

**Please note that Cypress is an Infineon Technologies Company.**

The document following this cover page is marked as “Cypress” document as this is the company that originally developed the product. Please note that Infineon will continue to offer the product to new and existing customers as part of the Infineon product portfolio.

**Continuity of document content**

The fact that Infineon offers the following product as part of the Infineon product portfolio does not lead to any changes to this document. Future revisions will occur when appropriate, and any changes will be set out on the document history page.

**Continuity of ordering part numbers**

Infineon continues to support existing part numbers. Please continue to use the ordering part numbers listed in the datasheet for ordering.



THIS SPEC IS OBSOLETE

Spec No: 002-05347

Spec Title: AN205347 - FM3 MB9A310 SERIES TORQUE  
COMPENSATION APPLICATION IN PMSM  
DRIVE

Replaced by: NONE

## FM3 MB9A310 Series Torque Compensation Application in PMSM Drive

This application note describes the background, principle, implementation and test result of torque compensation.

### Contents

|     |  |   |     |  |    |
|-----|--|---|-----|--|----|
| 1   | Introduction.....                            | 1 | 2.3 | Measurement.....                         | 5  |
| 1.1 | Purpose .....                                | 1 | 3   | Implementation of TC .....               | 8  |
| 1.2 | Definitions, Acronyms and Abbreviations..... | 1 | 3.1 | Feature .....                            | 8  |
| 1.3 | Document Overview .....                      | 2 | 3.2 | Flow chart of Voltage Compensation ..... | 9  |
| 2   | Principles of Torque compensation .....      | 2 | 3.3 | Waveform of TC.....                      | 10 |
| 2.1 | Torque Equation .....                        | 2 | 4   | Document History.....                    | 12 |
| 2.2 | Vibration Reason .....                       | 3 |     |  |    |

## 1 Introduction

### 1.1 Purpose

This application note describes the background, principle, implementation and test result of torque compensation.

As you know, in order to decrease the cost of air conditioner system, more and more producers use low cost motor, such as single rotor motor. The load torque of this type motor in one mechanical circle is out of balance, which result in the speed of motor is fluctuated. Then the air conditioner system will be violent vibration. This phenomenon is very obvious especially when the frequency of the motor is very low. If we ignore this phenomenon, it will result in two kinds of bad result. One is noise, once we use air conditioner, it will influence our life. The other is life of air conditioner system, maybe we use two or three years, the air conditioner system will break down.

So, we must research a technology to eliminate this phenomenon, torque compensation is just the technology that we need.

### 1.2 Definitions, Acronyms and Abbreviations

|            |   |   |
|------------|---|---|
| TC         | - | Torque Compensation                                     |
| PMSM       | - | Permanent Magnet Synchronous Motor                      |
| $T_L$      | - | Load torque   |
| $T_e$      | - | Electrical torque                                       |
| $J$        | - | Rotor inertia   |
| $P$        | - | Rotor pole pairs  |
| $\Phi_m$   | - | Amplitude of natural magnetic flux of permanent magnets |
| $\omega_m$ | - | Mechanical speed  |
| $\omega_e$ | - | Electrical speed  |
| $\theta_e$ | - | Electrical angle  |
| $i_{sd}$   | - | phase current in d axis                                 |
| $i_{sq}$   | - | phase current in q axis                                 |
| BEMF       | - | BACK electromotive force                                |
| FOC        | - | Field orient control                                    |
| $k_d$      | - | Viscosity coefficient                                   |

### 1.3 Document Overview

The rest of document is organized as the following:

Chapter 2 explains the principles of torque compensation.

Chapter 3 explains the implementation of torque compensation.

## 2 Principles of Torque compensation

### 2.1 Torque Equation

For PMSM, one phase electrical voltage equation could be written like this:

$$V = z \cdot i = Ri + \frac{d\Phi}{dt} = Ri + \frac{d(Li + \Phi_m(\theta))}{dt} \quad (1)$$

Where the term  $\frac{d(\Phi_m(\theta))}{dt}$  corresponds to BEMF, it also could be written like this:  $\frac{d(\Phi_m(\theta))}{dt} = \frac{d(\Phi_m(\theta))}{d\theta} \omega_e$  (2)

Where  $\omega_e$  corresponds to rotor electrical speed.

It is supposed that the flux is sinusoidal, the BEMF has the following equation:

$$\bar{E} = \begin{bmatrix} E_a(\theta) \\ E_b(\theta) \\ E_c(\theta) \end{bmatrix} = -\omega_e * \Phi_m \begin{bmatrix} \sin(\theta_e) \\ \sin(\theta_e - \frac{2\pi}{3}) \\ \sin(\theta_e - \frac{4\pi}{3}) \end{bmatrix} = \omega_e * \Phi_m * k(\theta_e) \quad (3)$$

In PMSM system, the torque is expressed like this:

$$T_e = p * [I_s] * \Phi_m * k(\theta_e) \quad (4)$$

Where p is the pole pairs of rotor

It could be proven that the best solution to produce a constant torque is to drive sinusoidal motor by sinusoidal current:

$$T_e = p * \Phi_m * (I_a * K_a(\theta) + I_b * K_b(\theta) + I_c * K_c(\theta)) \quad (5)$$

