Top Motor Control Driver Considerations for DC Motors

With the advent of high-power-density electrical energy storage technologies and growing interest in electrification, DC electric motors are becoming increasingly common in applications from toys to transportation. There are three main types of DC motors: brushed, brushless, and stepper/stepping. Each of these motor types have advantages, disadvantages, and features that make them suited to a wide range of applications and come with unique design challenges. Among the design challenges of incorporating a DC motor into a product is determining appropriate control/drive technology for the motor. Fortunately, there is an expansive variety of motor control drivers (MCDs) that provide control/drive functions for each motor type.

Given the range of DC motor applications, there are also diverse requirements and features unique to each DC motor type and use case. This article provides an introduction to the three main DC motor types, discusses some of the application considerations for each motor type, and details key MCD features and how they pertain to the DC motor types.

Brushed DC motors

Brushed DC motors are relatively simple to control and exhibit moderate power density compared with other DC motor types for simple motion applications. To power a brushed motor, the motor merely needs DC voltage applied to the terminals, as shown conceptually in Figure 1. The speed of the brushed motor can be set by precision control of the applied voltage, and most brushed DC motor MCDs can directly operate with pulse-width–modulated (PWM) signals. At high speeds, brushed motors can maintain a reasonably high torque at the expense of higher power dissipation. Hence, DC brushed motors can have a good torque-inertia ratio. Torque-inertia ratio is the holding torque divided by the inertia of the rotor; the higher the ratio, the higher the maximum acceleration.

Brushed DC motors do have several disadvantages linked to commutation. Because of the physical contacts and associated friction between the brushes and the rotor commutators, brushed DC motors are not particularly efficient and are noisy. Such contact results in sparking, which makes these motors unsuitable for environments with combustible materials. The brushed motor commutation also may cause high electromagnetic interference. The brushes in this motor type are also worn as a result of commutation and require periodic maintenance to prevent motor failure.

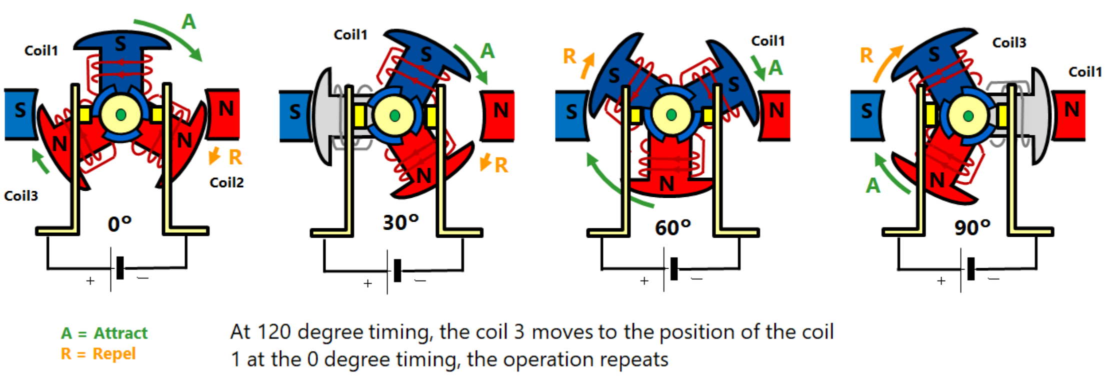


Figure 1: Brushed motor operation

Brushless motors

Brushless DC (BLDC) motors are synchronous motors that use DC electricity powering an inverter to drive the phases of the motor for performance-centric applications in which brushed motors cannot deliver the required performance. These motors exhibit good power output at all ranges, good power density, and excellent torque-inertia ratio. Moreover, BLDC provides some of the highest efficiency, longest lifespan, and lowest noise of the DC motor types. This is mainly due to lack of a mechanical connection and associated friction between the stator and rotor, other than the friction caused by the high-efficiency bearings. For this reason, they also tend to emit far less EMI than brushed DC motors.

Brushless DC motors rely on knowing the permanent-magnet rotor's position relative to the electromagnet stator in order to energize the stator windings to create the push or pull action onto the rotor (Figure 2). As a result, rotor position detection is required. Rotor position detection is commonly implemented with Hall sensors embedded in the motor and are called sensor-based BLDC motors. On the other hand, rotor position detection can also be done without sensors, called sensorless BLDC motors, wherein the controllers generally rely on sensing the back electromagnetic force or the rotor's torque and magnetic axis vectors for field-oriented control (FOC).

