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Spec No: 002-05347

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

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AN205347

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

1.1 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
Φ_m	-	Amplitude of natural magnetic flux of permanent magnets
ω_m	-	Mechanical speed
ω_e	-	Electrical speed
θ_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:

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

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 ω_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:

$$T_e = p * \Phi_m * (Sin^2(\omega_e * t) + Sin^2\left(\omega_e * t - \frac{2\pi}{3}\right) + Sin^2\left(\omega_e * t - \frac{4\pi}{3}\right))$$

$$= \frac{3}{2} p * \Phi_m * I_S \quad (7)$$

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:

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

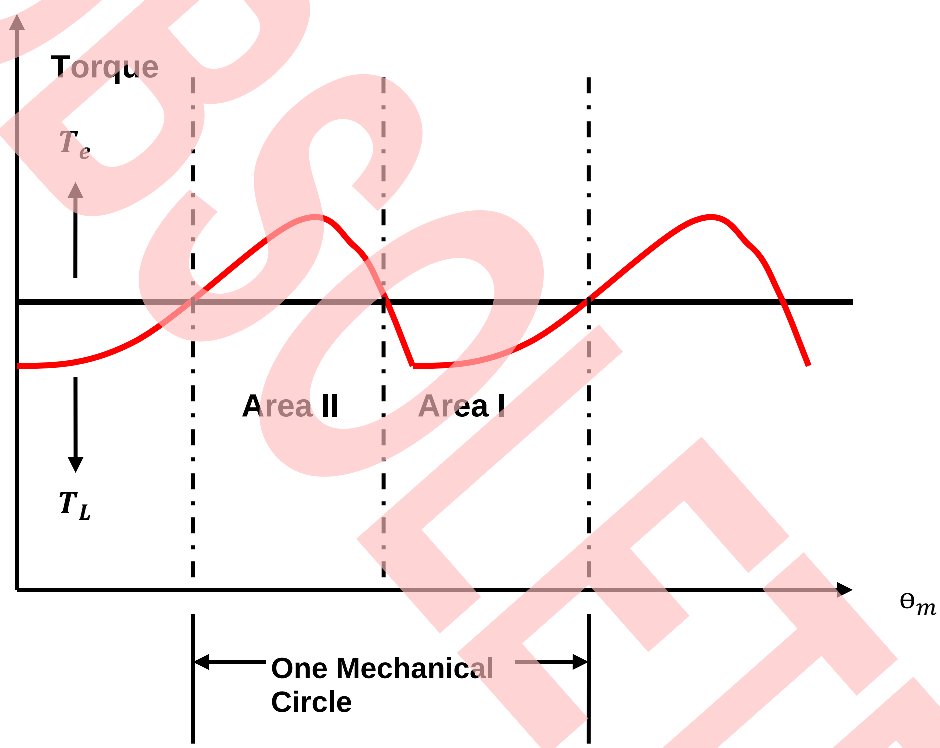
The electrical power delivered to the motor, a part is transformed in joule losses, another part is going to the energy storing in magnetic field and the last part is transformed in mechanical energy. The last part could be understood as torque production. The torque created by energy conversion process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

