TOSHIBA

Technical Review

Brushless DC Motor Control Technology to Realize Efficient Driving of Cooling Fans

The demand for data centers is increasing with the ongoing digitization of society. To reduce the power consumption of data centers, it has become indispensable to improve the efficiency of the large number of motors that power the cooling fans generally used in data center servers.
Toshiba Electronic Devices & Storage Corporation developed Intelligent Phase Control, a technology that can achieve high-efficiency driving of a three-phase brushless direct current (BLDC) motor using three Hall sensors, and applied this technology to a three-phase BLDC motor driver integrated circuit (IC) in February 2016. We have newly developed both a Hall sensor position compensation function to reduce the number of Hall sensors from three to one in order to save the installation space for cooling fans and a closed-loop speed control function to realize stable rotation speed under any load conditions. We commercialized the TC78B025FTG three-phase BLDC motor driver IC with Intelligent Phase Control incorporating these functions in April 2018.

1.Introduction

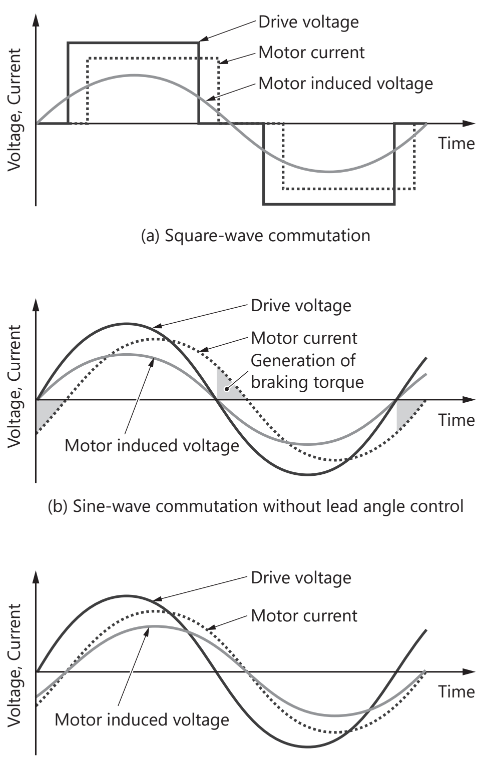
In recent years, the emergence of big data and the Internet of Things (IoT) has been driving the demand for data centers to store and process huge amounts of information. The power consumption of data centers is growing every year, currently accounting for approximately 2% of the world's energy demand. Roughly 30% of the power consumed by data centers is used to cool servers[(1)]. Forced-air cooling using fans is the most widely used method for this purpose. It is therefore important to improve the drive efficiency of fan motors in order to reduce the power consumption of data centers.
Cooling fans with a three-phase BLDC motor are increasingly used in data centers because three-phase BLDC motors are not only more energy-efficient but also produce less vibration than other types of motors. Surface permanent magnet (SPM) motors, which have magnets on the surface of the motor rotor, are the most commonly used type of three-phase BLDC motors for cooling fan applications. To improve the efficiency of a fan motor, it is necessary to adjust the phase of the motor drive voltage (i.e., auto control the lead angle) according to a motor's operating conditions so that the phase of the motor's induced voltage matches that of the motor current. However, lead angle adjustment is a complicated and time-consuming task.
To date, Toshiba Electronic Devices & Storage Corporation has developed Intelligent Phase Control, a proprietary technology with a simple system configuration to automatically improve the drive efficiency of SPM BLDC motors using three Hall sensors, and incorporated Intelligent Phase Control into its motor driver integrated circuits (ICs)[(2)].
This report describes an overview of Intelligent Phase Control, an enhancement of Intelligent Phase Control that realizes three-phase BLDC motors with only one Hall sensor for cooling fans for data centers, and the application of the enhanced Intelligent Phase Control to a motor driver IC.