Either type of BLDC motor requires sensing and more complex control than brushed or stepper motors. This drawback can be mitigated with the use of motor driver ICs or special-purpose motor-control microcontrollers (MCUs) that are designed specifically for BLDC motors and include features that simplify the control circuit and programming complexity. For applications that require high speed, high torque, or low torque ripple, BLDC motors are a good fit and come in a wide variety of configurations. Some example applications include fans, pumps, compressors, appliances, electric vehicles, drones, and power tools.

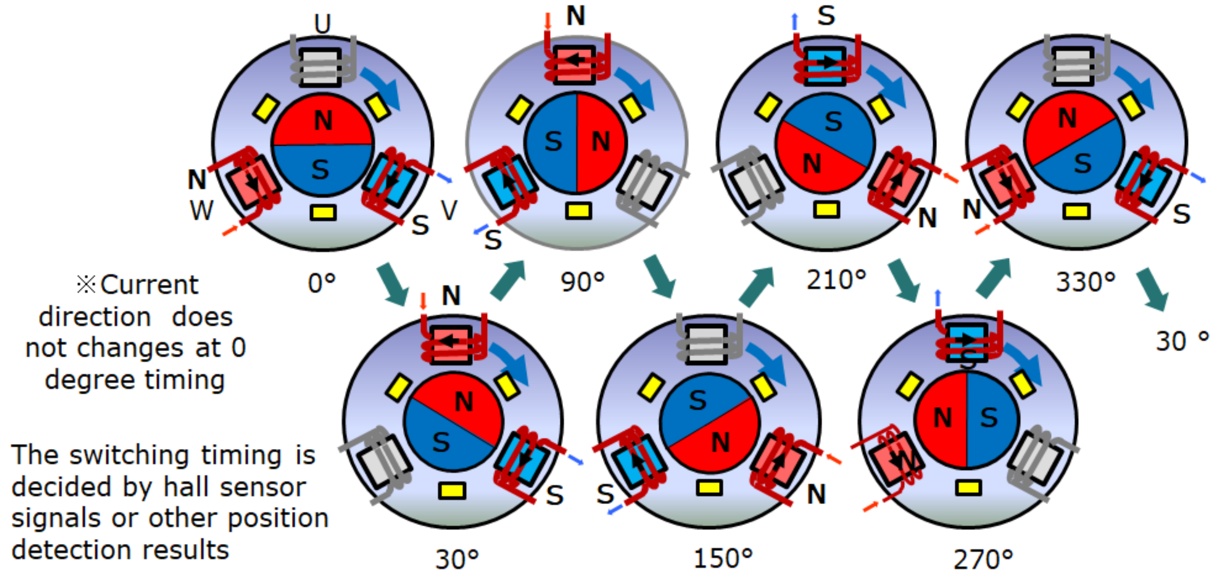


Figure 2: One typical scheme of sensor based brushless motor operation

DC stepper/stepping motors

Stepper motors are simple and cost-effective DC motor types for precision applications. With DC stepper motors, the motor moves in discrete "steps." By counting these steps, a stepper motor driver can usually move the motor into a desirable position without the need for additional motor position sensors and electronics for cost-sensitive applications. Stepper motor control is also relatively simple and doesn't require complex calculations because the simplicity relies on the fact that stepper motors can be driven open-loop and yet achieve similar to closed-loop precision in ideal conditions. Motor control ICs with micro-stepping capability can perform additional precision positioning between the motor steps, but this comes at the expense of proportionally lower speed.

At a given step resolution driving, a stepper motor exhibits higher torque at low speed than it is at high speed. It also has higher torque at full step than it is at high step resolution driving. Stepper motor can be noisy at low step resolution driving at nominal speed. It can be very quiet at high step resolution driving but it will be very slow. Moreover, stepper motors provide excellent position holding and can essentially hold their position indefinitely once set.

Unlike brushed and brushless motors, stepper motors typically operate at maximum set current at all times to prevent motor stalling, as it can cause failures, and therefore present limited power efficiency compared with other motor types. These motors also have lower torque-inertia ratio compared with other DC electric motors. Stepper motors are generally used in high-precision but not high-speed applications such as CNC machines, printers, and actuators.

