WHITE PAPER

CONTROLLING DC MOTOR SPEED IN CLOSED LOOP

Portescap's Athlonix brush DC and Ultra EC™ brushless DC motors

Brush DC and brushless DC motors are often driven in open loop, using a voltage to generate a specific speed. However, when a load is applied, the rotational speed will naturally decrease according to the specific speed-torque characteristic of the motor. Many applications can tolerate this natural decrease without issue, like a personal drill or an electric screwdriver. However, for demanding applications such as a peristatic pump or some surgical power tools, it is critical to both keep the speed extremely stable and accurately control the speed of the motor. To continuously regulate this speed in DC motors at the desired value, a controller with closed loop speed control can be utilized. In this article, we will cover the differences between closed and open loop systems and explore using closed loop speed control to regulate DC motors.

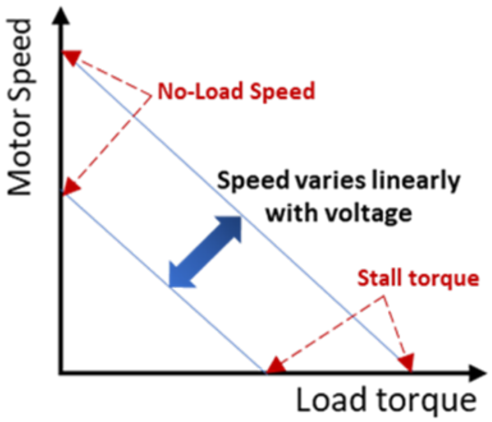


Figure 1: Speed-torque Variation of a DC Motor with Voltage

IDENTIFY THE SPEED TORQUE CHARACTERISTIC OF DC MOTORS

A DC motor has a specific speed torque characteristic, meaning that for a given voltage, the motor will rotate at a specific speed that will be reduced depending on the applied torque. The speed changes linearly with the voltage, where doubling the voltage will double the speed (Figure 1).

We can find this characteristic curve by knowing the No-Load Speed and the Stall Torque of a motor for a specific voltage. If no torque is applied, the motor will turn at the No-Load Speed, provided in the following formula (rotational losses not considered):

$$No\ load\ speed\ (rad/s) = \frac{Voltage\ (V)}{Torque\ constant\ (N.m/A)}$$

The motor will be stopped at the Stall Torque, which is the maximum torque that the motor can provide at a specific voltage; this is provided in the following formula:

$$Stall\ torque\ (N.m) = \frac{Voltage\ (V) * Torque\ constant\ (N.m/A)}{Coil\ Resistor\ (Ohm)}$$

OPEN LOOP SPEED CONTROL IN DC MOTORS

Many applications require a simple control of the DC motors to achieve the required movement, which is usually completed by generating a defined cycle of voltage; the speed is not verified in this approach, and the motor is expected to run properly according to its speed torque characteristic. This is referred to as open loop (Figure 2).

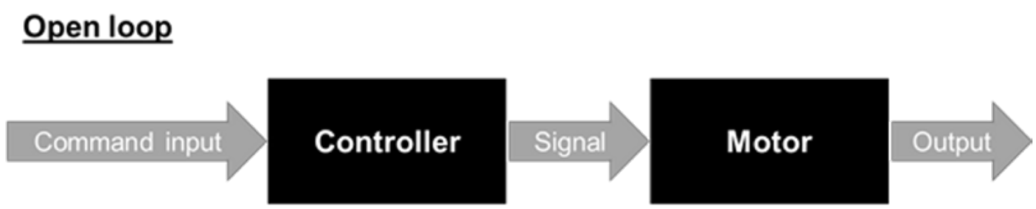


Figure 2: Open Loop Control in DC Motors

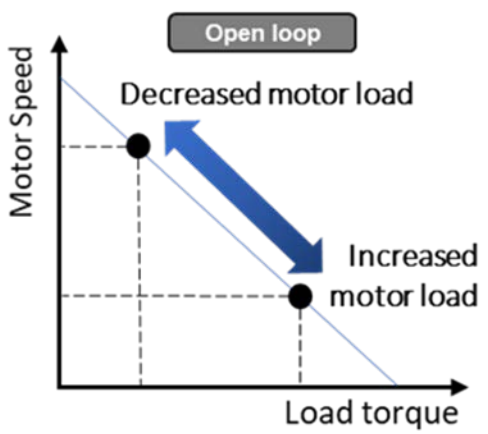


Figure 3: DC Motor Voltage Control in Open Loop

In open loop, if the load increases, the speed of the motor will drop. An excellent example is the use of a personal drill, where you feel the speed of the drill decrease as it becomes more difficult to drill (increased motor load). While this way of driving a motor is ideal for several applications, using a more powerful motor or adding a gearbox can be a solution to reduce the speed loss. However, the phenomenon will still exist and may be a problem for critical applications.

