IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Research on Vector Control and Subdivision Drive Technology of Two-phase Hybrid Stepper Motor Based on SVPWM

To cite this article: Xiaolin Hu *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **381** 012140

View the article online for updates and enhancements.

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

This content was downloaded from IP address 181.215.74.210 on 16/08/2018 at 18:13

IOP Conf. Series: Materials Science and Engineering **381** (2018) 012140 doi:10.1088/1757-899X/381/1/012140

Research on Vector Control and Subdivision Drive Technology of Two-phase Hybrid Stepper Motor Based on SVPWM

Xiaolin Hu[1,a], Yanrong Zhang[1,b,*] and Yan Lu[1]

[1]School of Mechanical Engineering, Southwest Jiaotong University, Chengdu 610031 China
E-mail: [a]xlinhu993@163.com, [b]642784176@qq.com.

Abstract. In this paper, the principle of vector control of two-phase hybrid stepping motor is analyzed, the subdivision drive and speed control of the stepper motor are realized under current loop. According to control of the double H-bridge topology of stepping motor, seven-stage SVPWM algorithm is designed. Smaller switching loss and rotation ripple are achieved by reasonably selecting and distributing the basic vector and the zero vector. Finally, the experimental research is carried out and the results show the correctness and superiority of SVPWM algorithm.

1. Introduction

Stepping motor is a widely used control motor; it has such advantages as simpler structure, lower cost and easier control compared with the servo motor. Especially two-phase hybrid stepping motor, it has a wide range of applications. In a variety of industrial automation and control systems. The traditional control methods of the stepper motor include single voltage drive, high and low voltage drive, chopper constant current drive, etc. Although these control methods are very mature, they all have the problems of low frequency oscillation, high frequency torque and slow response [1], so looking for better control has become an important direction of the development of stepper motor.

Vector control is widely used in AC motor control. Hybrid stepping motor is equivalent to multi-pole AC permanent magnet synchronous motor in structure [2], so vector control of hybrid stepping motor has become a research hotspot in recent years. Literature [3] studied the torque vector control of two-phase hybrid stepping motor, it turned out that the vector control has good steady-state and dynamic performance for stepper motor. And reference [4] studied the vector control of hybrid stepping motor with two-phase and three-leg arms.

As a new type of PWM technology, SVPWM (Space Vector Pulse Width Modulation) can significantly reduce the harmonic content of the inverter output current, improve the inverter DC voltage utilization and reduce the torque ripple. At the same time, it is easy to implement on embedded chips such as microcontrollers, so it is widely used in various AC motor control [5]. The literature [6] and [7] both studied the SVPWM of the hybrid stepping motor vector control. In this paper, aiming at the double H-bridge control of two-phase hybrid stepping motor, the SVPWM algorithm is redesigned to further improve the control performance of the stepping motor.

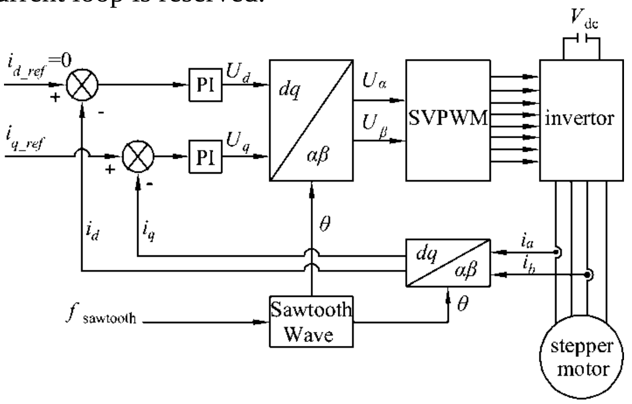
2. Stepper motor vector control

The vector control block diagram of the two-phase hybrid stepping motor is shown in Fig.1. The control strategy of $i_d = 0$ is used [8]. In order to further reduce the volume of the stepping motor

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

IOP Conf. Series: Materials Science and Engineering **381** (2018) 012140 doi:10.1088/1757-899X/381/1/012140

driver and reduce the price of the driver, the position loop and speed loop are canceled, only the current loop is reserved.