2.Automatic lead angle control technologys

2.1 Driving methods and lead angle control for three-phase BLDC motors

There are two driving methods for three-phase BLDC motors: square-wave commutation that applies a square-wave current to the motor (**Figure 1**(a)) and sine-wave commutation that applies a sine-wave current to the motor (Figure 1(b) and Figure 1(c)). Sine-wave commutation provides less torque ripple than square-wave commutation and is therefore more suitable for achieving low motor vibration.

In the case of sine-wave commutation, if the phase of the motor current lags that of the motor's induced voltage as shown in Figure 1(b), braking torque occurs, reducing the motor drive efficiency. To avoid this problem, lead angle control is necessary to ensure that the phase of the motor's induced voltage matches that of the motor current (Figure 1 (c)).



(a) Square-wave commutation

(b) Sine-wave commutation without lead angle control

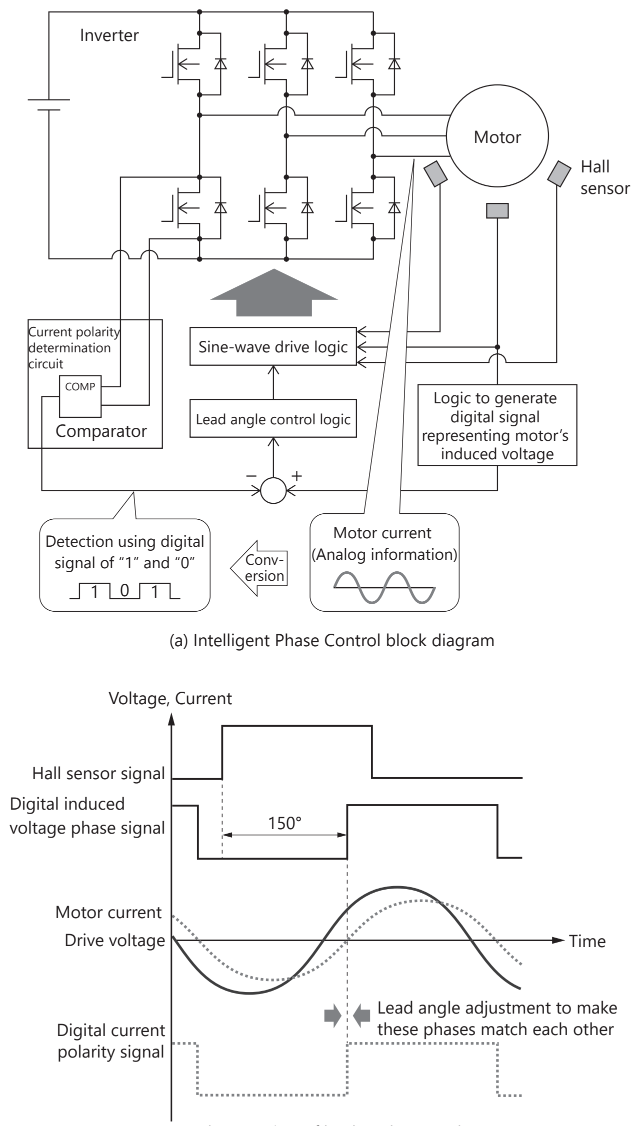
(c) Sine-wave commutation with lead angle control

Figure 1. Comparison of three-phase BLDC motor driving methods and effect of lead angle control

Sine-wave commutation achieves high motor drive efficiency by adjusting the phase of the motor drive voltage so that the phase of the motor current matches that of the motor's induced voltage.

2.2 Intelligent Phase Control

Figure 2 shows the configuration of a drive system incorporating Intelligent Phase Control for a three-phase BLDC motor.



(a) Intelligent Phase Control block diagram

(b) Overview of lead angle control

Figure 2. Configuration of Intelligent Phase Control system

An analog motor current is converted into a digital signal for automatic real-time lead angle control.

