A New Algorithm Research and Simulation for Permanent Magnet Synchronous Motor AC Servo System

Jingmeng Liu[α] Tianmiao Wang[β]
[α] School of Automation
Beijing University of Aeronautics and Astronautics
Beijing, China
Ljmbuaa110@163.com

Dong Xu[β] Linan Cong[β]
[β] Robotics Institute
Beijing University of Aeronautics and Astronautics
Beijing, China
Andy@me.buaa.edu.cn

***Abstract* - In this paper, the block diagram of the principles and the structure of the PMSM ac servo vector controlling system are described. The distinct features of the system are to replace electric current hysteresis controller with SVPWM. Besides, the paper introduces the principle of space voltage vector PWM (SVPWM) and the algorithm of SVPWM and also introduces the function of every module. Moreover, it introduces how to apply SVPWM algorithm into the computer to increase the efficiency of calculating ,and gives the Simulink simulation diagram of current and speed double closed loop. And it analyses the structure and realization method of inside modules of SVPWM system and offers the simulation waveforms of permanent-magnetic synchronous motor servo system.**

***Keywords*-PMSM, Simulation, Ac Servo System, Sector, SVPWM**

I. INTRODUCTION

In the filed of industry, the servo system has been widely applied into NC machine tools. With the development of the NC technique, NC system has more and more requirements for servo system, for example, small error, accurate orientation, small overshoot of system response, rapid response, short and stable recovery time of servo system, wide speed-adjusting range of servo system(more than 1:10000), more torque output at low speed, capability of shouldering strike charge and acceleration and deceleration torque several times than certain torque when in motion. In order to satisfy the above requirements, in recent years, automatic control[1], adaptive control[2 3 4], sliding mode variable structure control[5 6 7], direct torque control[8 9 10] , and vector control have emerged[11 12 13]. Since vector control has the linearity characteristic of torque control and strong points of efficient usage of current and easy realization of adjuster design, vector control is widely used both home and abroad . This paper is based on the ac servo system design of vector system algorithm.

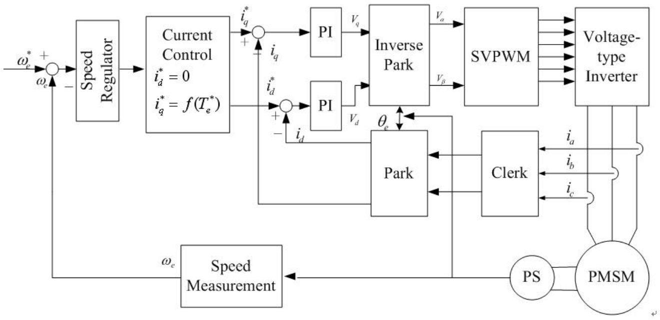

Figure 1. The block diagram of vector control of permanent magnet synchronous motor

As Figure.1 shows, the structure diagram of permanent-magnetic synchro-motor vector control is in accordance with the mathematics module of permanent-magnetic synchro-motor and the theory of vector control. Besides vector transforming , the diagram uses SVPWM technique. It must be emphasized here that vector control and PWM technique of space vector are different. The former simplifies the module of ac motor and controls the speed and torque , while the latter is one way of producing voltage and has a lot of advantages. The reasons for using it in the paper is to replace current hysteresis comparator in the inner loop of ac servo. Because within the servo period 0.1ms, for ac servo motor with big power, longer on-time with greater impact circuit. The synchronic data tells that within a servo period, the current is able to vary from the positive maximum(30A) to negative maximum(-30A). Therefore, the methods of current hysteresis comparison can not be applied into the servo system in this paper. In order to decrease the current strike, pulse width has to be adjusted. The classic method for doing that is SPWM and SVPWM. However, SPWM doesn't work here because it is hard to be connected with current loop. Therefore, this paper adopts SVPWM as the method to switch transform the inner loop (current loop).