Knowing that:

$$I_a = I_s \sin(\omega_e * t) \quad (6)$$

$$I_a = I_s \sin(\omega_e * t - \frac{2\pi}{3})$$

$$I_a = I_s \sin(\omega_e * t - \frac{4\pi}{3})$$

We could obtain:

$$\begin{aligned} T_e &= p * \Phi_m * (\sin^2(\omega_e * t) + \sin^2(\omega_e * t - \frac{2\pi}{3}) + \sin^2(\omega_e * t - \frac{4\pi}{3})) \\ &= \frac{3}{2} p * \Phi_m * I_s \end{aligned} \quad (7)$$

Because according to the theory of FOC, the d axis current is equal to 0, the q axis current is equal to  $I_s$ , we could obtain:

$$T_e = \frac{3}{2} p * \Phi_m * I_{sq} \quad (8)$$

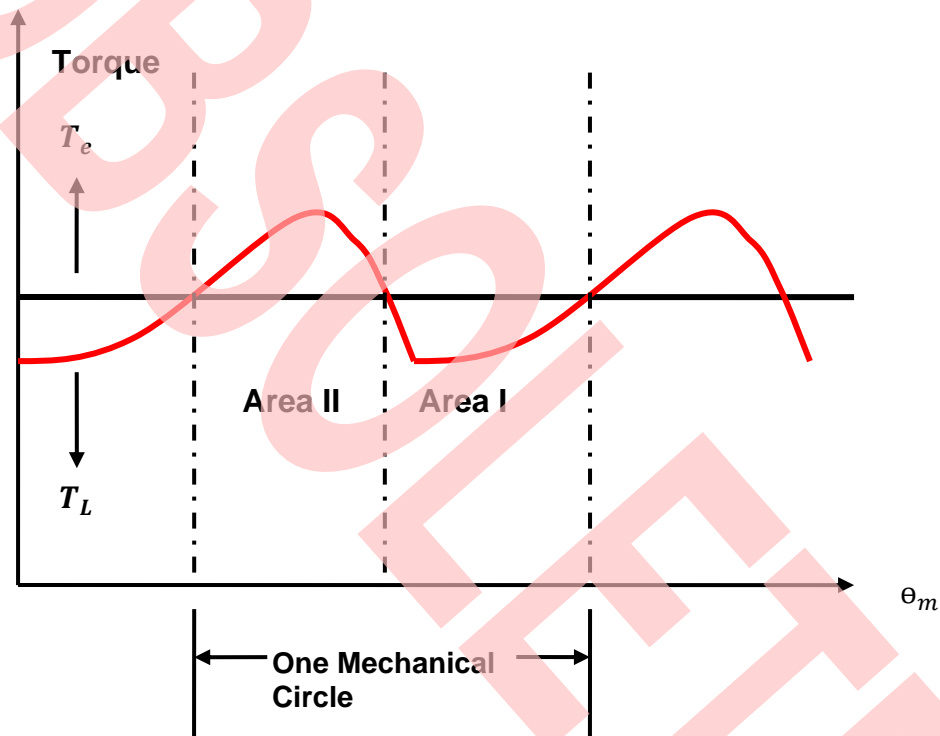
The electrical power delivered to the motor, a part is transformed in joule losses, another part is going to the energy storing in magnetic field and the last part is transformed in mechanical energy. The last part could be understood as torque production. The torque created by energy conversion process is then used to drive mechanical load. Below is the torque balance equation:

$$T_e = T_L + k_d \omega_m + J \frac{d\omega_m}{dt} \quad (9)$$

## 2.2 Vibration Reason

For single rotor motor, the load torque curve like this:

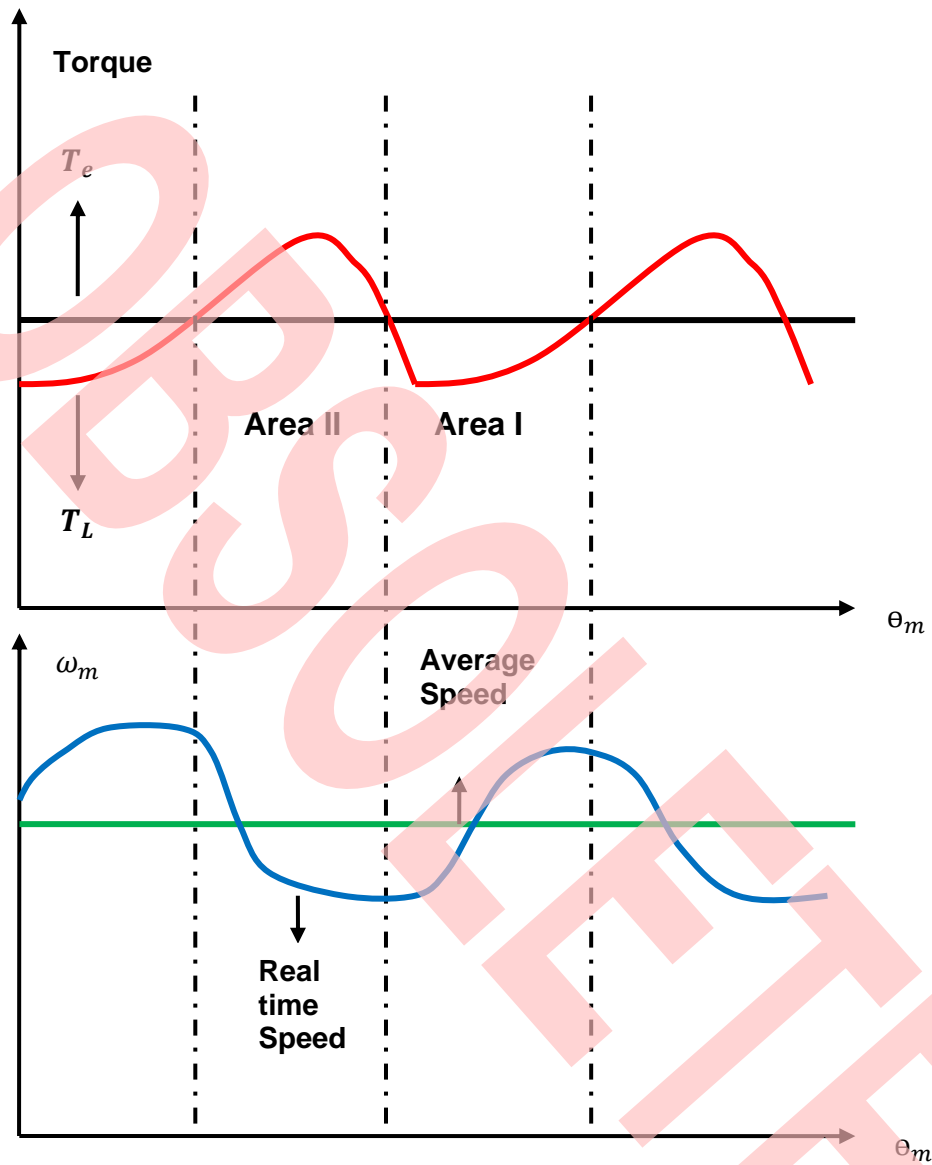
Figure 1. Torque Curve



In the above illustration,  $T_L$  (red line) is the load torque and  $T_e$  (black line) is electrical torque. You could find that the load torque curve is variable in one mechanical circle, this phenomenon will become graver and graver in low frequency area, especially when the frequency is less than 30HZ.

In Area I, because  $T_L$  is less than  $T_e$ , the speed of rotor will increase. On the other hand, in area II, the speed of rotor will decrease, the speed curve like this:

Figure 2. Rotor Speed Curve



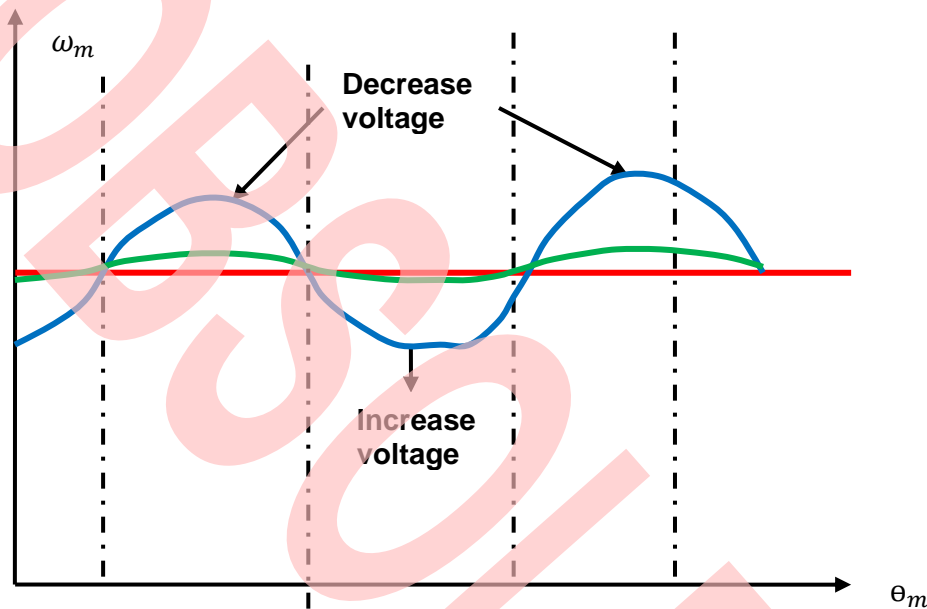
Where the green line represents average speed of rotor and the blue line represents the real time speed of rotor.

## 2.3 Measurement

Now, we have known the actual reason of speed ripple, but how to eliminate this phenomenon? Usually, there are two methods: voltage compensation and current compensation.

