AN205339

FM3 Microcontroller, Electrical Weight on Wash Machine

This application note describes electrical weight method on wash machine. This solution is either adapted for direct drive wash machine and draft drive machine.

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1 INTRODUCTION

1.1 Purpose

This application note describes electrical weight method on wash machine.

This solution is either adapted for direct drive wash machine and draft drive machine.

1.2 Definitions, Acronyms and Abbreviations

Te: Motor Magnetic Torque

P: Motor Power

Vsq: Voltage on q axis of d/q coordinates in FOC algorithm

Vsd: Voltage on d axis of d/q coordinates in FOC algorithm

Isq: Current on q axis of d/q coordinates in FOC algorithm

Isd: Current on d axis of d/q coordinates in FOC algorithm

M: Load weight

N: Wash machine’s bucket speed

OOB: Wash machine’s

PMSM: Permanent Magnet Synchronous Motor

BLDC: Brush less DC Motor

1.3 Document Overview

The rest of document is organized as the following:

Chapter 2 explains the principle of electrical weight on wash machine.

Chapter 3 explains how to calculate the power consume in weight process.

Chapter 4 introduce the test weight data on DD wash machine.

2 Electrical Weight Principle

This chapter introduces the algorithm of electrical weight.

2.1 Overview

Body weight can be achieved from electronic weight throwing sensor, but in some case, we can't have the sensor or the field is very worse that can't install sensor such as wash machine.

This chapter will talk about it from the connection of input electrical power, body weight and moving. If the load were very weight, the input electrical weight must be very large or small .That is to say, the load's weight can be obtained from the input electrical power which is easy to be detected. The basic electrical weight principle is on the Law of Energy Conversation. To achieve the body's weight, first should acknowledge the liner moving module, then can understand rotation moving module easily.

2.2 Basic Moving Module

Electrical machine are usually connect to mechanical system, and it converts the electrical energy to mechanical energy as a motor and converts mechanical energy to electrical energy as a generator. Hence, in these energy conversation processes, understanding of mechanics is essential to learn the energy transform principle.

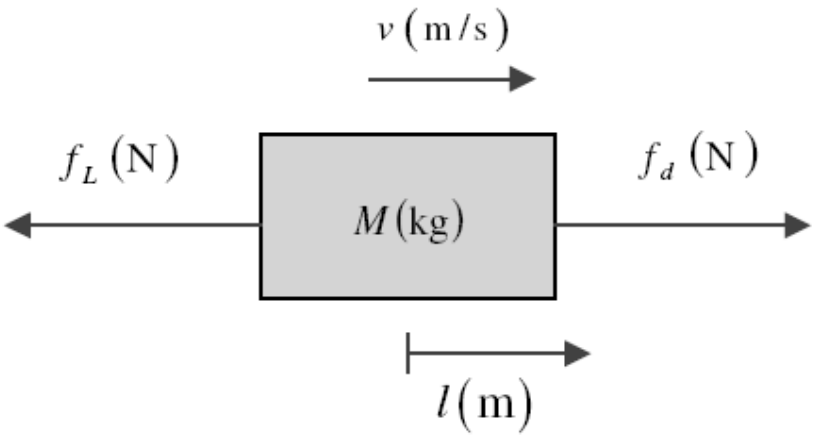
As we know that the net force on a body is proportional to the time rate of change of its linear momentum as equation (2-1).

$$f = \frac{d(Mv)}{dt} \qquad (2\text{-}1)$$

In the liner motion system as shown in Figure 1, the equation of the motion with external forces can be derived as equation (2-2) from equation (2-1):

$$f_d - f_l = M\frac{dv}{dt} = M\frac{d^2l}{dt^2} \qquad (2\text{-}2)$$

Figure 1. External forces in a liner motion system

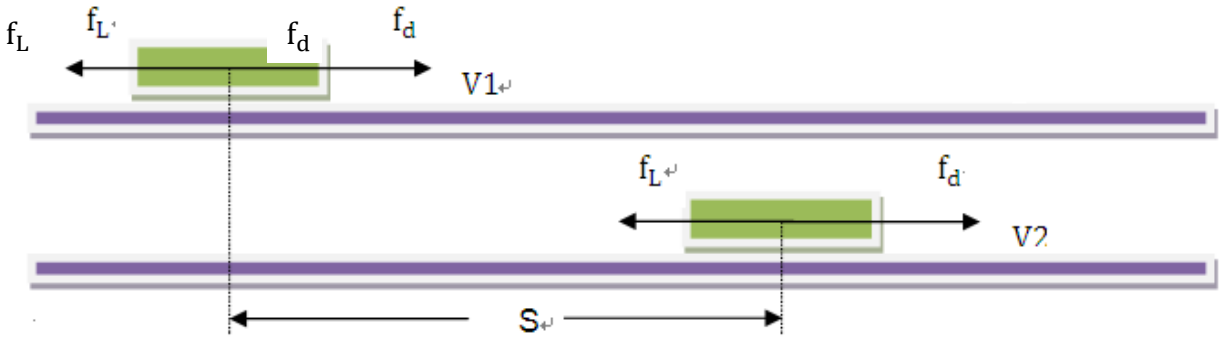


In Figure 1, the $f_L(N)$ and $f_d(N)$ is a pare of iverse force. $l(m)$ is the body's moving distance. $v(m/s)$ is moving speed.

If the body moving in a accelate speed in Figure 2, then its mass can be achieved by equation (2-3).

$$m = \frac{(f_d - f_L)t}{V_2 - V_1} = \frac{2(f_d - f_L)S}{V_2^2 - V_1^2} \quad (2\text{-}3)$$

Figure 2. External Torque in a Liner Motion System

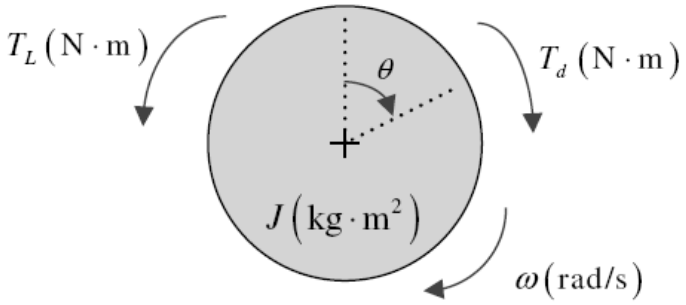


In Figure 2, S is the moving distance.Variable V2,V1, f_d, f_L is easy be detected. Throwing equation (2-3), body's mass can be checked easily. And next , we will talk about the rotation moving module.Whatever, these two module has the same property.