II. THE PRINCIPLE OF PULSE WIDTH MODULATION IN VOLTAGE SPACE VECTOR

SPWM tries to output a sine-wave motor supplying power whose three parts are balanced and whose frequency and voltage can be adjusted. Its controlling principle is to try to decrease output harmonic components. When sine voltage with its three parts balanced supplies power forac motor, the range of stator magnetic chain space vector is certain and circulates at certain speed and locus of magnetic chain forms a round space

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circulating magnetic field. Three- phase windings of the motor can define a three phase static coordinate system, it has three axes, the interval of each phase is 120^0. The phase voltage of three-phase stator Ua, Ub and Uc are on three-phase windings, and form three phase votage vector Ua, Ub and Uc. Their directions are on their own axis and their volumes change with time in accordance with the sine regulation. Therefore, all three phase voltage space vector form a total voltage space vector u, which is a space vector circulating at the speed of power angle frequency ω.

$$U = U_a + U_b + U_c \,,$$

Likewise, we can define the space vector of current and magnetic chain, I and ψ. Therefore,

$$U = RI + \frac{d\psi}{dt} \,,$$

When the circulating speed is not too low, neglecting voltage drop by stator resistance,we can get

$$U = \frac{d\psi}{dt} \,,$$

or

$$\psi = \int u dt \,.$$

Considering

$$\psi = \psi_m e^{j\omega} \,,$$

then

$$u = \omega \psi_{em} e^{j(\omega t + \pi/2)} \,.$$

Motor can be controlled to slide by making use of the opening and closing condition and the orders of the inverter power and by modulating the time of opening and closing. Different combinations of switch tube constitute eight space voltage vectors, six of which are non-zero voltage vectors and the other two are zero vectors. After Clark transforming, phase voltage in the three-phase ABC plane coordinate system can be changed into Oαβ right-angled coordinate system. Its transforming formula is:

$$\begin{bmatrix} U_\alpha \\ U_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix}$$

In ABC plane coordinate system, every voltage vector is in accordance with a phase voltage, so in Oαβ plane, every non-zero voltage vector is in accordance with one only coordinate. Figure 2 gives vectors, sectors and waveforms of SVPWM. Starting from zero degree(the first sector), anti-clockwise plus one every 60^0 sectors. The definition of sector is not only one. Some resources define sector circulating anti-clockwiseas 0~5, while some define sector as 315462, and they are different. This paper adopts the order of 1~6. In every sector, figure 2 gives the order of PWM conduction and the best vector approximation group. The order of conducting PWM is decided by motor operating principle and it is unique, so the best vector approximation group is also unique.

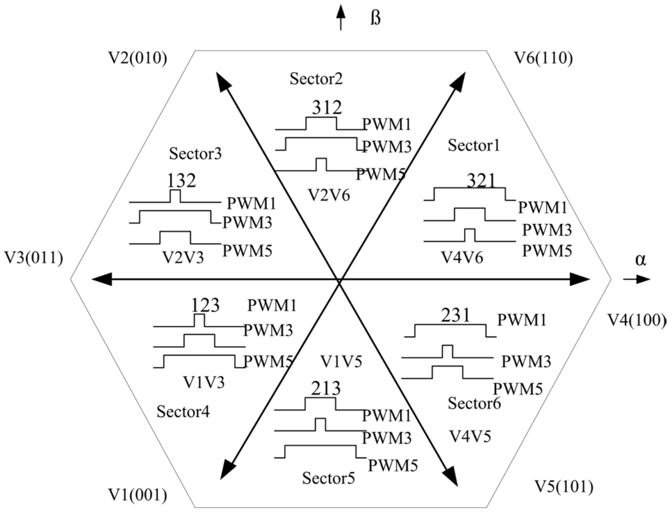


Figure 2. Vectors , sectors and waveforms of SVPWM

As to the formerly-designed transducer of SVPWM, in every sector, switch tube only are adjusted for several times. However, this time, it is different. Within every servo period(0.1ms), the switch vector is adjusted effectively. So the response speed of cross –current servo increase rapidly. Since sector and the best approximation vector group have been decided, the rest problem is how to decide the time of every non-zero vector. This paper applies 7segment voltage space vector, so the next problem is how to get t0,t1,t2. The emerge of zero vector is the most important characteristics of space vector. Within the time when motor is operating at low speed, it depends on zero vector to decrease the circulating of space vector.