### 2.3.1 Voltage Compensation

Figure 3. Principle of Voltage Compensation

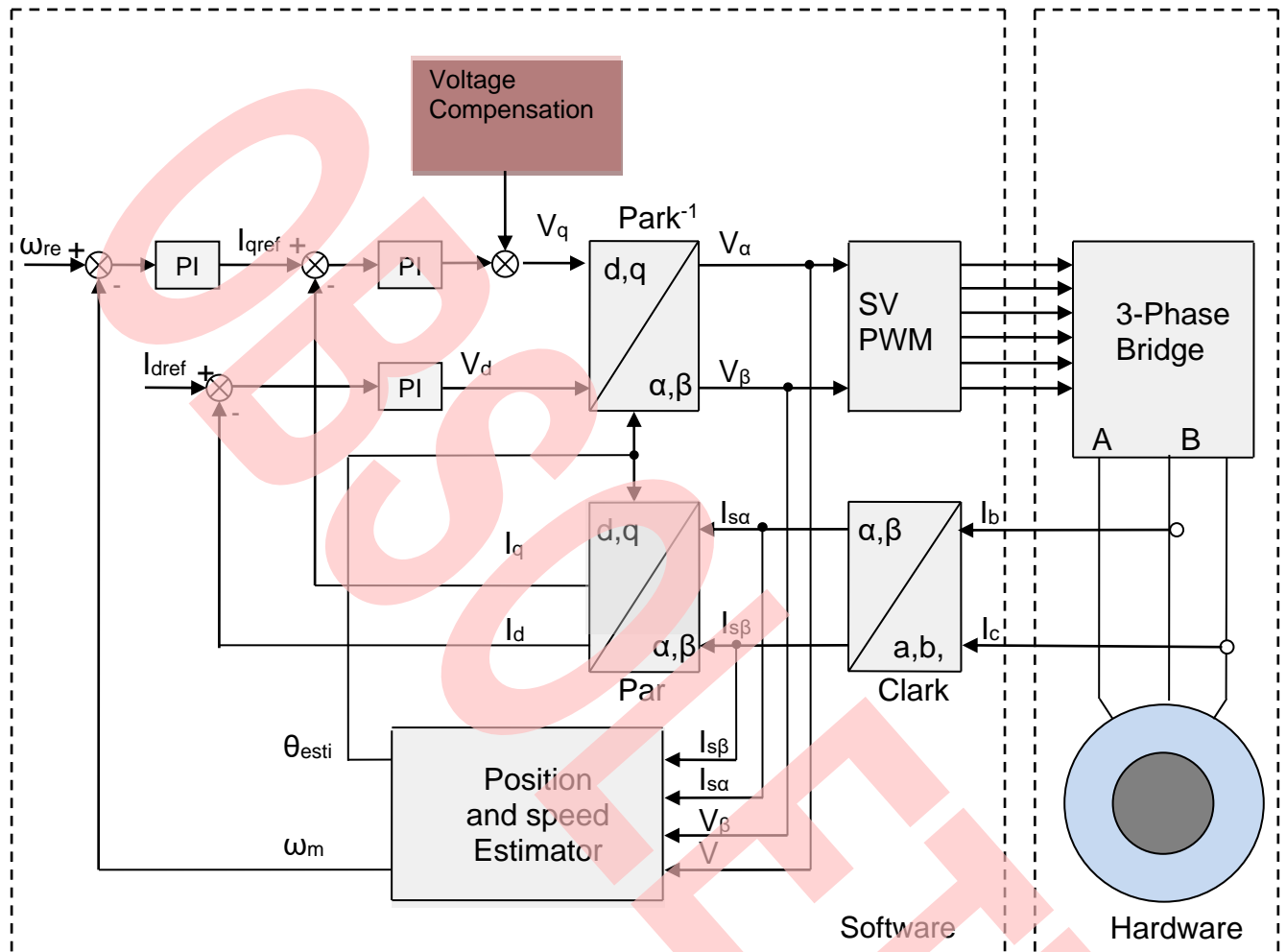


Above illustration is to explain the principle of voltage compensation. When the speed is lower than average speed, it needs to increase output voltage so that the real time speed could increase; but when the speed is higher than average speed, it needs to decrease the output voltage so that the real time speed could decrease. After compensation, the ripple of speed curve decreases obviously (blue line is the speed curve before compensation, green line is the speed curve after compensation).

Where the red line represents the average speed before voltage compensation, the blue line represents real time speed before voltage compensation; the green line represents real time speed after voltage compensation.

After add voltage compensation module, PMSM controlling system will be changed as below:

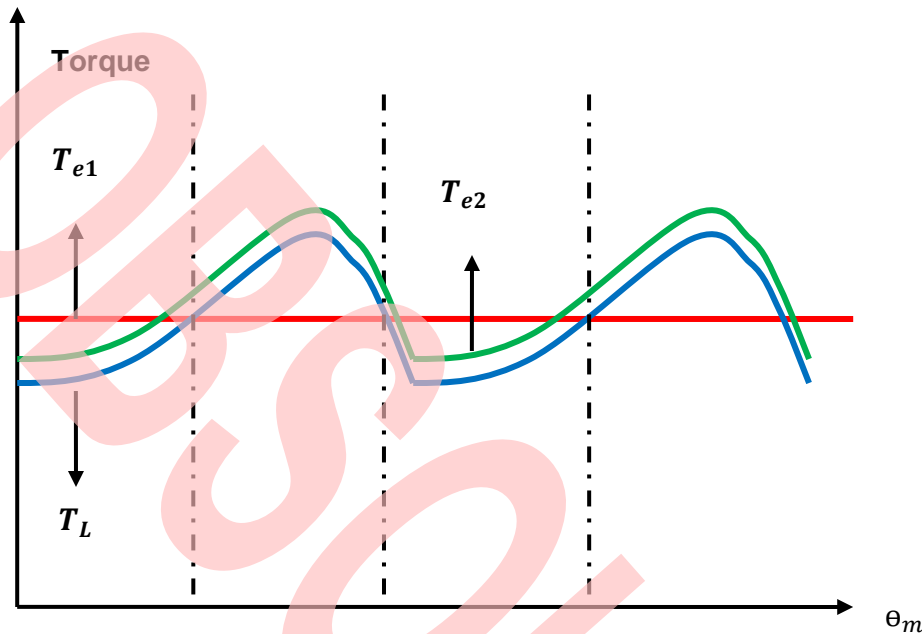
Figure 4. PMSM Control Block with Voltage compensation