CLOSED LOOP SPEED CONTROL IN DC MOTORS

For some applications, it is important to maintain a stable speed or to provide maximum power while the load torque is increasing. In these cases, you may consider using a controller with a closed loop speed control function. This controller will continuously measure the real speed of the motor, with feedback being provided by hall sensors, encoders, or any process that will monitor the motor's EMF. The controller will then compare this speed to the reference and readjust the voltage or current to keep a constant speed according to the desired speed command.

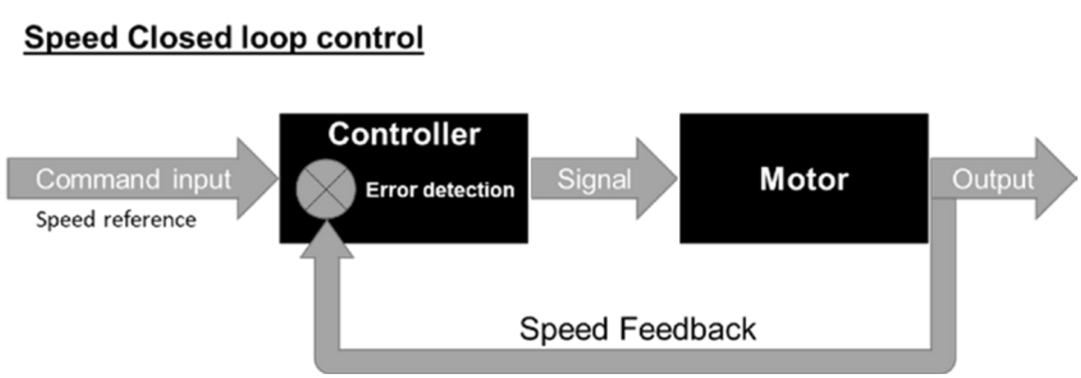


Figure 4: Closed Loop Speed Control in DC Motors

The available voltage and current are typically limited (thermally or by the power supply) for a given application, which creates limitations in what speed and torque the motor can provide. Figure 6 illustrates these boundaries:

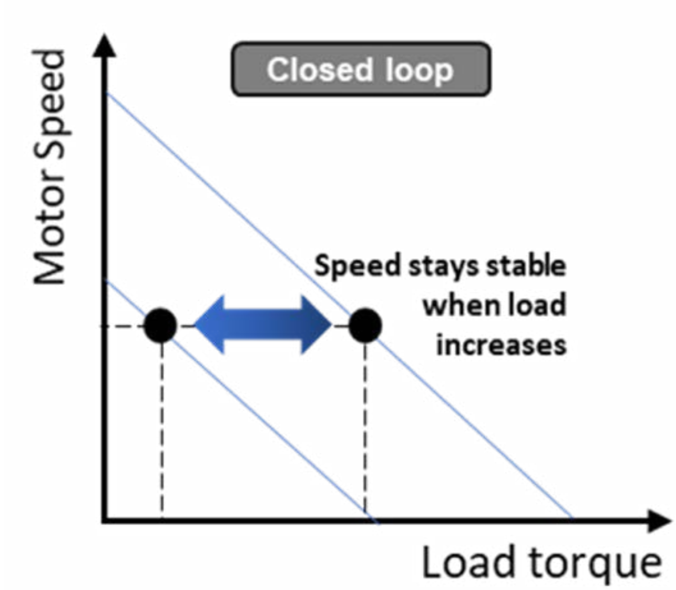


Figure 5: DC Motor Speed Control in Closed Loop

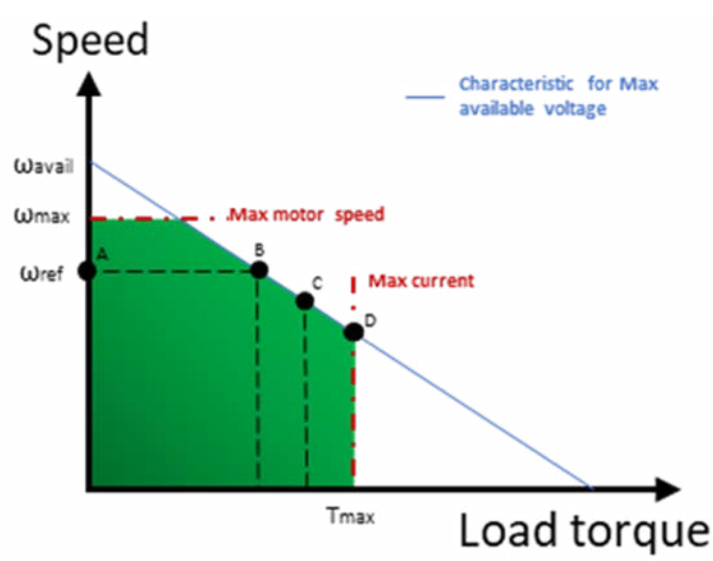


Figure 6: Limits of Closed Loop Speed Control

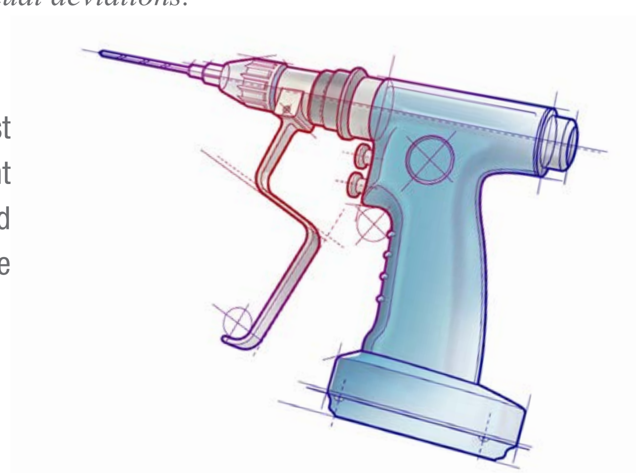
- Keep in mind that **ω**ref is the reference speed generated by the command and targeted by the controller.
- From Point A to Point B, the speed control works properly and keeps the speed stable according to the reference speed **ω**ref.
- If the load becomes bigger than the value in Point B, as in Point C, the motor will behave as if it is controlled in voltage control; i.e. the speed will drop according to the speed torque characteristic of the motor at the maximum available voltage. This corresponds to **ω**avail, the maximum available speed.
- If the load is bigger than the maximum torque value, Tmax, in Point D, the motor will stop. This maximum torque is calculated according to the torque constant of the motor and the maximum available current, Imax, with the below formula:

$$Tmax = Torque\ constant\ (mNm) * Imax\ (A)$$

Note: A small speed difference between the targeted speed and the read speed will remain and it is important to verify that this error value is acceptable. This is called the residual deviations.

APPLICATION IN FOCUS: SURGICAL HAND TOOLS

The discussion of open loop vs. closed loop speed control is best understood when grounded in a specific application. Here we highlight surgical hand tools, which can work either in open loop or in closed loop. Portescap provides both types of controllers to adapt to the preferences of each surgical tool manufacturer.



Controlling Surgical Hand Tools' Speed via Speed Control (Closed Loop)

With speed control, the user will press the button to define the requested speed. When a load is applied to drill or cut, the speed will stay stable, meaning the user will not have to press further on the button to increase the torque. To achieve this, the controller will automatically keep the motor speed constant at the requested reference speed even if the torque increases up to Point B (Figure 7). This is illustrated in Figure 7, where from Points B to C, the speed will decrease according to the speed torque characteristic of the motor at the maximum available voltage. The motor will stop at Point C because of the current limit.

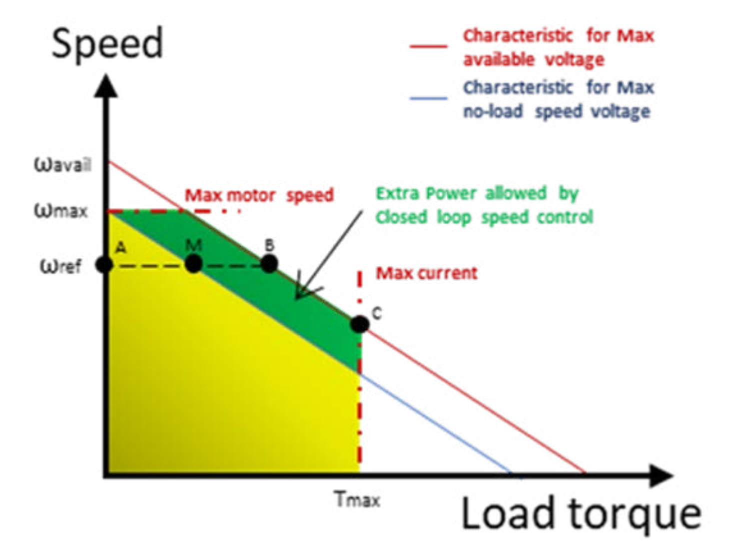


Figure 7: Limits of Speed Control in Closed Loop and Open Loop

Controlling Surgical Hand Tools' Speed via Voltage Control (Open Loop)

With voltage control, the user will press the button to define the requested voltage. When a load is applied to drill or cut, the speed will drop; the user will then have to press further the button to achieve more torque. The speed adjustment will be continuously done by the user. As seen in Figure 7, if the maximum available voltage (ωavail) is higher than the voltage used to achieve the maximum motor speed (ωmax), then the maximum motor power will be limited. For the reference speed, we would achieve a max torque at Point M instead of Point B.

CONCLUSION

Though DC motors are typically driven in open loop, closed loop speed control offers an effective option for controlling motor speed, especially for critical applications that require precise speed control. Knowing which speed control method to utilize in your application or product may be tricky, which is why engaging a trusted motor supplier like Portescap early in the process is key. Whether you're designing the next generation of your application or specifically searching for a controller to use in speed or voltage control, Portescap's engineers are on-hand to assist.

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