In a rotating motion system as shown in Figure 3, similar equation can be derived. In this equation ,the rotation inertia, J,may vary according to the motion in some case. Generally, to consider the varation of the inertia,equation (2-3) can be applied to the rotation motion.

$$T_d - T_L = \frac{d}{dt}(J\omega) \quad (2\text{-}4)$$

Figure 3. External Torque in a Rotation Motion System

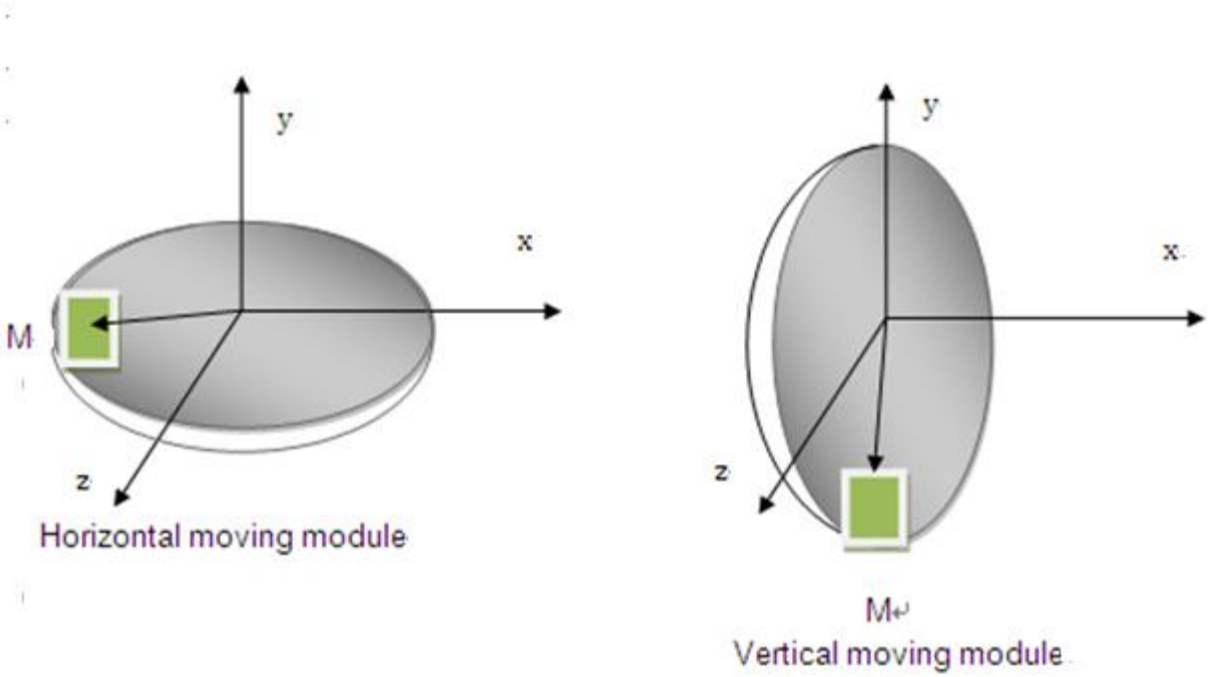


Generally consider that T_d as the magnetic torque (T_e) and T_L as load torque. J as a specially property of mass body, it won't change in any conditon but for its mass. So when the body is in a rotating status , there has a anoher equation (2-4),as below.

$$J = Mr^2 \quad (2\text{-}4)$$

From above transforming, it can be seen that the mass, M, is converted to equivalent inertia, J, at the rotational motion of sheave. And to calculate the J, it has similary method with the liner motion module. But, there will be a little different in two module: Horizontal rotational moving and vertical rotational moving Figure 4.

Figure 4. Horizontal and Vertical Rotation Motion System



These two diferent rotation module has different mothod to calculate body's mass.

In horizontal rotation system, It is easy to be changed as a liner moving modle. Body's mass calculate could be predigst as equation (2-5).

$$m = \frac{(f_d - f_L)t}{\omega_2 - \omega_1} = \frac{(f_d - f_L)S}{\omega_2^2 - \omega_1^2} \qquad (2\text{-}5)$$

Where s is the moving radian. ω_2 and ω_1 is the begin testing angle speed and over testing angle speed.

In vertical rotation system, body's force status has been changed. Besides outside forces, its body gravity also has done power on self. So mass calculation seems to be complex. The moving balcance equation may be constitute from power.

Image that the body is rising up from the bottom to the top around the center throw axis, equation can be expressied as (2-6).

$$P_{te} - 2mgr - fs = \frac{1}{2}J(\omega_2^2 - \omega_1^2) \qquad (2\text{-}6)$$

On the other hand, if the body fall down from the top to the bottom and has no force torque but for its gravity and friction, the moving balance equation changed as (2-7).

$$2mgr - fs = \frac{1}{2}J(\omega_3^2 - \omega_2^2) \qquad (2\text{-}7)$$

If the P_{te} can be known, From equation (2-4), (2-6) and (2-7), the body's mass can be achieved.At now, body's moving and body's mass has been connected throw above equation. Next, we will talk about how to use this math method to calcuate load weight in wash machine.

2.3 Electrical Weight on Wash Machine

According moving module, wash machine can be defined as two types: Pulsator washing machine and Roller-type washing machine. Pulsator washing machine's rotation is in horizontal direction. However, Roller-type washing machine's rotation is in the vertical direction. These two moving modules have been talked in 2.2.

