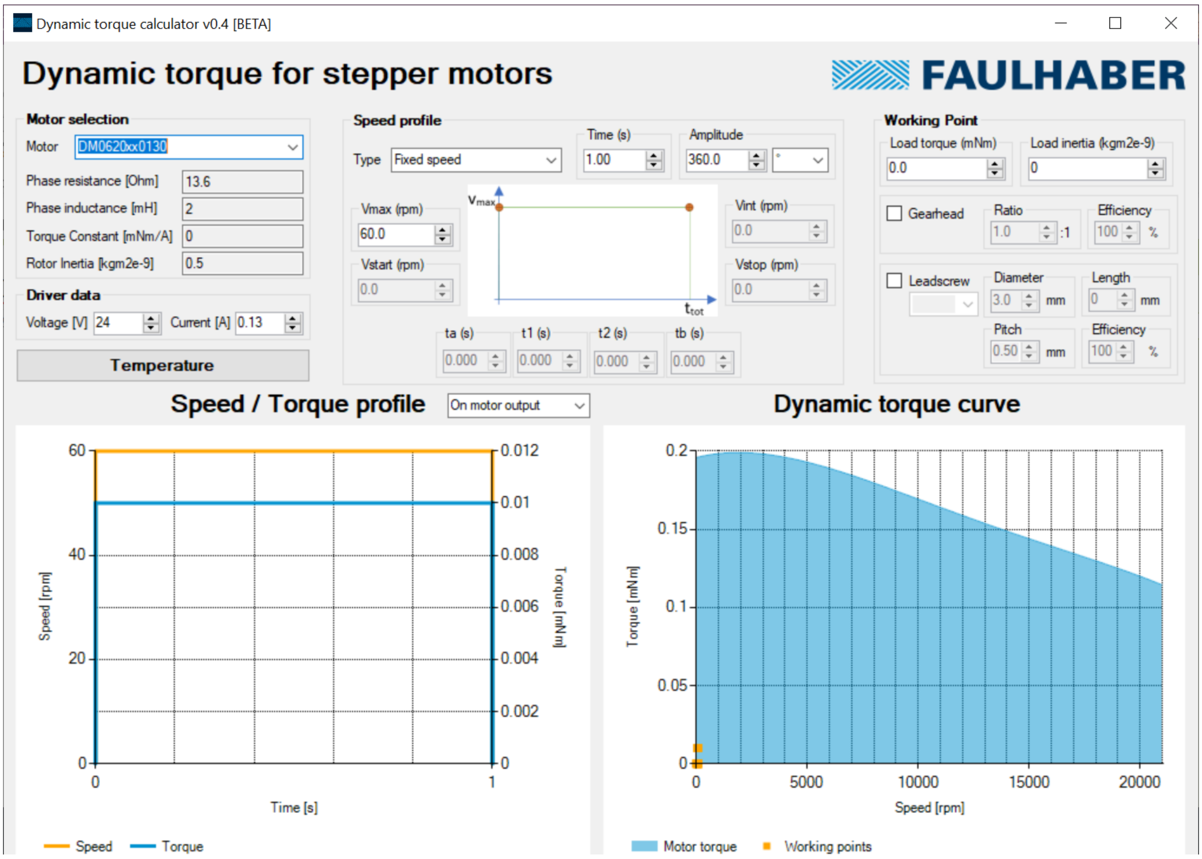

Figure 4 : Interface of the Dynamic torque calculator

The user may then select the type of stepper motor, the diver voltage, the speed profile and if a lead screw and gearhead are assembled or not. Depending on the selected speed profile, various parameters have to be provided, such as the start speed and movement time. The speed and torque profiles can be seen on the motor output, or on the gearhead or leadscrew if the option has been selected. Additionally, the torque curve with all the working points can be seen. If all working points are below the blue curve, as seen in Figure 5, then this means that the drive system can fulfill the speed/torque requirements.

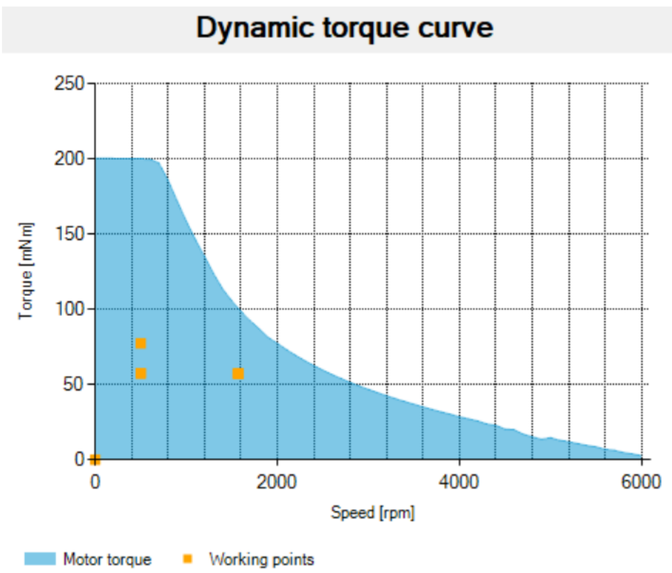

Figure 5 : Interface of the Dynamic torque calculator

For more details about the about the use of the Torque and Temperature calculator, please refer to our detailed user guide application note (AN022) available on the FAULHABER website.

References

[1] S. Motor, D. Considerations, and C. Problems, "APPLICATION NOTE STEPPER MOTOR DRIVER CONSIDERATIONS," no. December 2003, pp. 1–11.

[2] "Lead Screw Efficiency." [Online]. Available: http://www.askltd.co.jp/eng/technical_info/feed_screw. [Accessed: 19-Jun-2013].

[3] "Better Soldering." [Online]. Available: http://www.elexp.com/t_solder.htm. [Accessed: 20-Jun-2013].

[4] "Eddy Currents." [Online]. Available: http://en.wikipedia.org/wiki/Eddy_current. [Accessed: 20-Jun-2013].

[5] "Stepper motor types." [Online]. Available: www.anaheimautomation.com. [Accessed: 18-Jun-2013].

[6] Trinamic, "TMC223 Datasheet." [Online]. Available: http://www.trinamic.com/tmctechlibcd/integrated_circuits/TMC223/TMC223_datasheet.pdf. [Accessed: 18-Jun-2013].

[7] "The right and wrong of soldering." [Online]. Available: http://karma-laboratory.com/petridish/2005/01/the_right_and_w.html. [Accessed: 20-Jun-2013].

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