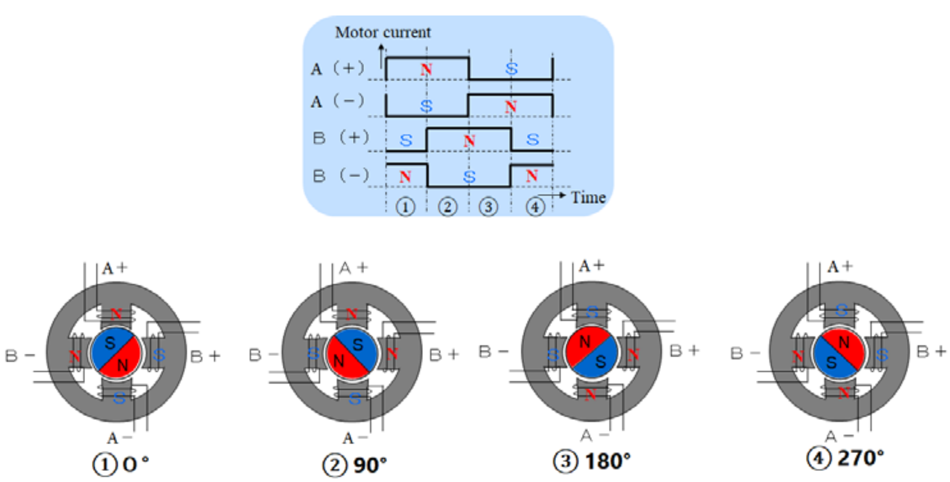


Figure 3: Stepper motor operation in full step

Key MCD features for DC motor types

Each of the DC motor types require different MCD driver technology. There are also distinct features that can be employed within MCDs for each motor type that yields unique benefits. The following section details such features for each motor type and includes a couple of MCD features that benefit all DC motor types.

All motor types

All motor control driver ICs use solid-state transistor technology for the motor drive for DC motors. These transistors consume some of the energy intended to drive the motor, expending the energy as heat. The drain-source on-resistance ($R_{DS(on)}$) is the main factor contributing to this loss. Second, the rate of the switching edge transitions also contributes to the switching loss. Hence, MCDs with transistors that exhibit low $R_{DS(on)}$ and low intrinsic capacitance characteristics are able to deliver more efficient motor drive capability. Another attractive feature of MCDs is to have ultra-low standby current, which limits the amount of power drawn over time while the MCD is in standby mode.

Brushed motor drivers

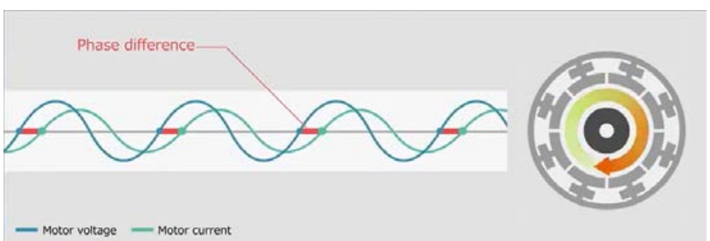
Brushed DC motors are a mature technology still widely used in many DC motor applications. Given the long legacy of brushed DC motors, there is a huge variety of these motors with numerous combinations of supply voltage, drive current, and configurations. In many applications, several brushed DC motors are used within a tight environment such as small robotics, dispensing machines, and surveillance cameras, increasing the complexity of the motor control circuit.

Therefore, MCDs that are able to provide flexible control of one or more brushed DC motors can simplify the complexity of a multi-motor system. Fortunately, there are brushed DC motor driver ICs that come in single-channel, dual-channel, and quad-channel configurations. Moreover, there are also some multi-channel MCDs with configurable motor drive technology whose channels can be used separately in a low-current configuration or combined into a single-, high-current channel for motor applications that require substantial drive current. An example of the multiple channel brushed motor MCD is the TB67H452FTG.

Brushless motor drivers

Brushless DC motors provide some of the best DC motor features but also require more complex motor control than the other DC motor types. Traditional BLDC motor control technology requires several electronic components, including sensors and MCUs, to optimize motor efficiency or minimize variations in rotational speed. Two MCD features that reduce the complexity of BLDC product design are intelligent phase control and closed-loop speed control. With these features, BLDC motor products can be implemented with minimal external components and burden to product designers.

Optimal BLDC motor designs require precise control of the voltage and current phases to ensure optimal motor efficiency. During BLDC operation, the motor parameters, temperature, rotations per minute, load, and other factors can create variations in the current and voltage phases needed to drive the motor. Even with typical lead angle control functions, a BLDC motor may not be driven with perfect alignment of the voltage and current phase across the entire speed range. Phase aligned motor current and voltage can be achieved with both sensor-based and sensorless BLDC motors using intelligent phase control. This feature can automatically align the phase of the induced voltage to match the motor drive current, which, in turn, delivers high efficiency irrespective of the speed compared with uncompensated operation. Intelligent phase control not only aids in reducing the BOM complexity for a BLDC motor and the external parts needed for lead angle adjustment, but also allows single point rather than multiple locations tuning in conventional designs for optimum efficiency in the entire speed range. An example of a BLDC motor controller with Hall Sensor inputs and Intelligent Phase Control is the TC78B016FTG.