2.3.1 Electrical Weight on Pulsator Wash Machine

Figure 5. Pulsator Washing Machine Rotation Motion System

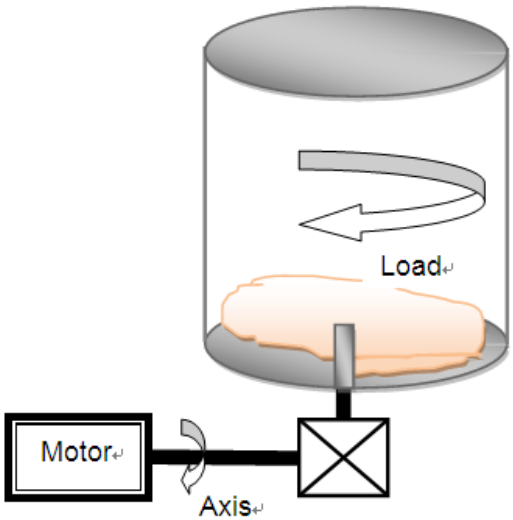
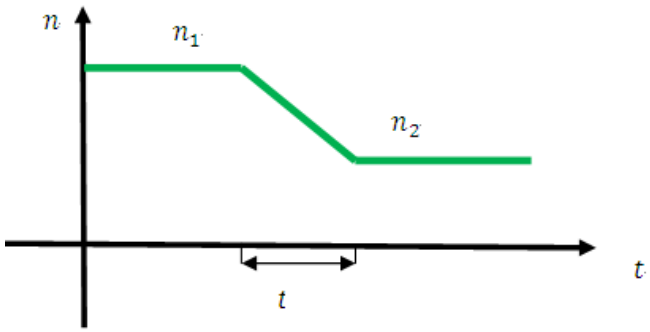


Figure 5 is a sample rotation working module of Pulsator washing machine. Motor's axis connected to wash machine's rotation axis with a transform box. May be the transform scale is 1;1 or other propotion, but it has no effection on our system. If load rotated with the barrel at a constant speed n_1, according the balcance of torque equation, Regardless the waste power, the magnetic torque equal to load torque ($T_E = T_L$). T_E can be refelcted by the motor power. And now, if the motor's driving lost, the load will fall down, when its angle speed fall at n_2, the moving balance bocome equation (2-8). GD^2 is the body's moment of inertia. From equation (2-8) and (2-9), the load's mass can be calculated. Figure 6 is the moving track.

$$T_L = \frac{GD^2}{375}\frac{(n_1 - n_2)}{t} \qquad (2\text{-}8)$$

$$GD^2 = \frac{mr^2}{4g} \qquad (2\text{-}9)$$

Figure 6. Pulsator Washing Machine Electrical Weight Moving Track



2.3.2 Electrical Weight on Roll-type Wash Machine

Figure 7. Roll-type Washing Machine Rotation Motion System

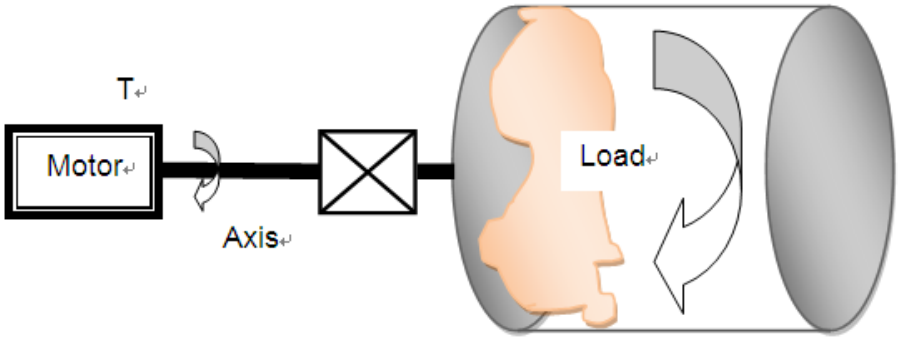
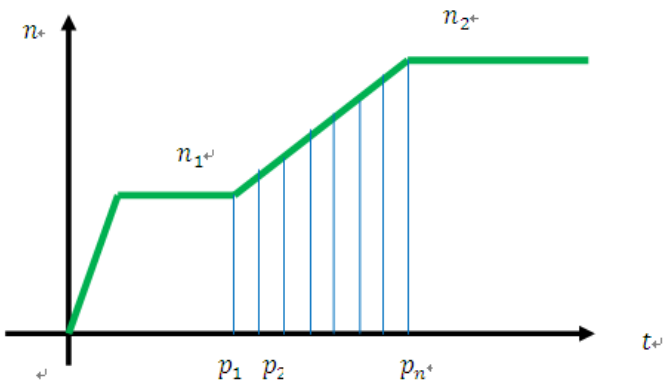


Figure 7 is a sample rotation working module of Roll-type washing machine. When the barrel rotated, it can't guarantee the evenly of the load. So the load's mass calculation has no ensure math type. It is just a dark module. However, from the motor power consuming, the load's mass may be estimated.

1. Analyze the problem as the wave wash machine. Suppose the transform box is 1:1.
2. Drive motor at the speed of n_1. The speed must set at 90r/min to 100r/min. For this can guarantee the load close to the barrel.
3. Keep this speed until 5 seconds passed. Do this step is for the motor running stable.
4. Drive motor rising at speed of n_2. Calculate motor power until the speed at n_2.
5. Observing the power can get load's mass. The power must be the inter gain of every electrical cycle power ($P_{sum} = p_1 + p_2 + \cdots + p_{n-1} + p_n$). So, if the load is not balance in barrel, its weight also can be reflected by power inter gain.
6. Set up a power table. From the step 4, it can be easy to set up a power table that according load's weight. Example; if load's weight at 500g, then the P_{sum} may be at 20w; if the load's weight at 1000g, the motor's consuming power may be at 40. That is to say, we should find the linear relationship about load weight and power.