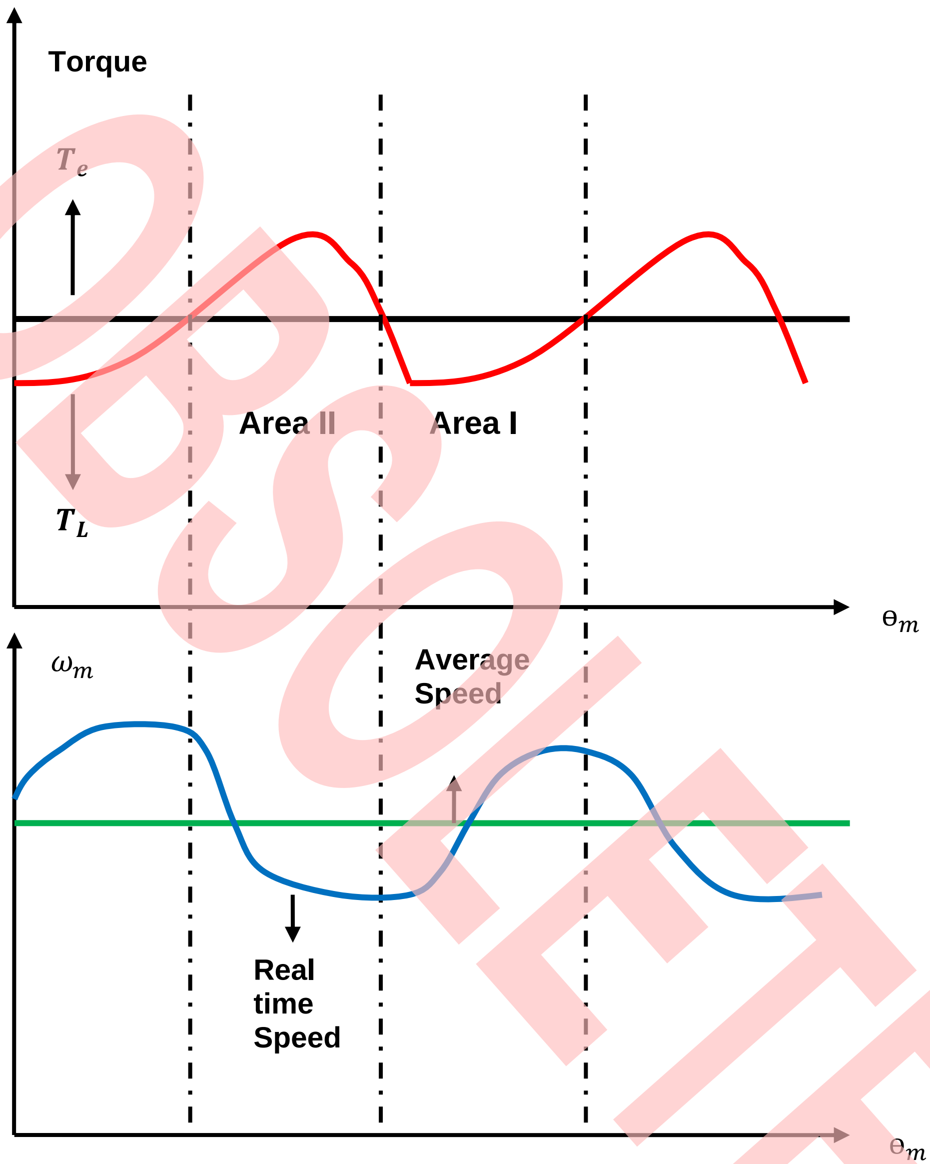
Figure 1. Torque Curve



In the above illustration, $\boldsymbol{T_L}$(red line) is the load torque and $\boldsymbol{T_e}$(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 $\boldsymbol{T_L}$is less than$\boldsymbol{T_e}$, 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



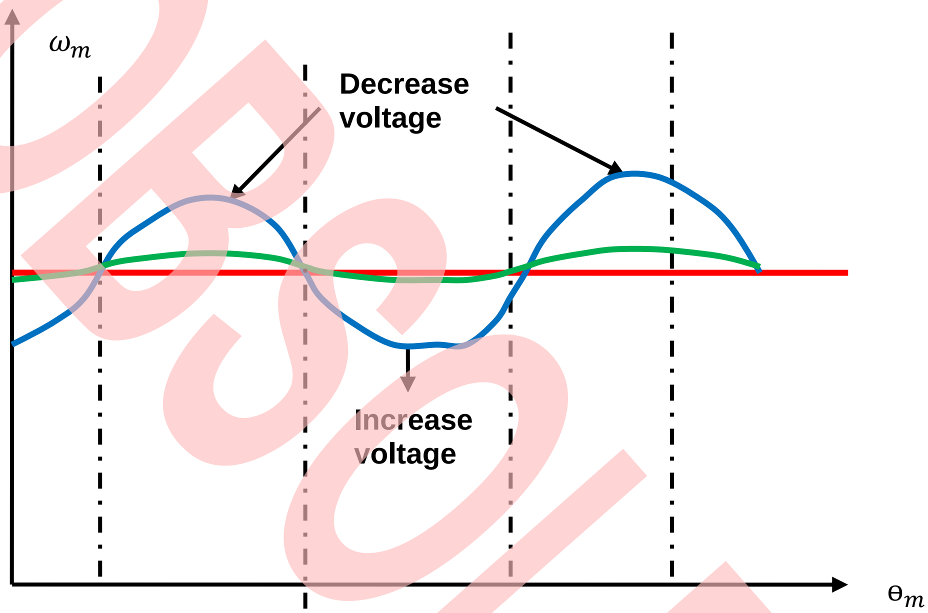
Where the green line represents average speed of rotor and the blue line represents the real time speed of rotor.