### 2.3.2 Current Compensation

Figure 5. Principle of Current Compensation

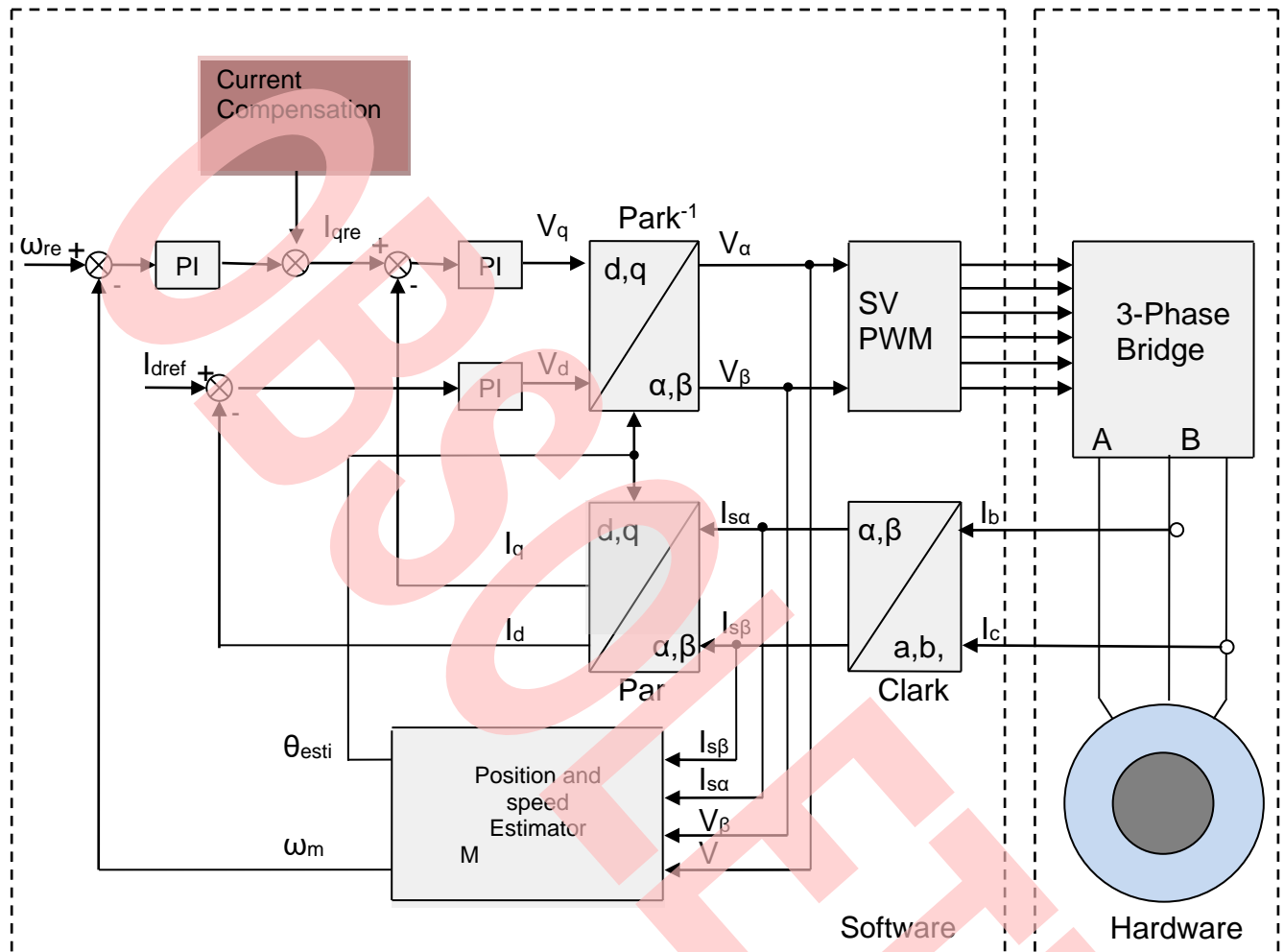


Above illustration is to explain the principle of current compensation. Core ideology of this method is to generate one electrical torque curve, whose shape is the same as load torque curve, but amplitude is bigger load torque curve. The amplitude difference between electrical torque curve and load torque curve is to keep the rotor running at a certain speed.

Where the blue line represents load torque, red line represents electrical torque before current compensation; green line represents electrical torque after current compensation.