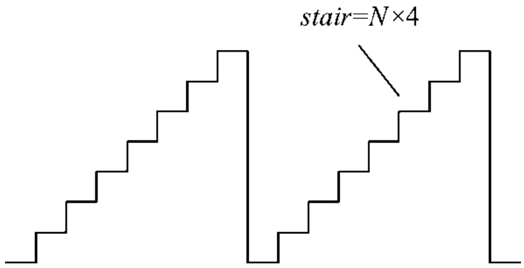


Figure 1. stepper motor vector control block diagram. **Figure 2.** ladder sawtooth waveform.

In Fig. 1, $i_{dref} = 0$, i_{qref} is the reference current, the two-phase stator current i_a, i_b are obtained through sampling resistance of the H bridge, i_d and i_q are obtained through Park transformation, then a differences is made with i_{dref} and i_{qref} separately, the difference is adjusted by the PI controller to obtain U_d and U_q, and the obtained U_d and U_q are further subjected to Park inverse transformation to obtain U_α and U_β. Finally, PWM waves are generated by the outputs of the SVPWM algorithm to realize the vector control of the stepper motor, and V_{bus} is DC bus voltage of the inverter, and $f_{sawtooth}$ is the sawtooth frequency.

The rotor position information of the stepping motor can't be obtained because of the cancellation of the speed loop. Therefore, the rotor angle is simulated with a periodic staircase sawtooth with a value of 0 to 2π, as shown in Fig. 2. Stair means the number of steps of sawtooth wave each cycle, each step of the sawtooth wave corresponds to each step of the step motor, so the subdivision control of the stepper motor can be realized by setting the number of steps each period of the sawtooth wave. Stepper motor speed can be expressed as

$$V_{stepper} = \frac{f_i \times 4}{\frac{360}{T} \times N} \times 60 = \frac{2Tf_i}{3N} \tag{1}$$

In formula (1), $V_{stepper}$ is the speed of the stepper motor (r/min), T is the step angle of the stepping motor (°), f_i is the frequency of the two-phase current (Hz) and N is the motor subdivision number.

It can be known from Park transformation and its inverse transform that

$$f_i = f_{sawtooth} \cdot \tag{2}$$

So it can be known through formula (1) and (2) that

$$V_{stepper} = \frac{2Tf_{sawtooth}}{3N} . \tag{3}$$

When the motor is working, the inherent step angle T is a fixed value related to the motor structure, the subdivision factor N is also constant after the selection. Therefore, the control of the stepping motor speed can be realized by controlling the frequency of the sawtooth wave.

3. Design of SVPWM algorithm

The object of this paper is the control of two-phase hybrid stepping motor, so a double H-bridge structure is used, it is shown in Figure 3. However, the traditional SVPWM algorithm is designed for three-phase inverter control, so it is necessary to redesign the SVPWM algorithm.

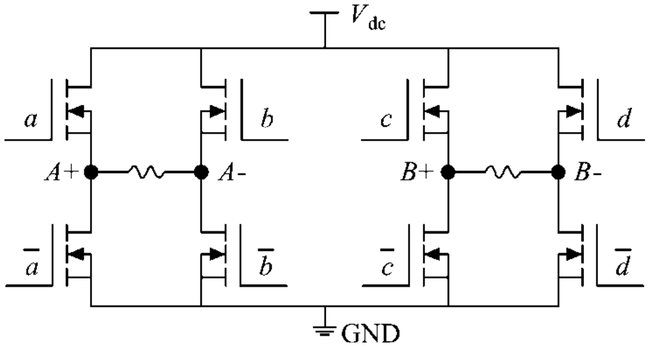


Figure.3. double H bridge inverter structure.