The weight step can be seen as Figure -8.

Figure 8. Roll-type Washing Machine Electrical Weight Moving Track



3 Power Calculation

This chapter introduces motor power calculation on FOC control system

3.1 Overview

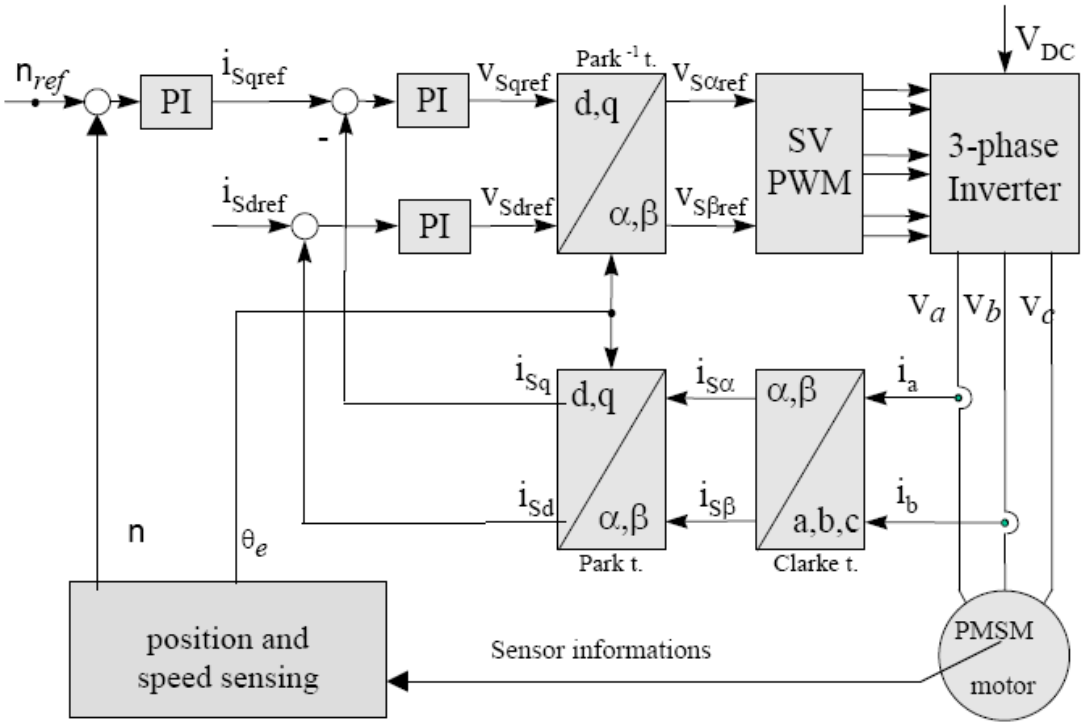
From chapter 2's talk, to calculate the load's weight has been focus on the power calculation. Our control method is based on the FOC system that power calculation seems to be very easy. And this chapter will talk about it detail.

3.2 Power Calculation

3.2.1 FOC Algorithm

FOC algorithm is a high effect vector control method on motor. Throwing its decoupling, making the control at a liner status. Figure 9 is the control structure on wash machine.

Figure 9. FOC Control Structure



To the wash machine, the position and speed sensing is Hall sensor. From hall sensor's status, motor's rotor position can be detected clearly.

Wash machine's normal work can be defined as two modules: wash module and spin module. In wash module, the barrel's speed may at 30r/min to 50r/min. In spin module the barrel's speed may change from 150r/min to 1200r/min. Electrical weight process is at 90r/min to 150r/min.

3.2.2 Power Calculate algorithm

Figure 10. AC Motor Equivalent Circuit

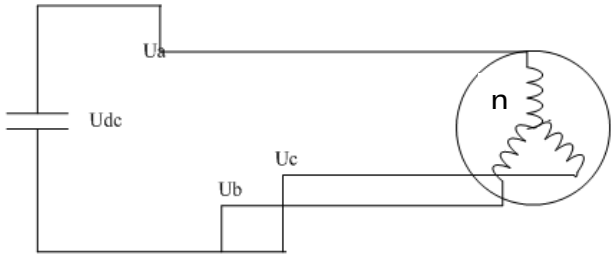


Figure 10 is an equivalent circuit of an ac motor. Its power can be generally expressed as equation (3-1).

$$P = Uan * Ian + Ubn * Ibn + Ucn * Icn \quad (3\text{-}1)$$

Uao, Ubo and Uco are the phrase voltage. Iao, Ibo and Ico are the phrase current. If motor's back EMF is sinusoid, its power also can be predigest as equation (3-2).

$$P = \sqrt{3}U_{ab}Ian \quad (3\text{-}2)$$

If adopt this math module to calculate the motor's power, the hardware must have the electrical component to detect the line-line voltage and phrase current. It is too expensive to build the hardware to the control system. And this method can't adapt to the invert status. However, because the control system is vector field control, some time-varying equations can be transformed time-invariant equations. In figure (3-1), the structure of the motor controller is then as simple for a separately excited DC motor.

From Clarke transform and Park transform, the motor's phrase current and phrase voltage has been change from a, b, c coordinate to d/q frame. And this transform's fundamental is based on the phrase magnitude invariance, where the magnitude of the variable at each phrase of the three-phrase system is the same to that of d-q axis components in the balance steady state. So the power and torque expressed in d-q axis should be multiplied 3/2 to get the same power and torque expressed in terms of three phrase variables.

From above talk, the motor's power calculation can be replaced as equation (3-3).

$$P = \frac{3}{2}(V_{sd} \cdot I_{sd} + V_{sq} \cdot I_{sq}) \quad (3\text{-}3)$$

Throw equation (3-3), It can calculate motor's instantaneous input power, which is adapt to our wash machine's OOB problem. Generally, the power of motor is very small when PMSM or BLDC running at 90r/min to 150r/min. So when program, the d/q axis's voltage and current is transformed larger than its real number.