The conventional drive system for a three-phase BLDC motor uses signals from three fixed Hall sensors to provide sine-wave commutation. Fixed lead angle control sets the lead angle based on the predefined external input voltage. Suppose, for example, that the lead angle is adjusted to achieve high drive efficiency at a given rotation speed point. In this case, when a motor's rotation speed exceeds this point, the phase of the motor current lags that of the motor's induced voltage. Conversely, when a motor's rotation speed drops below the said point, the phase of the motor current leads that of the motor's induced voltage. Therefore, the drive efficiency decreases at any rotation speed points other than the point at which the lead angle is adjusted. However, the rotation speed of a cooling fan must be controlled according to its ambient temperature. For such motor applications, it is necessary to control the lead angle in real time according to a motor's rotation speed.

To date, various techniques have been invented to automatically control the lead angle according to the motor current or rotation speed, but most of them require an adjustment by means of actual equipment. For example, this adjustment is necessary each time a motor's load condition changes, making it difficult to maintain the efficiency of a fan motor because its load condition changes considerably with airflow.

To solve this problem, the existing Intelligent Phase Control system detects the polarity of the motor current and converts it into a digital signal while generating a signal that represents the phase of the motor's induced voltage from the output signals of fixed Hall sensors, in order to make their polarities change simultaneously. Intelligent Phase Control maintains high drive efficiency because it automatically controls the lead angle in real time according to a motor's operating conditions.

3.Enhancement of Intelligent Phase Control for three-phase BLDC motors for cooling fan applications

The three-phase BLDC motors using the existing Intelligent Phase Control need three fixed Hall sensors to achieve sine-wave commutation. Since most cooling fans for data centers are sized to 40 × 40 mm, there is not enough space to arrange three Hall sensors inside a motor. A motor drive system capable of sine-wave commutation with a single Hall sensor is therefore necessary. In addition, in many cases, Hall sensors cannot be placed in the ideal position because of an internal space constraint of a motor.

To solve these problems, the enhanced Intelligent Phase Control incorporates a Hall sensor position compensation function (**Figure 3**). Its effect is shown in **Figure 4**. The enhanced Intelligent Phase Control uses information about compensation for the position of a Hall sensor considering its predefined position in order to generate a position-compensated internal signal and adjusts the phase of the motor current based on this signal. The resulting lead angle control under the ideal driving condition provides high-efficiency motor drive.

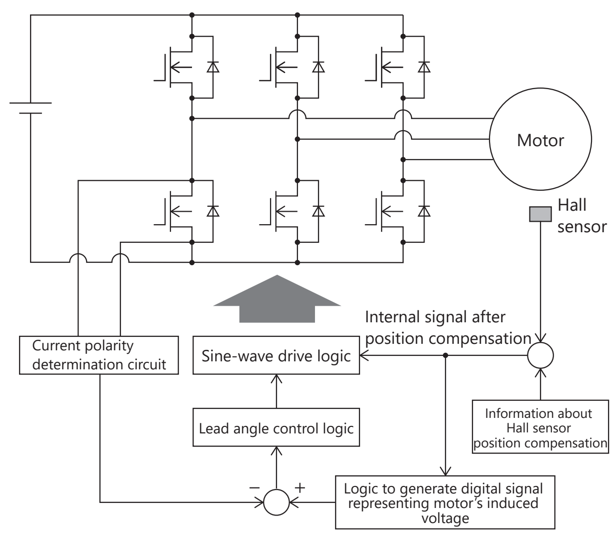
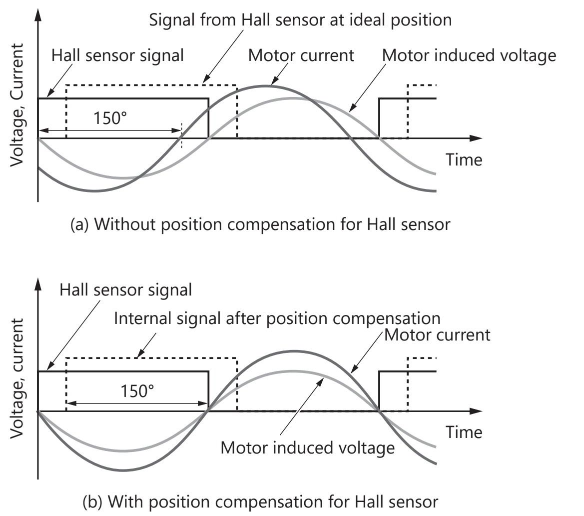