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

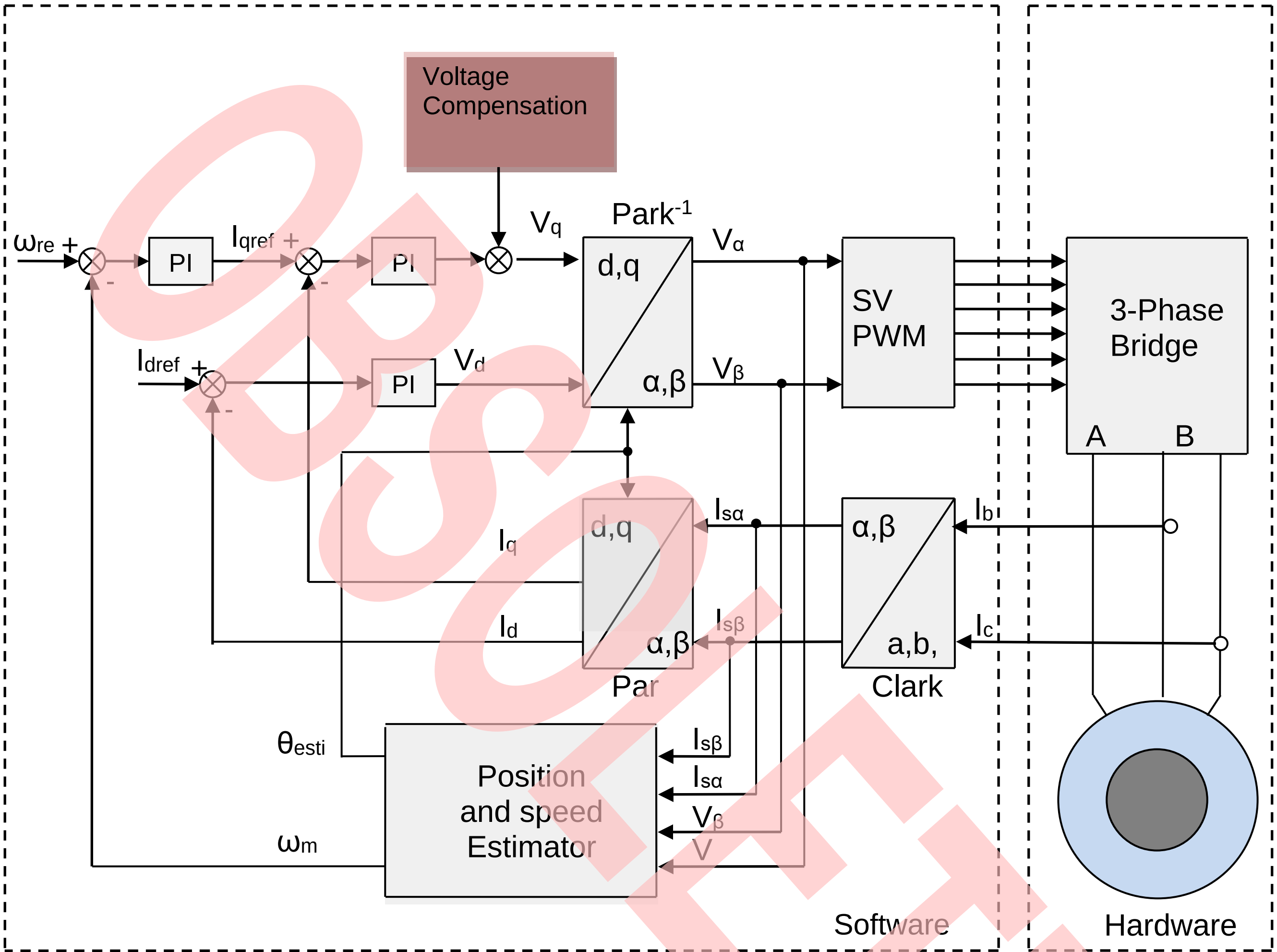


Above illustration is to explain the principle of voltage compensation. When the speed is lower than average speed, it needs to increase output voltage so that the real time speed could increase; but