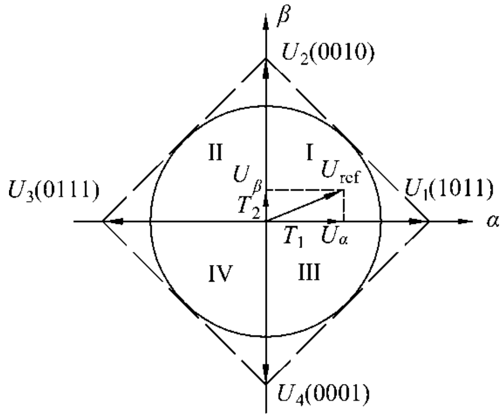


Figure.4. basic voltage vector diagram.

According to the inverter control principle, the upper and lower arms of each half-bridge can't be turned on at the same time, so assuming that the state is "1" when the upper arm is turned on and the lower arm is turned off, otherwise the state is "0". So there are 16 kinds of working conditions, corresponding to 16 kinds of voltage vector. In order to further reduce the motor torque ripple and improve the dynamic performance of the motor, a seven-stage SVPWM algorithm [7] is designed in this paper. Then four effective vectors $U_1(1011)$, $U_2(0010)$, $U_3(0111)$, $U_4(0001)$ and two zero vectors $U_0(0000)$, $U_5(1111)$ are selected as the basic vectors. So the voltage vector circle is divided into 4 sectors and the basic voltage vector diagram is constituted, as shown in Figure 4.

In Figure 4, U_{ref} is the reference voltage vector, synthesized by the basic voltage vector and zero vector of the sector where it is located. Suppose that: if $U_1 > 0$, then A=1, otherwise A=0; if $U_2 > 0$, then B=1, otherwise B=0. if $N = 1 + A + 2B$, the correspondence between the N and the sector can be gotten, as shown in Table.1.

Table 1. The correspondence between N and sectors.

sectors	I	II	III	IV
N	4	3	1	2

It can be concluded from Figure 4 that when U_{ref} is in sector I, there is

$$T_1 = \frac{T_s}{V_{dc}} U_\alpha, T_2 = \frac{T_s}{V_{dc}} U_\beta. \tag{4}$$

In formula (4), T_1 and T_2 are respectively U_{ref} equivalent to the action time on U_1 and U_2, T_s is the period of PWM, V_{dc} is the DC bus voltage of the inverter, U_α and U_β are the projections of U_{ref} on the α-axis and β-axis, respectively. Similarly, the action time of each basic vector in other sectors can be drawn. Assuming that

$$X = \frac{T_s}{V_{dc}} U_\alpha, Y = \frac{T_s}{V_{dc}} U_\beta. \tag{5}$$

So the time of each sector t_0 (t_5), t_1 and t_2 can be gotten, as shown in Table.2.

Table 2. Action time of each sector.

N	1	2	3	4
T_1	$-X$	X	$-X$	X
T_2	$-Y$	$-Y$	Y	Y
$T_0(T_5)$	$T_0(T_5) = (T_s - T_1 - T_2)/2$			

If $T_1 + T_2 > T_s$, over modulation is necessary, so

$$T_1 = \frac{T_1}{T_1+T_2} T_s, T_2 = \frac{T_2}{T_1+T_2} T_s \tag{6}$$

In order to further reduce the motor torque ripple and reduce the switching losses, the order of the basic vector functions need to be assigned. The principle of distribution is selected as follows: when switching state is changing, the number of phases that change the state of the switching should be minimized and the zero vector should be evenly distributed in time so that the generated PWM is symmetrical, which can effectively reduce the switching frequency, switching losses and the harmonic components of PWM. At the same time, it is also easy to achieve software algorithms. The seven-stage SVPWM algorithm switching sequence is shown in Figure 5.