III. THE METHOD TO DECIDE THE TURN-ON TIME OF NON-ZERO VECTOR

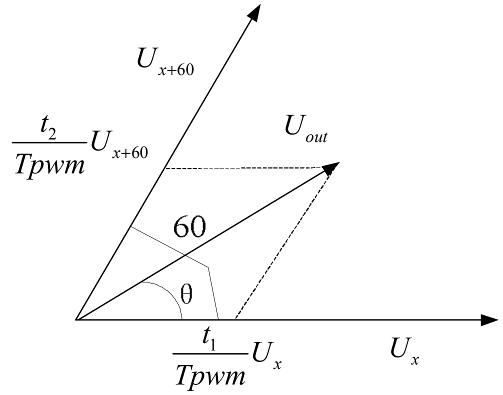


Figure 3. The combing method of voltage space vector

When T_{pwm} U_{out} , U_x and U_{x+60} projection in right-angled coordinate system Oαβ, there is a formula:

$$\begin{bmatrix} t_1 \\ t_2 \end{bmatrix} = T_{pwm} \begin{bmatrix} U_{x\alpha} & U_{x\pm 60\alpha} \\ U_{x\beta} & U_{x\pm 60\beta} \end{bmatrix}^{-1} \begin{bmatrix} \frac{U_\alpha}{U_\beta} \end{bmatrix}$$

After knowing the projection $(\frac{U_\alpha}{U_\beta})$ of inverse matrix $\begin{bmatrix} Ux\alpha & U_{x\pm 60\alpha} \\ Ux\beta & U_{x\pm 60\beta} \end{bmatrix}^{-1}$ and U_{out} in right-angled coordinate system, t_1 t1and t_2 are certain. So this paper defines three variables, X,Y,Z. Through the table of sectors number, the motion time of non-zero vector in every sector can be decided.

So this paper defines:

$$X = \sqrt{2} * T_{pwm} * \frac{U_\beta}{U_d}$$

$$Y = \sqrt{2} * T_{pwm} * \frac{1}{U_d} * (\frac{\sqrt{3}}{2} U_\alpha + \frac{1}{2} U_\beta)$$

$$Z = \sqrt{2} * T_{pwm} * \frac{1}{U_d} * (-\frac{\sqrt{3}}{2} U_\alpha + \frac{1}{2} U_\beta)$$

Then, since sectors are known, multiplexers can be used to choose the motion time of non-zero vector. In order to clearly express the choice of XYZ, the relationship of index number, sector number and the motion time of non-zero vector is listed in TABLE1 .

TABLE I. The relationship of index number, sector number and non-zero vector

Index Number P	1	2	3	4	5	6
Sector N	2	6	1	4	3	5
t_1	Z	Y	-Z	-X	X	-Y
t_2	Y	-X	X	Z	-Y	-Z

Index number, mentioned in the above formula will be introduced in detail. Suppose that index number is known, saturation judgement must be conducted after t_1 , t_2 are valuated , the calculating formula of saturation is:

When $t_1 + t_2 > T_{pwm}$;

$$t_1 = \frac{t_1}{t_1 + t_2} T_{pwm} ;$$

$$t_2 = \frac{t_2}{t_1 + t_2} T_{pwm} ;$$

IV. CALCULATE VECTOR TRANSFORMING POINT AND THE JUDGMENT OF PRODUCE OF PWM AND SECTOR THAT VOLTAGE VECTOR IS IN

Define

$$T_a = \frac{(T_{pwm} - t_1 - t_2)}{2} ;$$

$$T_b = T_a + T_1 ; U_\beta = -\sqrt{3} U_\alpha B_2 = -\frac{\sqrt{3}}{2} U_\alpha - \frac{1}{2} U_\beta \;;$$

$$T_c = T_b + T_2 \,.$$

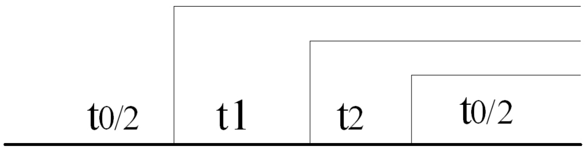


Figure 4. Turn-on time of every vector

Therefore, two zero-vectors are in two ends, two non-zero vectors which constitute the conduction orders of zero-vector, non-zero vector ,non-zero vector and zero-vector are in the middle. Then Ta, Tb and Tc are given to Tcm. The best approximation vector group in every sector is different from another, so valuation of transforming point Tcm1, Tcm2 and aTcm3 is showed in TABLE 2. Since the time TABLE of transforming points, it is simple to output PWM signals. For DSP: it is just to send the time of transforming points to comparable register; for Simulink, generator of Repeating Sequence is needed to compare with time transforming point and then hysteresis comparator outputs the voltage.