when the speed is higher than average speed, it needs to decrease the output voltage so that the real 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.

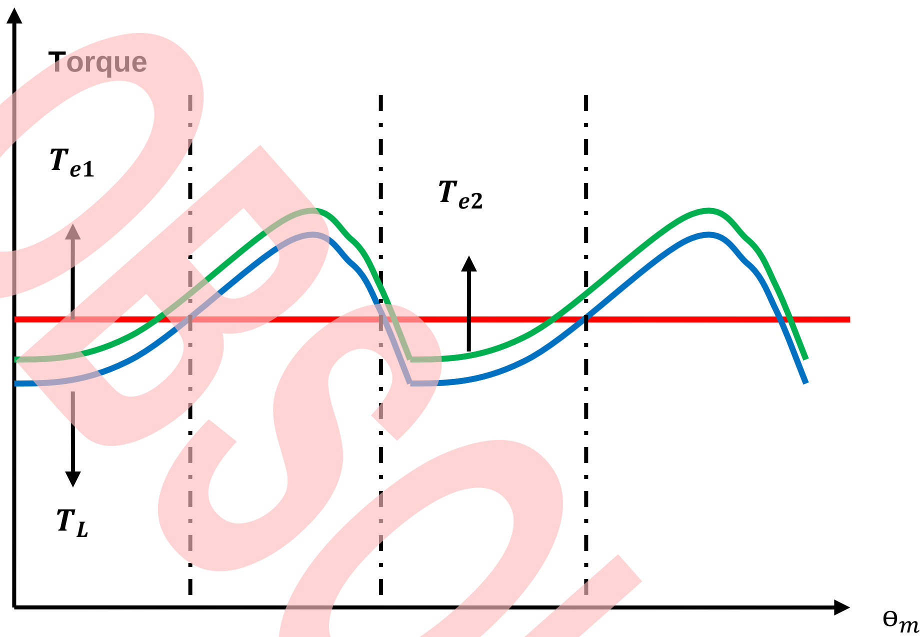
After add voltage compensation module, PMSM controlling system will be changed as below:

Figure 4. PMSM Control Block with Voltage compensation



2.3.2 Current Compensation

Figure 5. Principle of Current Compensation

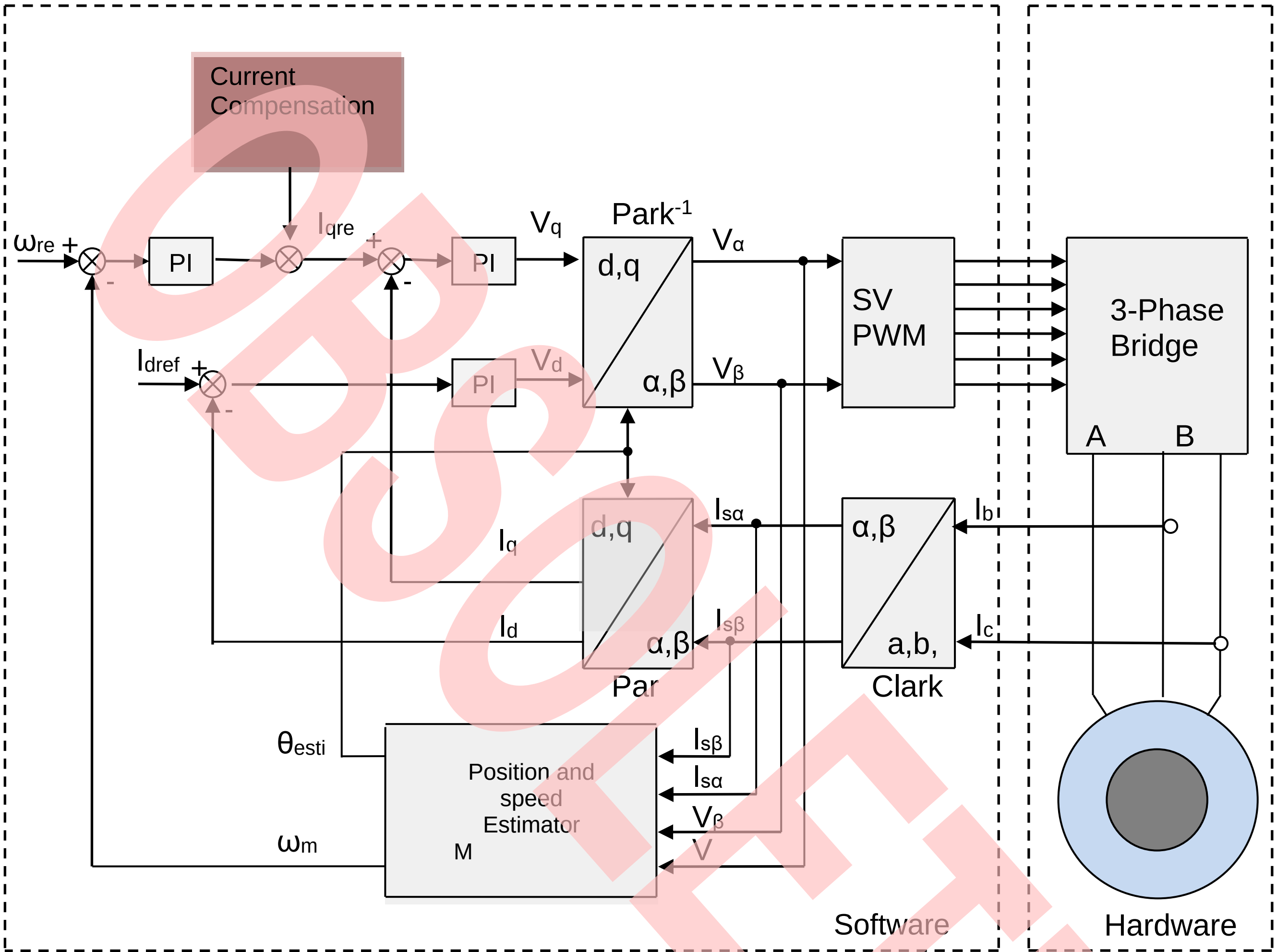


Above illustration is to explain the principle of current compensation. Core ideology of this method is to generate one electrical torque curve, whose shape is the same as load torque curve, but amplitude is bigger load torque curve. The amplitude difference between electrical torque curve and load torque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