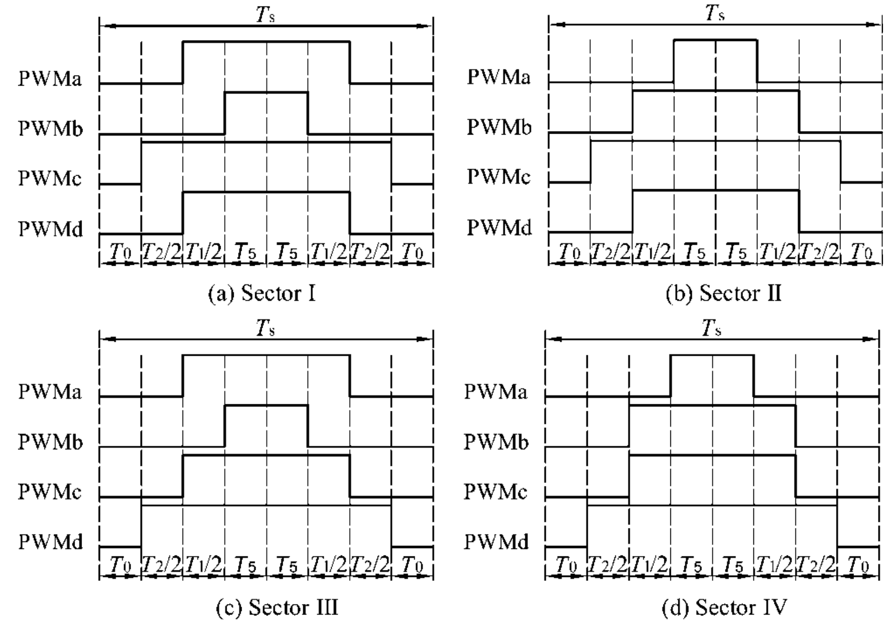
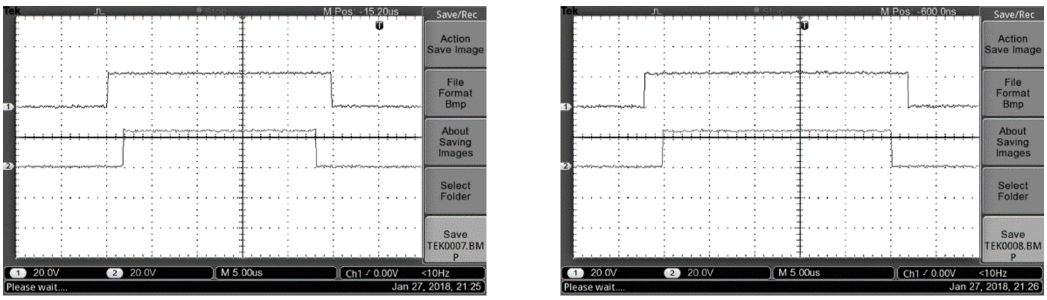


Figure.5. Seven- stage SVPWM algorithm waveform.

4. Experiments and results analysis

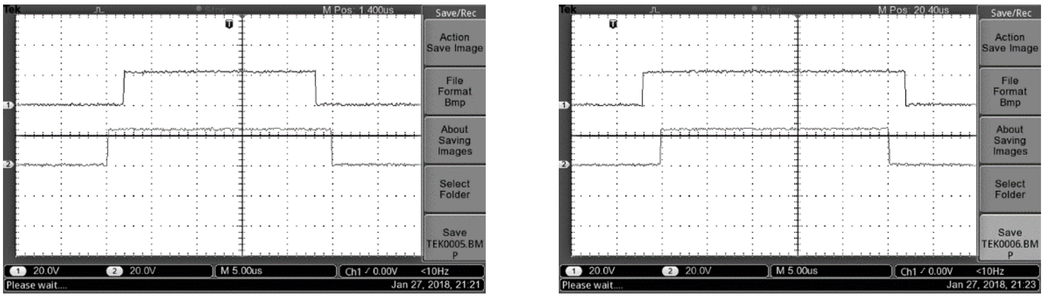
In order to verify the correctness and feasibility of the proposed vector control and SVPWM algorithm of two-phase hybrid stepping motor in theory, a hardware platform is set up. The experimental platform adopts STM32F103RT6 as the master chip, YH42BYGH47 two-phase hybrid stepping motor is selected. The rotor number of the motor is 50, the rated current is 1.5A and the inverter DC bus voltage is set to 24V.