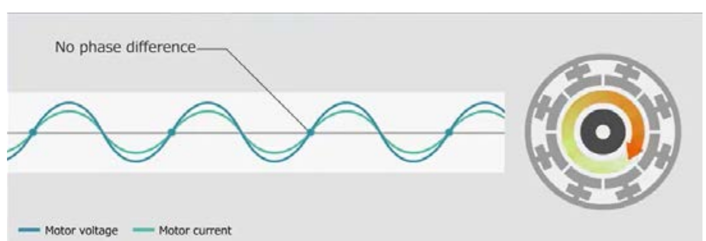


Figure 4: Conventional driving (left), wherein driving phase voltage and current are not aligned, therefore contributing loss. Intelligent phase control (right) automatically aligns driving phase voltage and current, therefore providing all the real power to the load.

Advanced closed-loop speed control for BLDC motors is a feature that enables MCDs to maintain constant rotational speed while the motor is subjected to a varying load or supply. With this feature, flexible speed control can be performed without the need for an external host to calculate the speed-control algorithm. MCDs with nonvolatile memory and closed-loop speed-control capability ensure constant motor rotation without the need for external components such as an MCU. An example of a closed loop speed control capable MCD is the TC78B009FTG. The benefit of this BLDC motor control technology is that it is packaged in an extremely compact, surface-mount–technology IC package, which is ideal for applications with footprint constraints. Applications that benefit from this technology include compact fan uses in personal computers, server racks, or other electronic thermal management applications.

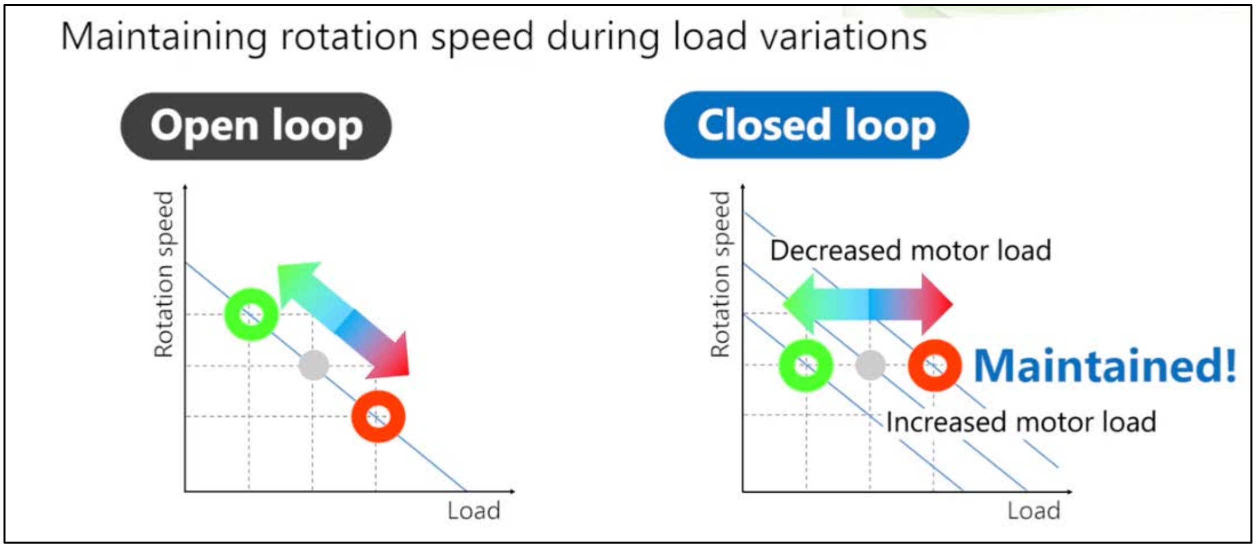


Figure 5: Closed-loop speed control, wherein speed automatically maintains at various loading

BLDC motors can also be made without Hall-effect sensors that monitor the position of the motor and are used in BLDC motor control. Though these sensors aid in determining the current phase and amplitude, sensorless BLDC motors are lower-cost and can be more reliable due to reduced motor complexity. Sensorless BLDC motors require MCDs that can start up reliably. Noise levels in sensorless BLDC motors are generally higher than the sensor-based controls unless advanced motor control techniques like Field Oriented Control (FOC) are used, which may complicate the design. Nevertheless, there are many vendors providing special-purpose MCUs with FOC processing performed with a hardware accelerator, software, or hybrid approach. An example of a MCU with FOC processing capability is the TMPM375FSDMG.