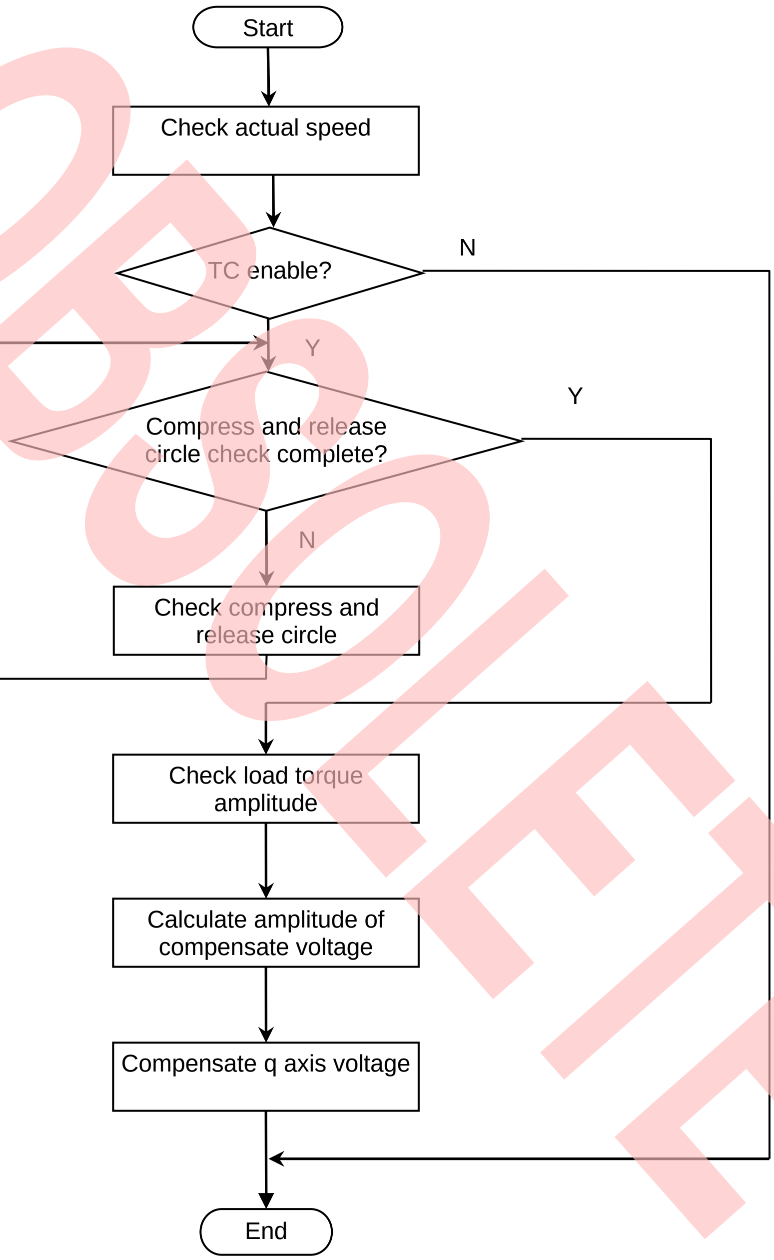
Now, we will use voltage compensation as example to explain the implementation of torque compensation.