(a)wave of a and b half-bridge (b)wave of c and d half-bridge

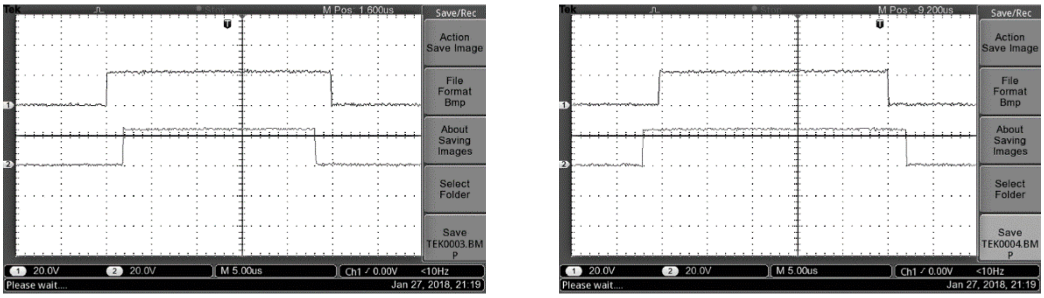
Figure 6. Sector I of SVPWM.

IOP Conf. Series: Materials Science and Engineering **381** (2018) 012140 doi:10.1088/1757-899X/381/1/012140



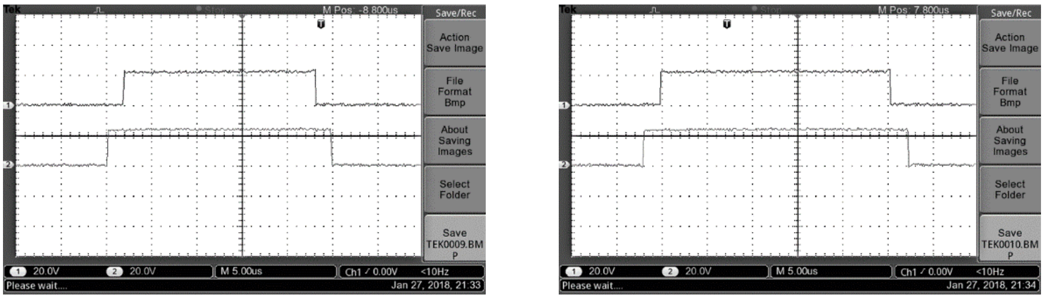
(a)wave of a and b half-bridge (b)wave of c and d half-bridge

Figure 7. Sector II of SVPWM.



(a)wave of a and b half-bridge (b)wave of c and d half-bridge

Figure 8. Sector III of SVPWM.

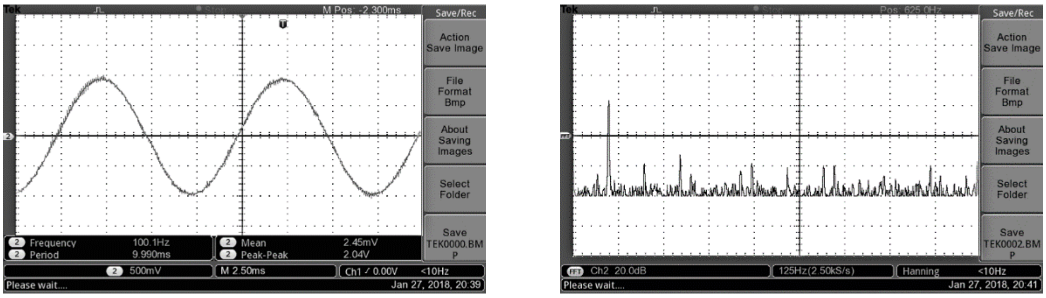


(a)wave of a and b half-bridge (b)wave of c and d half-bridge

Figure 9. Sector IV of SVPWM.