Figure 3. Block diagram of Intelligent Phase Control system with one Hall sensor

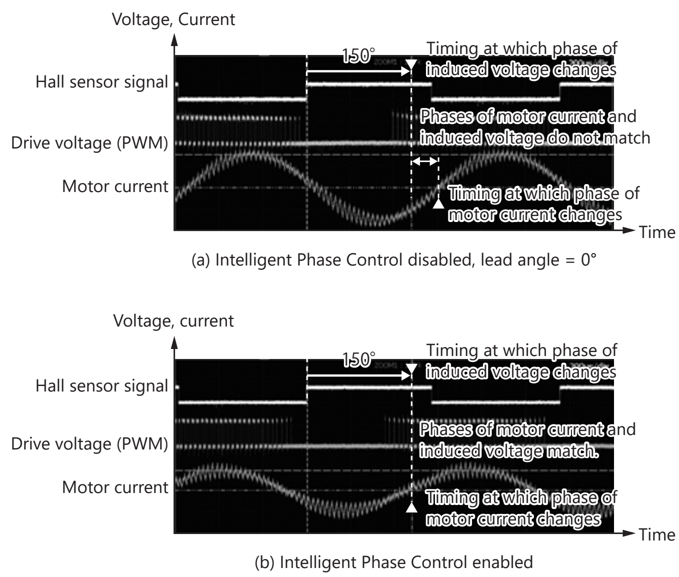
While the conventional Intelligent Phase Control system requires three Hall sensors, the new Intelligent Phase Control system needs only one Hall sensor to achieve sine-wave commutation. In addition, the Hall sensor position compensation function makes it possible to place a Hall sensor at an arbitrary position.



(a) Without position compensation for Hall sensor

(b) With position compensation for Hall sensor

Figure 4. Effect of Hall sensor position compensation function
Automatic lead angle control based on a phase-compensated Hall sensor signal provides high motor drive efficiency.



(a) Intelligent Phase Control disabled, lead angle = 0°

(b) Intelligent Phase Control enabled

PWM: pulse-width modulation

Figure 5. Drive waveforms of cooling fan motor
When Intelligent Phase Control is enabled, the phase of the motor current matches that of the motor's induced voltage.

As an example, **Figure 5** shows the result of an experiment on the drive circuit using the enhanced Intelligent Phase Control for a cooling fan motor. The waveforms of the Hall sensor and motor currents differ considerably when Intelligent Phase Control is enabled and disabled. As can be seen from Figure 5, when Intelligent Phase Control is enabled, the phase of the motor current matches that of the motor's induced voltage.
In addition, **Figure 6** indicates that the enhanced Intelligent Phase Control provides automatic phase adjustment over a wide rotation speed range. The enhanced Intelligent Phase Control also provides higher drive efficiency than the conventional fixed lead angle control, reducing the power consumption of a motor over the entire rotation speed range. For example, at 12,500 rpm, the enhanced Intelligent Phase Control provides a roughly 10% reduction in the power consumption of a motor.

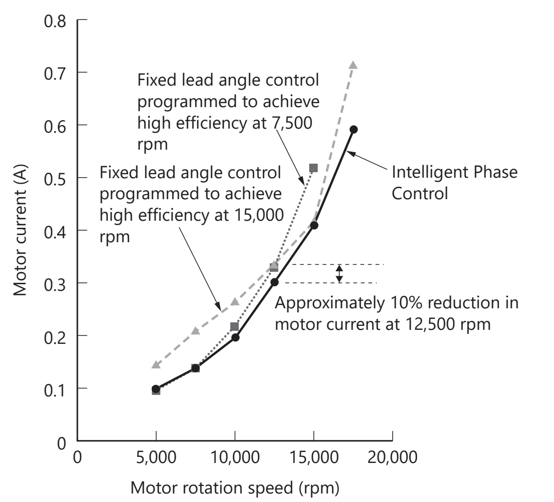


Figure 6. Reduction of motor current
At 12,500 rpm, Intelligent Phase Control provides a roughly 10% reduction in motor current compared to the conventional fixed lead angle control.