After add current compensation module, PMSM controlling system will be changed as below:

Figure 6. PMSM Control Block with Current Compensation



### 3 Implementation of TC

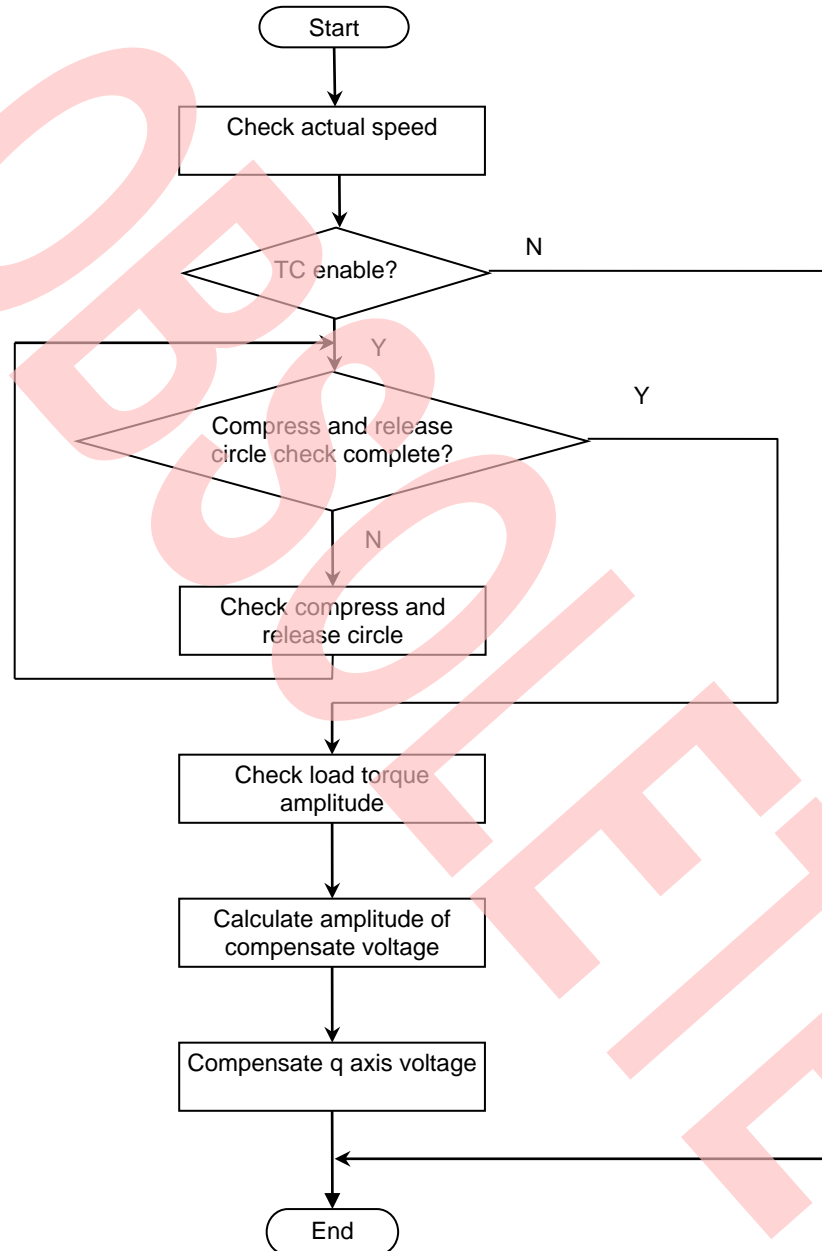
Now, we will use voltage compensation as example to explain the implementation of torque compensation.

#### 3.1 Feature

- Set up torque compensation frequency range automatically, 5HZ~37HZ is recommended frequency range.
- Modify the compensation amplitude according to amplitude of load automatically, so that it could get good performance regardless of heavy load or light load.
- Parameters correlative with torque compensation module are less, only need to change compensate angle and compensate voltage amplitude (different frequency has different compensate voltage amplitude).