What's all, to accomplish our item: find the relation of power and load weight, the power should have clear distribution with different load. Using equation (3-3) can make this problem more easily.

3.3 Software Design

Figure 11. Electrical Weight Follow Chart

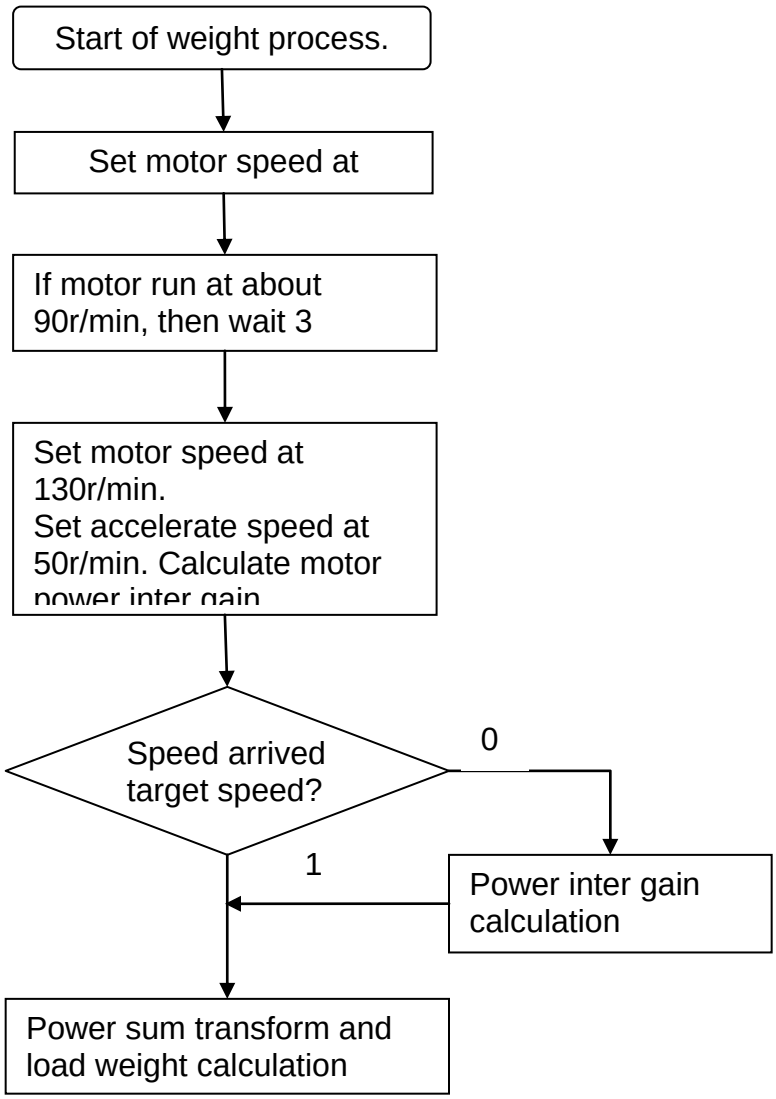


Figure 11 seems to be very easy, but there are still some notes during the weight process.

When the motor accelerate from 90r/min to 130r/min, power calculation must doing in every PWM cycle, to achieve the dynamic power inter gain.

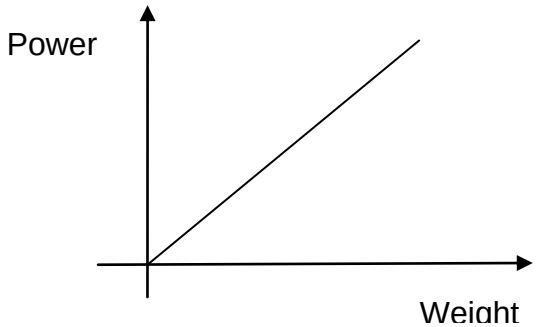
When begin power calculation, motor's speed must close to the target speed.

Motor rise from 90r/min to 130r/min, power inter gain should at a whole cycle. For example; if the motor's speed reached at 130r/min, but have run 4.5 barrel cycles, the power inter gain should not include the last 0.5 cycle. For doing this is to counteract the weight power on load seeing Chapter 2.

3.4 Weight Calculation from Power

From testing the input power on different load, system would get a load-power table. It may be looks as Figure 12. Looking at the table, would get load's weight.

Figure 12. Power and Load-weight Curve



4 Verification

This section provides the weight testing data on wash machine

4.1 Overview

To validate the electrical algorithm, this chapter try some experience on wash machine.

Testing motor: 12 pole pairs; rated current 7.5 A; PMSM module; three hall sensor; sin wave back-EMF.

Testing control board; FUJITSU_WM-0.1.2

Testing software; FUJITSU_WM-FW0.1.2

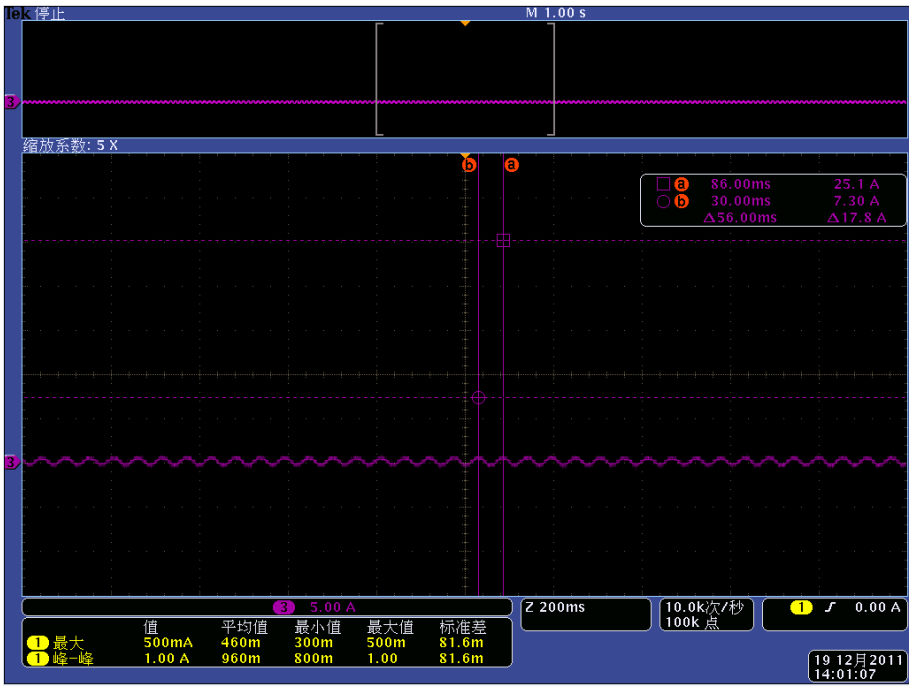
Washing machine type: Roll-type washing machine