Stepper motor drivers

Stepper motors are most often used in precision positioning tasks. Micro-stepping can support applications inaccessible to stepper motors with larger steps ratings at the expense of slower and reduced torque. It is not uncommon to find MCDs that can support 1/64, 1/128, or even higher step resolution nowadays. For high-precision applications, designers may choose high step resolution parts as buffers but they should still test and determine the desirable step resolution needed for the applications in order to minimize the trade of.

A technique to minimize stepper motor power loss is to use active gain control (AGC) measures. This feature actively monitors the stepper motor back-EMF and other parameters during operation and enables adjustment of the running current to reduce power loss and enhance responsiveness. An example of the MCD with AGC is the TB67S249FTG. In addition to this, some MCDs can operate with advanced dynamic mixed-decay (ADMD) modes that use both slow-decay modes and fast-decay modes to quickly discharge the motor current during the off period. Because a motor’s inductive current polarity cannot be changed instantaneously, it can only decay during the off period. ADMD can enhance the speed and efficiency of stepper motor operation. This is an improvement over typical mixed-decay–mode stepper motor control technology, as ADMD exhibits an improved current operation capability. The TB67S128FTG stepping motor MCD is capable of operating with ADMD.

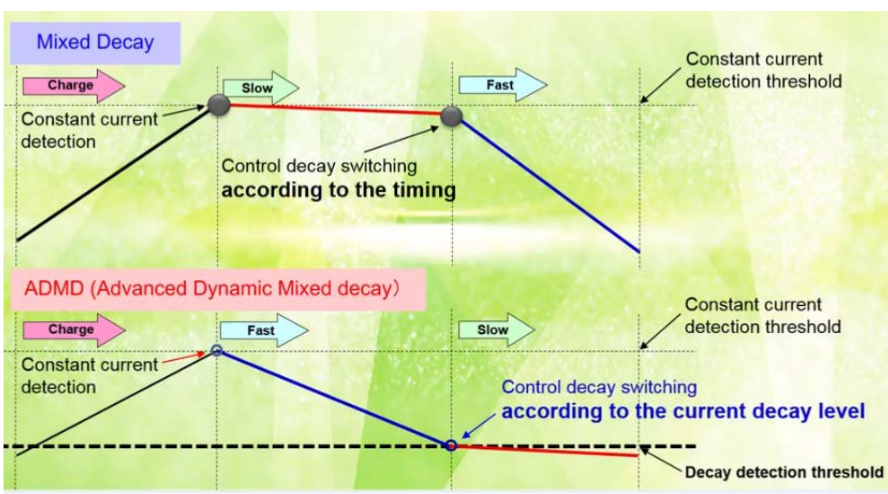


Figure 6: Advanced dynamic mixed-decay illustrations

Conclusion

The latest generation of DC motor control/driver ICs are equipped with new and improved motor control features that optimize the performance of DC brushed, brushless, and stepper motors. This new generation of MCDs can save valuable motor control/driver board space while improving efficiency and simplifying the motor control scheme. Here are the flagship products from Toshiba that feature the technologies described in this article for reference:

Highly Configurable Multi-Channel Brushed Driver — TB67H452FTG
Intelligent Phase Control — TC78B016FTG
Closed-Loop Speed Control — TC78B009FTG
Active Gain Control — TB67S249FTG
Advanced Dynamic Mixed Decay — TB67S128FTG
Field-Oriented Control — TMPM375FSDMG

References

1. Toshiba Motor Driver ICs
2. Brushed DC Motor Driver ICs
    - 2.1. Configurable Motor Drivers
    - 2.2. Capable of constant current controlling (PWM) Bridge driver for brushed DC motors
    - 2.3. Bridge driver IC for brushed DC motors
3. Brushless DC Motor Driver ICs
    - 3.1. Intelligent Phase Control Technology
    - 3.2. TC78B009FTG Brushless DC Motor Driver IC
4. Stepper Motor Driver ICs
    - 4.1. Advanced Current Detect System (ACDS) Technology
    - 4.2. Active Gain Control (AGC) Technology
    - 4.3. Advanced Dynamic Mixed Decay (ADMD) Technology