### 3.2 Flow chart of Voltage Compensation

Figure 7. Flowchart of Voltage Compensation



### 3.3 Waveform of TC

Figure 8. Current Waveform before Torque Compensation

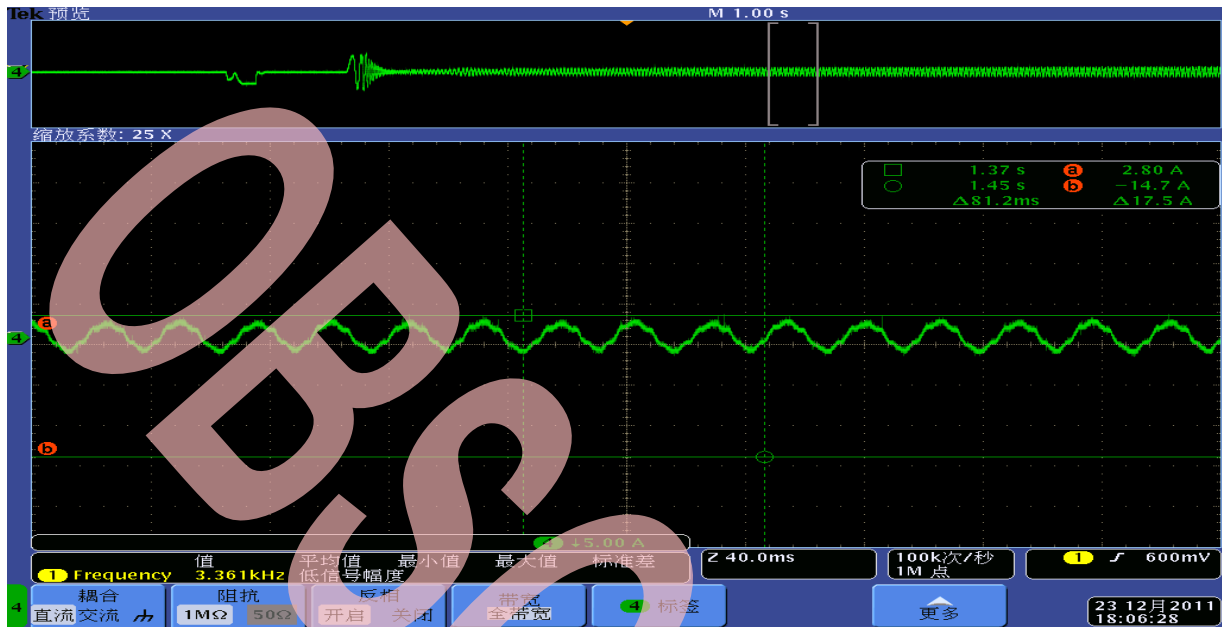
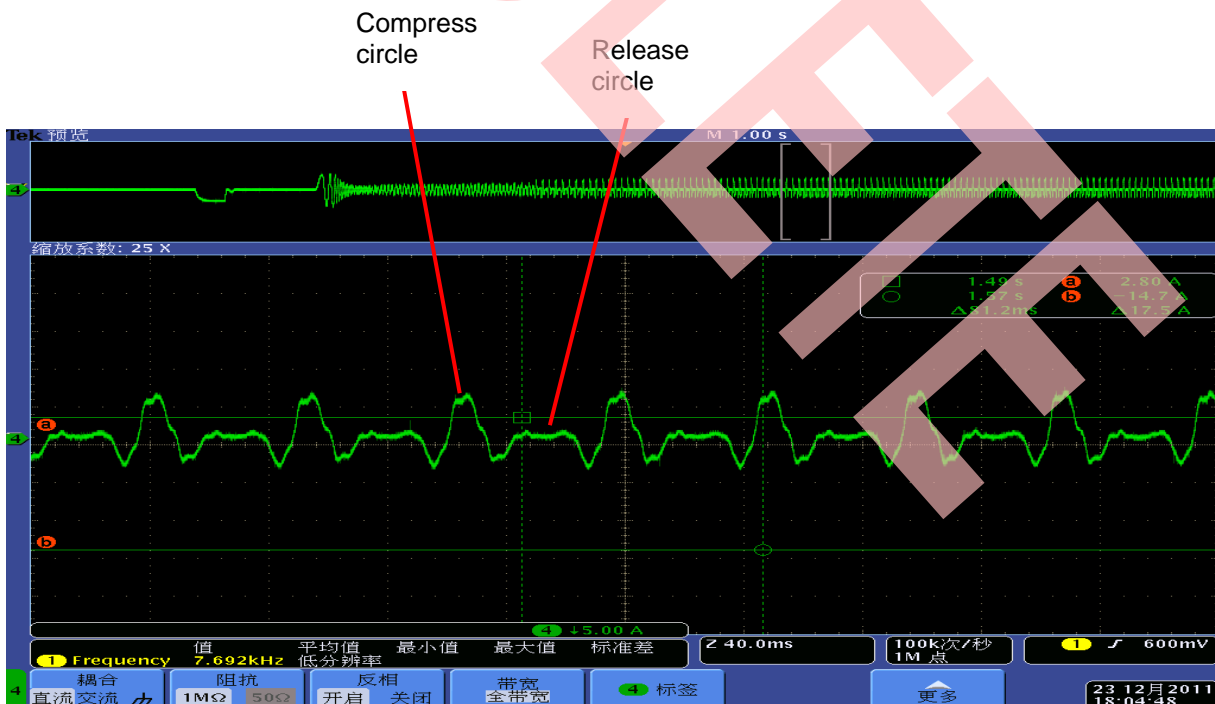


Figure 9. Current Waveform after Torque Compensation



The above two illustrations show the phase current waveform before and after torque compensation. After add torque compensation function, the current waveform has been changed obviously. In compress circle, because the load becomes bigger and bigger, the speed of rotor will decrease, the BEMF will decrease at the same time, according to voltage balance formula:

$$V = Ri + L \frac{di}{dt} + E \quad (10)$$

The phase current will increase. The target of torque compensation is to increase the speed, so we must increase the output voltage, then phase current will become bigger. On the other hand, in release circle, because the load becomes smaller and smaller, the speed of rotor will increase, the BEMF will increase at the same time, according to voltage balance equation also, the phase current will decrease. The target of torque compensation is to decrease the speed, so it must decrease the output voltage, then phase current will become smaller. When you see the phase current is strange after add torque compensation function, don't be nervous, because it is just what we want to get.