4.2 Motor Current

4.2.1 Stable current in empty barrel

Electrical weight process is at 90r/min to 150r/min. So it require system have a stable wave in the zone. Figure 13 is the empty load at 90r/min current wave. When the motor run stable, the static speed error is 0r/min. Current's sinusoid is very smooth.

Figure 13. Empty Barrel at 90r/min Phrase Current Wave



From figure 13, it can be seen that, when motor run at 90r/min, the current is very small. It may be 200mA peak current. Power in this condition is also very small. It validate that the control system's power factor is very high. From our forward testing, the power factor may around at 1.0.

Figure 14 is the empty load at 130r/min's current wave. Compare with (4-1), there seems no change in the current peak, but for the electrical cycle time. Indeed, because system's high effect control, the two statue's current peak is too little that hard to be detected. It is also one reason for electrical weight should adopt the equation (3-3).

Figure 14. Empty Barrel at 130r/min Phrase Current Wave

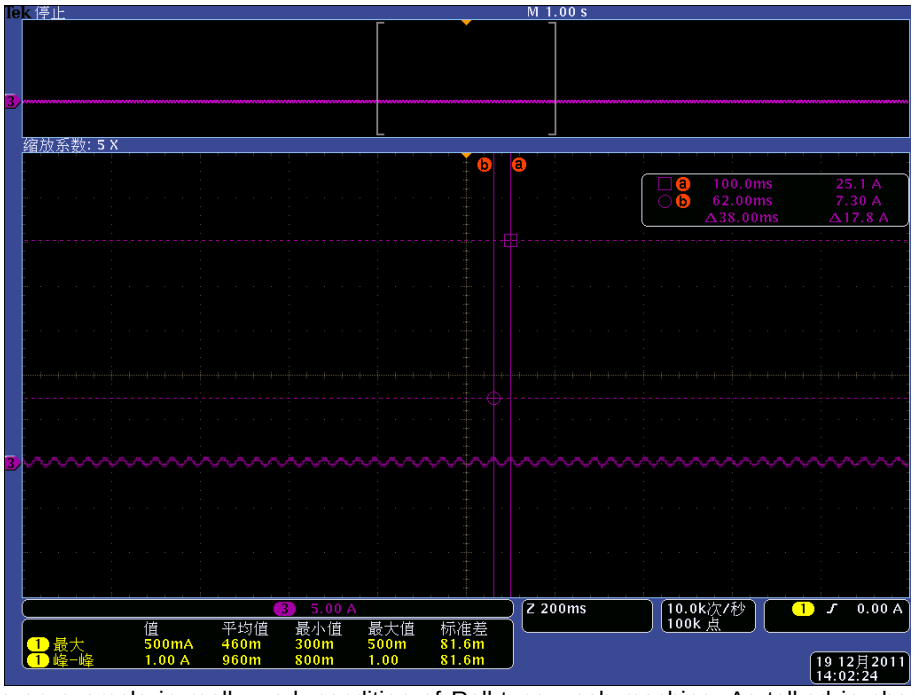
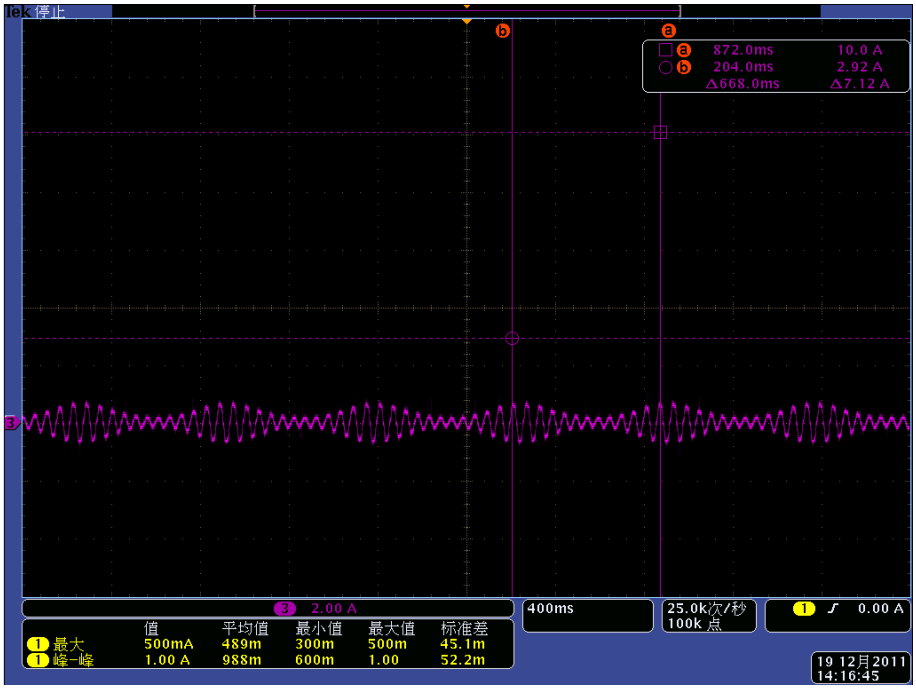


Figure 14 is an example in really work condition of Roll-type wash machine. As talked in chapter 2, tumble wash machine's work status is much rigorous than wave wash machine. Its stable current peak is exchange with the OOB. Figure 15 has clearly explained it. This is why should inter gain the power in the processing of electrical weight.