4.Incorporation of Intelligent Phase Control into a motor driver IC

We have commercialized the TC78B025FTG, a three-phase BLDC motor driver IC incorporating the enhanced Intelligent Phase Control function for sine-wave commutation with a single Hall sensor. **Figure 7** shows the TC78B025FTG, and **Table 1** gives its main specifications(3).

In addition to Intelligent Phase Control, the TC78B025FTG provides a closed-loop speed control function to reduce variations in the rotation speed of a cooling fan. The enhanced Intelligent Phase Control provides stable rotation speed regardless of a motor's load condition since it automatically adjusts the IC output by comparing the rotation speed information from a Hall sensor with the user-specified rotation speed. The TC78B025FTG incorporates nonvolatile memory to program user parameters, making it possible to achieve flexible motor rotation speed control without an external microcontroller unit (MCU).

In addition, the TC78B025FTG requires no current-sensing resistor, reducing the board space necessary for motor control.

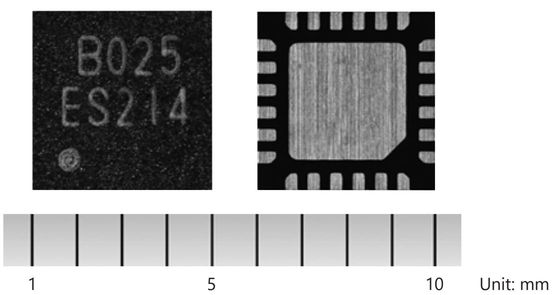


Figure 7. TC78B025FTG three-phase BLDC motor driver IC
Housed in a small package for cooling fan applications, the TC78B025FTG provides a rotation speed control function in addition to Intelligent Phase Control.

Table 1. Main specifications of TC78B025FTG

Characteristic	Specification
Supply voltage (Operating range)	4.5 to 16 V
Output current	3.5 A max (peak)
Commutation	Sine-wave or 150° trapezoidal commutation
Lead angle control	Intelligent Phase Control
Output on-resistance (high side + low side)	0.2 Ω (typical)
Speed control input	PWM input, analog voltage input
Fault detection function	Thermal shutdown, overcurrent protection, motor lock detection
Other Features	Closed-loop speed control function
	Standby function
	Support for Hall elements and Hall ICs
Package	VQFN24 (4 mm × 4 mm × 0.9 mm)

5.Conclusion

To meet the demand for the reduction of the power consumption of cooling fans for data centers, we have enhanced Intelligent Phase Control and incorporated Hall sensor position compensation and motor rotation speed control functions into a motor driver IC, achieving high-efficiency drive of a cooling fan and reducing the board space necessary for motor rotation control.

As demand for data centers grows, demand for cooling fans with differentiating characteristics such as high rotation speed and high voltage is expected to increase. We will continue to develop core technologies for new products in order to satisfy the demand for even higher motor drive efficiency.

References

(1) The Green Grid. 2019. "Guidelines for energy-efficient datacenters.” EETimes. Accessed July 19, 2019. https://www.eetimes.com/document.asp?doc_id=1273184&utm_source=electronicproducts&utm_medium=relatedcontent#.

(2) Aizawa, T. et al. 2017. “Technology for Control of Brushless DC Motors to Achieve High Efficiency through Simple Configuration.” Toshiba Review: 72(2): 53–56. Accessed July 19, 2019. https://www.toshiba.co.jp/tech/review/2017/02/72_02pdf/f05.pdf.

(3) Toshiba Electronic Devices & Storage Corporation. 2019. “TC78B025FTG.” Product detail. Accessed July 19, 2019. https://toshiba.semicon-storage.com/jp/product/linear/motordriver/detail.TC78B025FTG.html.