TABLE II. The relationship of index number, sector number and timer time

Index Number P	1	2	3	4	5	6
Sector N	2	6	1	4	3	5
T_{cm1}	T_b	T_a	T_a	T_c	T_c	T_b
T_{cm2}	T_a	T_c	T_b	T_b	T_a	T_c
T_{cm3}	T_c	T_b	T_c	T_a	T_b	T_a

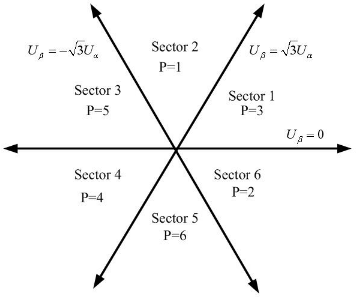


Figure 5. The calculation of sector

Sector number can be got directly if U_{out} U_{out} is given in the form of amplitude and angle, and also it can be got by the following method:

Index Number P=4Sign(B2)+2Sign(B1)+Sign(B). The reason is: in the right-angled coordinate system, the difference is 60^0 angle (one secto) three straight lines, and they are:

$$B_0 = U_\beta$$

$$B_1 = \frac{\sqrt{3}}{2} U_\alpha - \frac{1}{2} U_\beta$$

$$B_2 = -\frac{\sqrt{3}}{2} U_\alpha - \frac{1}{2} U_\beta$$

It can be seen from firure 5. that these three straight lines divide Oαβ plane into six districts, in other words, sectors and every sector is related to these three straight lines. Define U_β >=0, the half-plane on the line Sign(B0)=1, of course, under the line, Sign(B)=0; under the line $U_\beta = \sqrt{3} U_\alpha$, 2Sign(B1)=2, of course, above the line, 2Sign(B1)=0; under the line $U_\beta = -\sqrt{3} U_\alpha$; 4Sign(B2)=4, above the line, 4Sign(B2)=0. In this way, only one index number is got. It can be seen clearly from figure 5 the relationship between index number and sector. So the problem of calculating sector has been solved.

V. SIMULATION OF PERMANENT-MAGNETIC SYNCHRONOUS MOTOR SERVO SYSTEM

Simulation is one important part of the design of ac servo system. The result of simulation can be applied into the testing of the system and optimization of parameters, and also to verify the designing idea. Especially for this kind of task ,such as combination of strong and weak current of ac servo. Testing of parameter without simulation easily destroys permanently high-voltage module and drive circuit. In this paper, Simulink simulation for permanent-magnetic synchronous motor ac servo system is showed in Figure 6, including speed loop adjuster, current loop adjuster, coordinate transformer, SVPWM module, PMSM module and testing module and etc. SVPWM module and PMSM module are introduced in detail in this paper.

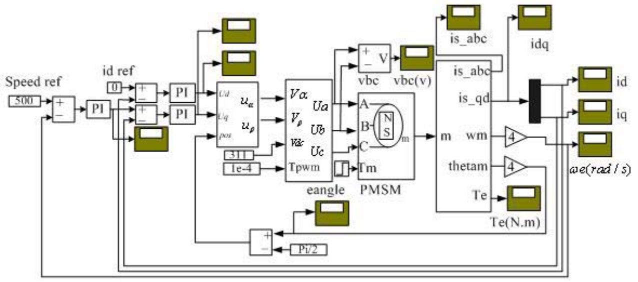


Figure 6. Simulink simulation of permanent-magnetic synchro-motor ac servo system

A. PMSM module

The input of PMSM module is phase voltage, A, B and C phase voltage, which are responsible for loading torque Tm; Phase voltage, firstly, through Clark and Park is transformed into straight axis voltage and cross-axis voltage and output three-phase current, cross and straight-axis current, mechanical rotational speed,mechanical position angle and electromagnetic torque . The inner structure of PMSM is showed in figure 7. It is the overall blueprint of PMSM. Figure 8 and figure 9 show its two central son module, which are used to calculate straight-axis and cross- axis current. Cross-axis current produces electromagnetic torque. And, the difference between electromagnetic torque and load torque is used to