Figure 15. With 1500g OOB at 90r/min Phrase Current Wave



4.2.2 Electrical weight current

Figure 16 is the one phrase current when electrical weight. The barrel here is empty.

Electrical weight begins from curious A and end at curious b. It only took 2 seconds to complete it. In figure (4-5), there has 1500g OOB in the barrel, its weight peak current is larger than the empty load in figure 14, and electrical time is also longer than figure 16.

Figure 16. Empty Barrel Electrical Weight Phrase Current

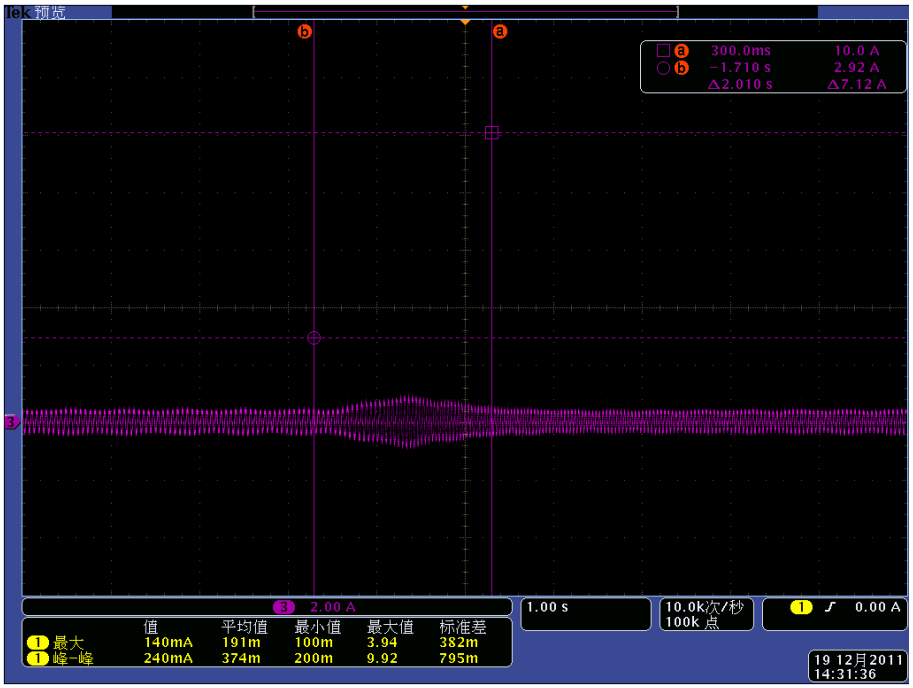


Figure 17. With 1.5 kg OOB Electrical Weight Phrase Current

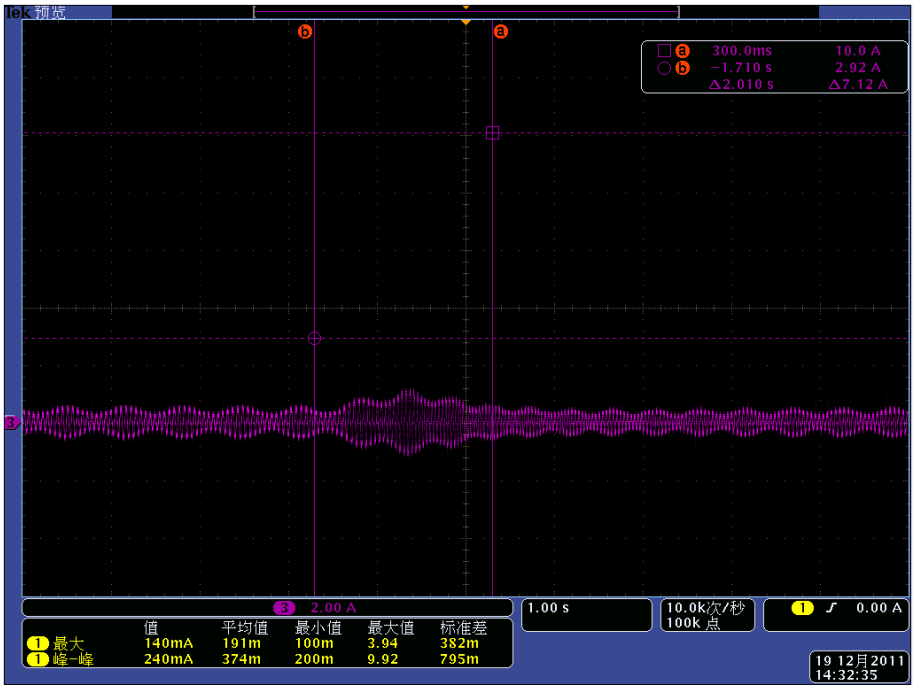
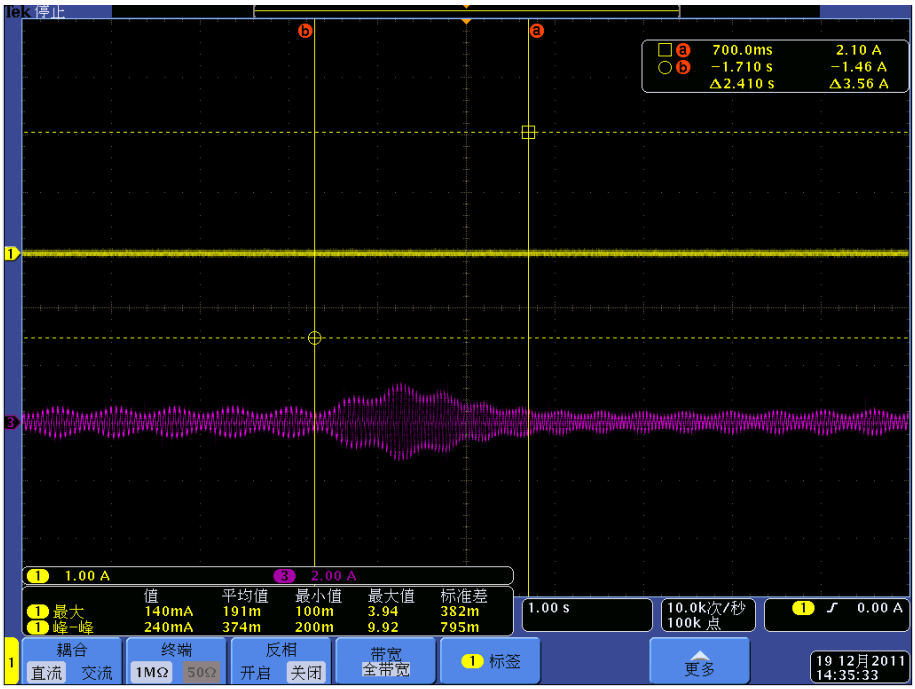