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

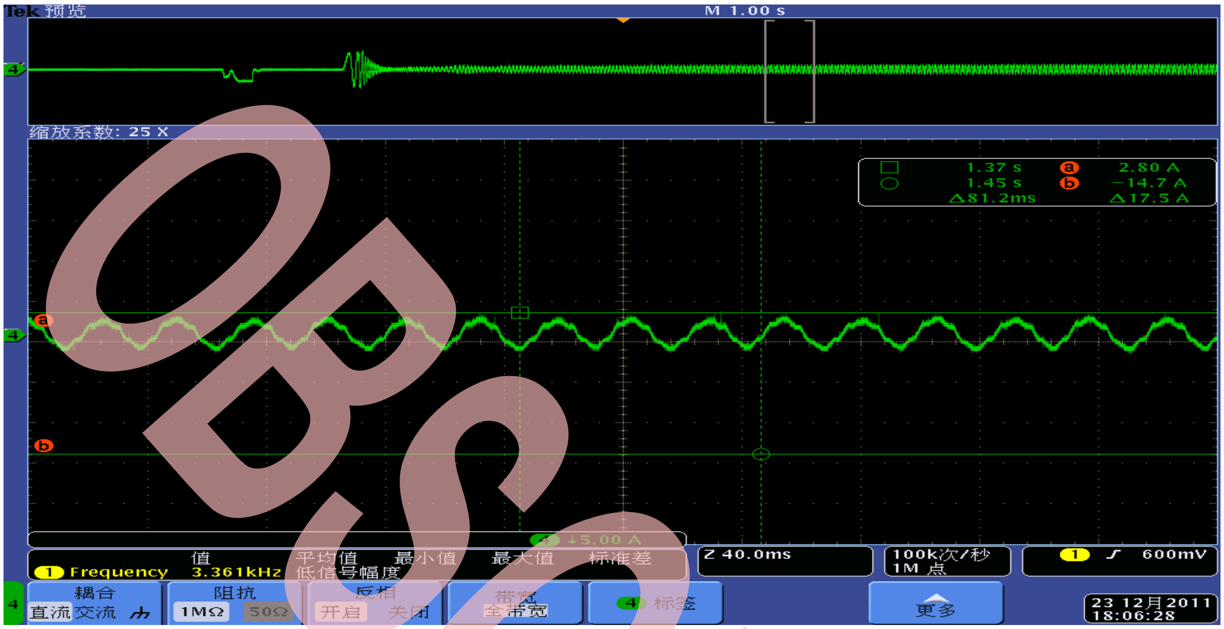
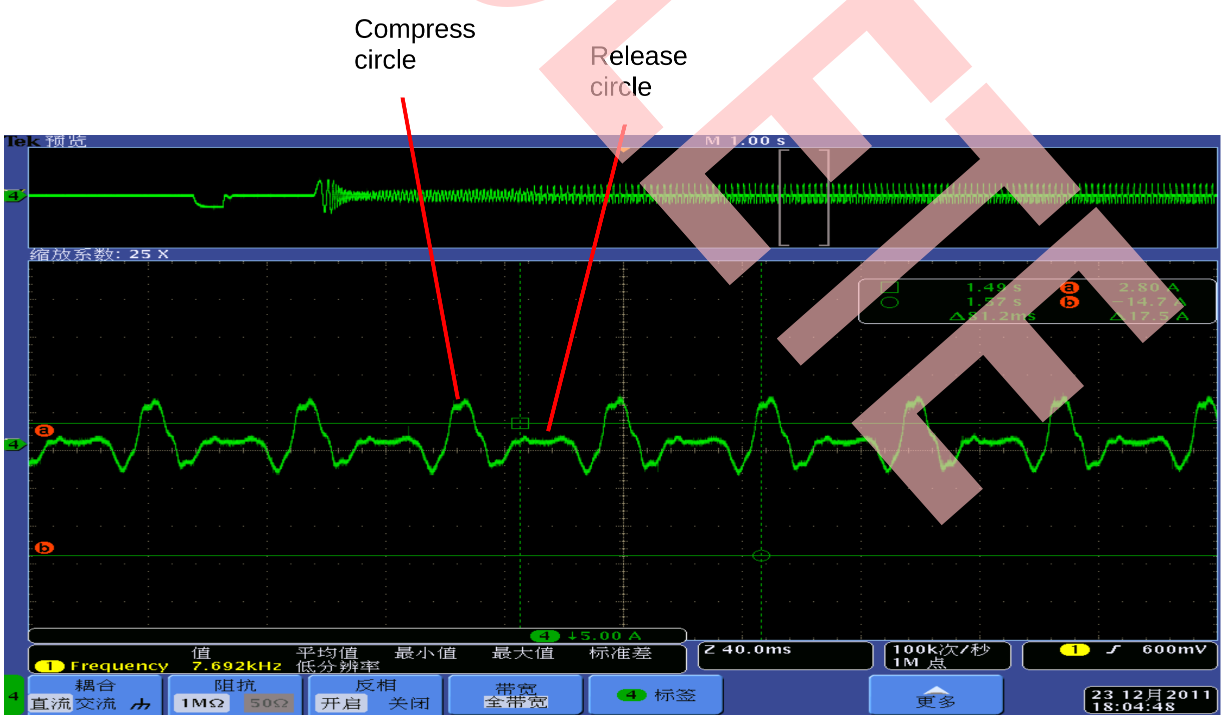


Figure 9. Current Waveform after Torque Compensation



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

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