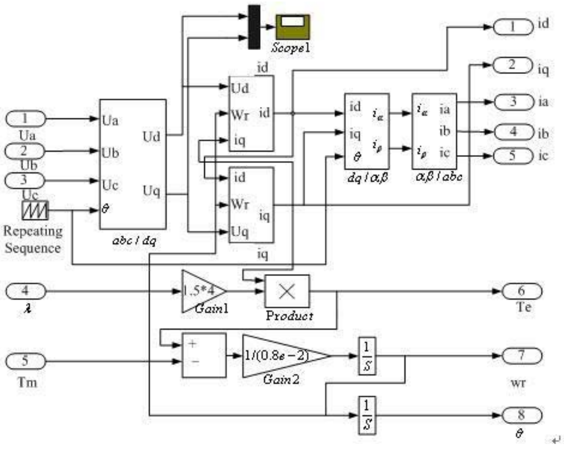


Figure 7. The inner structure of PMSM

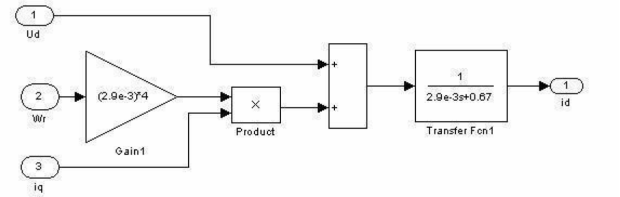


Figure 8. The inner central module of PMSM 1- The calculation of straight-axis current

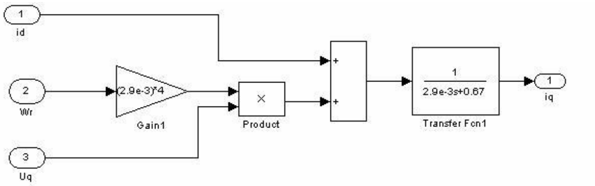
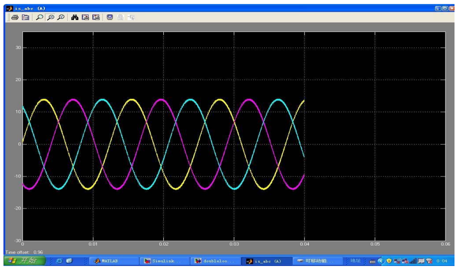


Figure 9. The inner central module of PMSM2- The calculation of cross-axis current

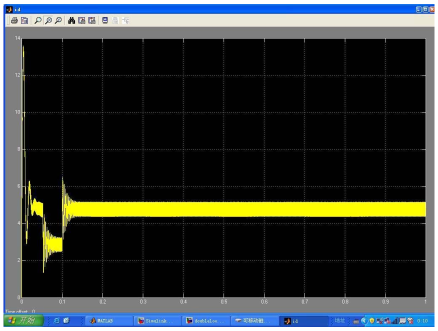
Figure 10. (a) Speed waveforms

calculate acceleration .Acceleration, after the first integral ,can get speed and position signals. During the time when Matlab tested, we were all worried about time mismatch since the first and second integrals both need time. However, the time of simulation is not fixed. Fortunately, practice proves that it is not necessary to worry about that, because integral time adjusts automately in accordance with the time of simulation.

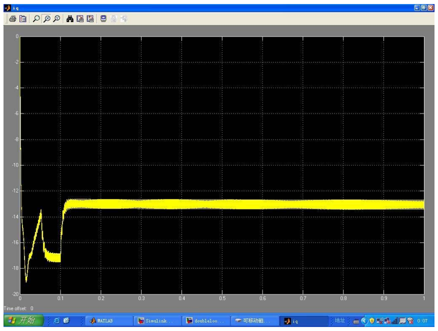
B. *Results of simulation*



(b) Motor three-phase current waveforms



(c)Motor straight- axis current waveforms



(d) Motor cross-axis current waveforms

Figure 10 . Simulation waveforms of permanent-magnetic synchro-motor ac servo system

Conclusion

In this paper, the simulation model of permanent-magnetic synchronous motor ac servo system is established and the results of simulation are showed in Figure 10 . It can be seen from the figure that motor phase current waveforms are ideal three-phase sine waves and there is a difference of 120^0 among the phase currents. Besides, straight-axis current is small, and cross-axis current increases when load increases and also overshoot of speed response curve and error are all small. In a word, effect of simulation is excellent.

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