Figure 18. With 4000g Load Electrical Weight Phrase Current



From figure 16, 17, and 18, it can be seen that, with the load's weight larger, the power action more, which validate the electrical weight algorithm right.

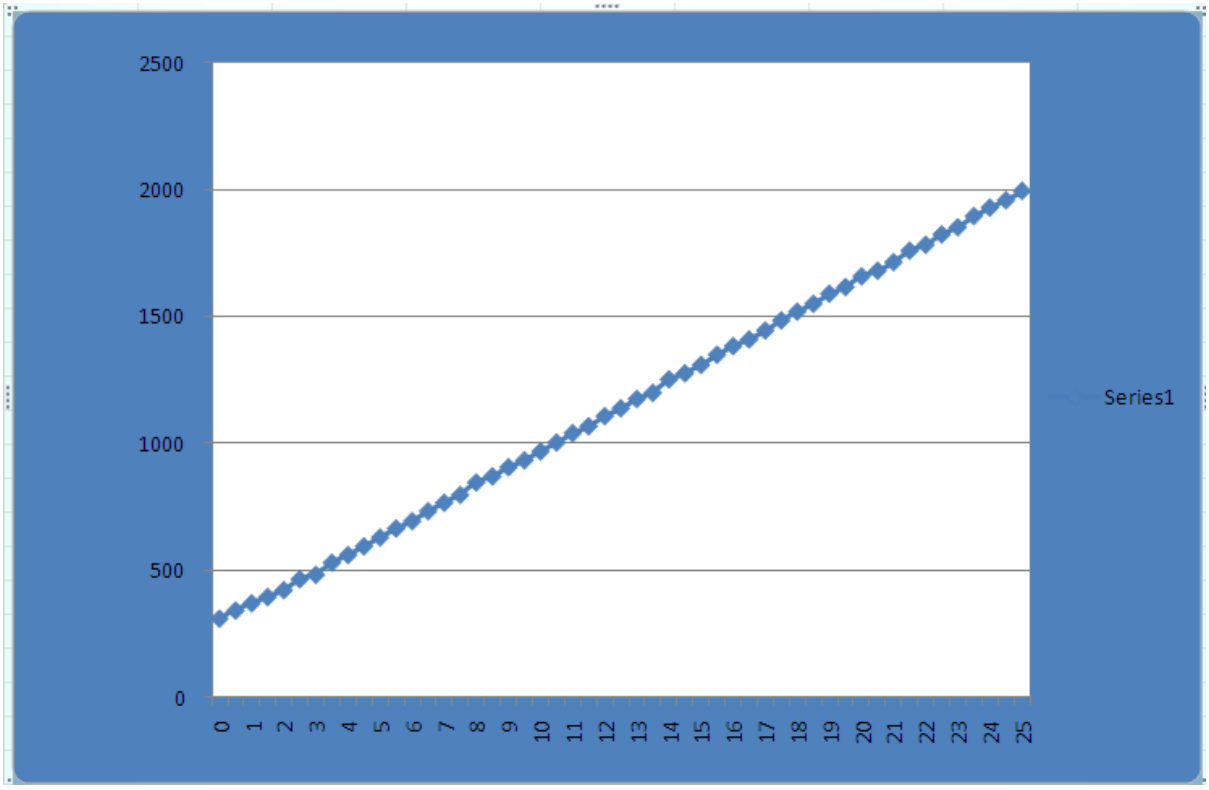
4.3 Power and Load-Weight

From above talk, and experience on the DD wash machine, power and load-weight has been connected in a line-line ship. Table 1 is one example of the ship. From the Figure 19, it can be seen that load's weight has been mapped with its electrical power inter gain during the weight process.

Table 1. Data of the power-quantification with the load's weight

weight (kg)	Power-quantification								
0	313	5.5	667	11	1042	16.5	1410	22	1782
0.5	345	6	696	11.5	1069	17	1445	22.5	1823
1	373	6.5	735	12	1109	17.5	1485	23	1851
1.5	398	7	768	12.5	1140	18	1519	23.5	1895
2	425	7.5	799	13	1176	18.5	1550	24	1928
2.5	468	8	848	13.5	1200	19	1590	24.5	1957
3	485	8.5	872	14	1253	19.5	1616	25	1994
3.5	533	9	908	14.5	1277	20	1658		
4	563	9.5	935	15	1310	20.5	1680		
4.5	597	10	970	15.5	1350	21	1714		
5	632	10.5	1005	16	1384	21.5	1759		

Figure 19. Liner-ship of Power-quantification with Load's Weight Curve



5 Document History

Document Title: AN205339 - FM3 Microcontroller, Electrical Weight on Wash Machine

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Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	—	DOHE	09/31/2011	Initial release
			06/07/2012	Changed the document format
*A	5043449	DOHE	12/09/2015	Converted Spansion Application Note “MCU-AN-510115-E-11” to Cypress format
*B	5840678	AESATMP9	08/01/2017	Updated logo and copyright.

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