## 4 Document History

Document Title: AN205347 - FM3 MB9A310 Series Torque Compensation Application in PMSM Drive

Document Number: 002-05347

| Revision | ECN     | Orig. of Change | Submission Date | Description of Change   |
|----------|---------|-----------------|-----------------|---|
| **       | -       | CBZH            | 08/23/2011      | Initial release   |
|          |         |                 | 06/14/2012      | Modified the format   |
| *A       | 5265996 | CBZH            | 10/13/2016      | Migrated Spansion Application Note MCU-AN-510108-E-11 to Cypress format |
| *B       | 5842004 | AESATMP9        | 08/02/2017      | Updated logo and copyright.   |
| *C       | 6329249 | SSAS            | 10/02/2018      | Obsoleted   |

## Worldwide Sales and Design Support

Cypress maintains a worldwide network of offices, solution centers, manufacturer's representatives, and distributors. To find the office closest to you, visit us at [Cypress Locations](#).

## Products

|                               |  |
|-------------------------------|--|
| ARM® Cortex® Microcontrollers | <a href="http://cypress.com/arm">cypress.com/arm</a>               |
| Automotive                    | <a href="http://cypress.com/automotive">cypress.com/automotive</a> |
| Clocks & Buffers              | <a href="http://cypress.com/clocks">cypress.com/clocks</a>         |
| Interface                     | <a href="http://cypress.com/interface">cypress.com/interface</a>   |
| Internet of Things            | <a href="http://cypress.com/iot">cypress.com/iot</a>               |
| Memory                        | <a href="http://cypress.com/memory">cypress.com/memory</a>         |
| Microcontrollers              | <a href="http://cypress.com/mcu">cypress.com/mcu</a>               |
| PSoC                          | <a href="http://cypress.com/psoc">cypress.com/psoc</a>             |
| Power Management ICs          | <a href="http://cypress.com/pmic">cypress.com/pmic</a>             |
| Touch Sensing                 | <a href="http://cypress.com/touch">cypress.com/touch</a>           |
| USB Controllers               | <a href="http://cypress.com/usb">cypress.com/usb</a>               |
| Wireless Connectivity         | <a href="http://cypress.com/wireless">cypress.com/wireless</a>     |

## PSoC® Solutions

[PSoC 1](#) | [PSoC 3](#) | [PSoC 4](#) | [PSoC 5LP](#) | [PSoC 6](#)

## Cypress Developer Community

[Forums](#) | [WICED IOT Forums](#) | [Projects](#) | [Videos](#) | [Blogs](#) | [Training](#) | [Components](#)

## Technical Support

[cypress.com/support](http://cypress.com/support)

All other trademarks or registered trademarks referenced herein are the property of their respective owners.



© Cypress Semiconductor Corporation, 2011-2018. This document is the property of Cypress Semiconductor Corporation and its subsidiaries, including Spanion LLC ("Cypress"). This document, including any software or firmware included or referenced in this document ("Software"), is owned by Cypress under the intellectual property laws and treaties of the United States and other countries worldwide. Cypress reserves all rights under such laws and treaties and does not, except as specifically stated in this paragraph, grant any license under its patents, copyrights, trademarks, or other intellectual property rights. If the Software is not accompanied by a license agreement and you do not otherwise have a written agreement with Cypress governing the use of the Software, then Cypress hereby grants you a personal, non-exclusive, nontransferable license (without the right to sublicense) (1) under its copyright rights in the Software (a) for Software provided in source code form, to modify and reproduce the Software solely for use with Cypress hardware products, only internally within your organization, and (b) to distribute the Software in binary code form externally to end users (either directly or indirectly through resellers and distributors), solely for use on Cypress hardware product units, and (2) under those claims of Cypress's patents that are infringed by the Software (as provided by Cypress, unmodified) to make, use, distribute, and import the Software solely for use with Cypress hardware products. Any other use, reproduction, modification, translation, or compilation of the Software is prohibited.

TO THE EXTENT PERMITTED BY APPLICABLE LAW, CYPRESS MAKES NO WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, WITH REGARD TO THIS DOCUMENT OR ANY SOFTWARE OR ACCOMPANYING HARDWARE, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. To the extent permitted by applicable law, Cypress reserves the right to make changes to this document without further notice. Cypress does not assume any liability arising out of the application or use of any product or circuit described in this document. Any information provided in this document, including any sample design information or programming code, is provided only for reference purposes. It is the responsibility of the user of this document to properly design, program, and test the functionality and safety of any application made of this information and any resulting product. Cypress products are not designed, intended, or authorized for use as critical components in systems designed or intended for the operation of weapons, weapons systems, nuclear installations, life-support devices or systems, other medical devices or systems (including resuscitation equipment and surgical implants), pollution control or hazardous substances management, or other uses where the failure of the device or system could cause personal injury, death, or property damage ("Unintended Uses"). A critical component is any component of a device or system whose failure to perform can be reasonably expected to cause the failure of the device or system, or to affect its safety or effectiveness. Cypress is not liable, in whole or in part, and you shall and hereby do release Cypress from any claim, damage, or other liability arising from or related to all Unintended Uses of Cypress products. You shall indemnify and hold Cypress harmless from and against all claims, costs, damages, and other liabilities, including claims for personal injury or death, arising from or related to any Unintended Uses of Cypress products.

Cypress, the Cypress logo, Spanion, the Spanion logo, and combinations thereof, WICED, PSoC, CapSense, EZ-USB, F-RAM, and Traveo are trademarks or registered trademarks of Cypress in the United States and other countries. For a more complete list of Cypress trademarks, visit [cypress.com](http://cypress.com). Other names and brands may be claimed as property of their respective owners.