In order to validate the SVPWM module, the PWM output waveforms of the inverter are shown in Figure 6~9 when the reference voltage U_{ref} measured by the current probe and oscilloscope in 4 different sectors respectively. Compared with the SVPWM waveforms designed in Figure 5, it is found that the waveform of each sector is consistent, which proves that the SVPWM algorithm is designed correctly.

In order to analyze the vector control performance of the motor, the reference current i_{qref} is set to 1.0 A, the motor subdivision factor is set to 32, and the sawtooth wave frequency is set to 100 Hz. A current probe with the magnification of 1 A / V is used to detect phase current, and the result is shown in Figure 10.



(a)wave of phase current (b)FFT of phase current

Figure.10. Analysis of phase current.

As can be seen from Fig. 6 (a), the peak-to-peak current of Phase A is 2.04 A and the frequency is 100.1 Hz, which is basically the same as the reference current. It can be seen from Fig. 6 (b) that the amplitude of fundamental wave of phase current is 100Hz by FFT analysis, which is consistent with the actual value. At the same time, there are less harmonic content, which proves the correctness and feasibility of the algorithm.

5. Summary

In this paper, the mathematic model of the two-phase hybrid stepping motor is established first, and then the vector control of the stepping motor is designed. The stepper motor subdivision control is realized by a periodic step-variable ladder sawtooth wave, which improves the control precision of the motor and realizes the control of motor speed by adjusting the sawtooth frequency. Aiming at the double H-bridge topology control of two-phase hybrid stepping motor, a new seven-stage SVPWM algorithm is designed. By choosing zero vectors and generating symmetrical PWMs flexibly, the switching action of each cycle is reduced as much as possible. Thus, the switching losses and current harmonics are reduced effectively, the stability of the motor operation is also improved, corresponding to the control of two-phase hybrid stepping motor has some reference and application value. Which has a certain reference and application value for the control of two-phase hybrid stepping motor.

6. References

[1] ZHU Hua, ZHANG Zhong-Wei, YUAN Zhen. Design of subdivision driver for two-phase hybrid stepping motor based on STM32F103RB. Electronic Design Engineering, 2012, 20 (10), 119-122.
[2] CHENG Shan-Mei, CAI Kai. Torque control scheme of stepping motor based on vector. Electric Drive Automation and Automation, 2007, 29 (6): 14-16.
[3] TANG Jia-Wei. Two-phase hybrid stepping motor torque vector control. Industrial Control Computer. 2016, 29 (2): 61-64.
[4] DONG Na. Research on Two-phase Hybrid Stepping Motor Control System Based on DSP. Xidian University. Xi An, 2014.
[5] XIONG Jing-Jing. Research and Implementation of Three-phase Hybrid Stepping Motor Driver Based on DSP. Wuhan University of Technology, Wu Han, 2014.
[6] SU Yi-Xin, SUN Gong-Wu, NIE Wei. Subdivision drive of stepping motor based on vector control. Small & Special Electrical Machines, 2014, 42 (2), 56-59.
[7] WANG Quan-Wu. Two-phase hybrid stepping motor high-performance closed-loop drives system. Zhejiang Sci-Tech University, Hang Zhou, 2016.
[8] LIU Yuan-Jing, Yang Xiang-Yu, Zhao Shi-Wei. Simulation of Position Tracking Servo System of Two-phase Hybrid Stepping Motor Based on SVPWM Technology, 2014 Annual Meeting of Low Power Motor Exchange, 2014, 31-36.
[9] Reference to a book:
[10] YUAN Lei, HU Bing-Xin, Wei Ke-Yin, etc. Modern permanent magnet synchronous motor control theory and MATLAB simulation, Beijing University of Aeronautics and Astronautics Press, 2016, 4.