

### Programmable Ministep Drive

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**Abstract:** A cylindrical permanent magnet inside the four-phase permanent magnet (PM) stepping motor is employed as the rotor. The stator has four teeth around, which its coils are wound. The mode of excitation can be classified into 3 modes: single-phase excitation, two-phase excitation and ministep excitation. The ministep drive is a method to subdivide one step into several small steps by means of electronics. The paper presents the programmable ministep technique drive. This technique decodes the results obtained from the counter to locate the data in Read Only Memory (ROM). The Sinusoidal Pulse Width Modulation (SPWM) is transformed to binary file and saved to the ROM. The experiment is performed with the four-phase PM stepping motor and drives from a two-phase programmable sinusoidal ministep signal, instead of square wave. The results show that the performances of the proposed programmable ministep technique drive have high efficiency, smooth step motion, and high speed response. Moreover, the resolution of sinusoidal ministep signal can be controlled by the input frequency (f command).

**Keywords:** Ministep, Sinusoidal ministep Drive, Programmable, Stepping Motor, Half Step, Full Step, Sinusoidal Pulse Width Modulation (SPWM)

#### 1. INTRODUCTION

The ministep drive is a method to subdivide one step into many small steps by mean of electronics. The idea of ministep comes from the sinusoidal bipolar drive of a hybrid stepping motor, which is a synchronous motor. The stepping motor is driven from a two phases of the sinusoidal signal, instead of square wave. The rotor motion is stepless and smooth. This paper presents the sinusoidal pulse width modulation (SPWM) ministep technique drive. This technique transforms SPWM signal to the binary file before saving to the ROM. The output data can be classified into 3 categories; three-phase drive, two-phase drive, and step drive. The resulting performances of the proposed programmable ministep technique drive have high efficiency, smooth step motion, and high speed response.

#### 2. PRINCIPLE AND THEORY

A basic four-phase PM stepping motor is shown in the Fig. 1. A cylindrical permanent magnet is employed as the rotor and the stator has four teeth around, which its coils are wound.

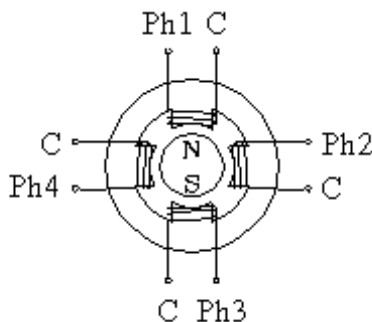


Fig.1 Cross Section model of the four-phase PM (Permanent Magnet) stepping Motor.

**Mode of excitation**  
Single-Phase Excitation

The single-phase excitation mode of four-phase motor uses

the shaded parts in the table 1 to represent the excited state and the white blanks to symbolize the phase which the current is not supplied and not excited. When the motor revolves clockwise in the excitation sequence of Ph1→ Ph2→ Ph3→..., it will revolves counter-clockwise by simply reversing the sequence to Ph3→ Ph2→ Ph1... .

Two-Phase Excitation

The apparently major difference between the single-phase exciting and two-phase exciting occurs during the transient response. The oscillation damps of the two-phase exciting are faster than the single-phase exciting. The step sequences are shown in Table 2.

Table 1. Excitation sequence of the single-phase operation

Sequence	Ph1	Ph2	Ph3	Ph4
1	•			
2		•		
3			•	
4				•
5	•			
6		•		
7			•	
8				•

Table 2. Excitation sequence of the two-phase operation

Sequence	Ph1	Ph2	Ph3	Ph4
1	•	•		
2		•	•	
3			•	•
4	•			•
5	•	•		
6		•	•	
7			•	•
8	•			•

Table 3. Excitation sequence of the half-step operation

Sequence	Ph1	Ph2	Ph3	Ph4
1	•			
2	•	•		
3		•		
4		•	•	
5			•	
6			•	•
7				•
8	•			•

Ministep Drive

Ministep drive or micro step drive is a method to subdivide one natural step into many small steps by mean of electronics. The idea of ministep comes from the sinusoidal bipolar drive of a hybrid stepping motor, which is a synchronous motor. If a hybrid stepping motor is driven from a two-phase sine wave supply, instead of square wave, it is expected that the rotor motion is stepless and very smooth. This is true when using with some motors in a particular condition. However, in many cases, a perfect stepless smooth motion is not realized due to the detecting effect, variable reluctance effect and sub harmonics induce into voltage by the magnet. To subdivide one natural step, the supply current is shaped into a step-wave as in fig. 2.

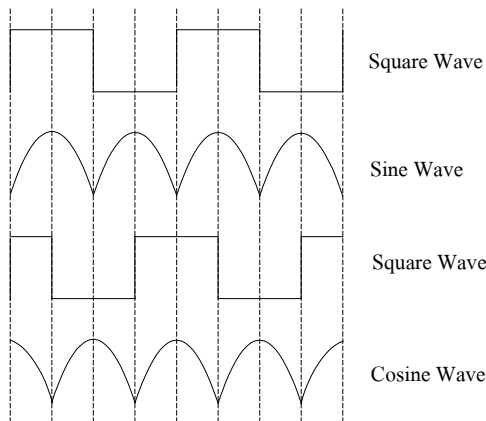


Fig. 2. The sine and cosine signals are used instead of the Square Wave.

3. DESIGN OF THE SYSTEM

3.1 Sinusoidal ministep signal

A period of sinusoidal signal is classified into 64 segments and each segment is modulated with the saw tooth signal. The amplitude of each segment sinusoidal signal is given by

$$v = V_m \sin\left(\frac{2\pi x}{64}\right) \tag{1}$$

where  $x$  is the sequence of segment

The sequences of segments vary between 1 to 64 because this paper uses the 6 bits digital signal. The sinusoidal signal is shown in Fig. 3.

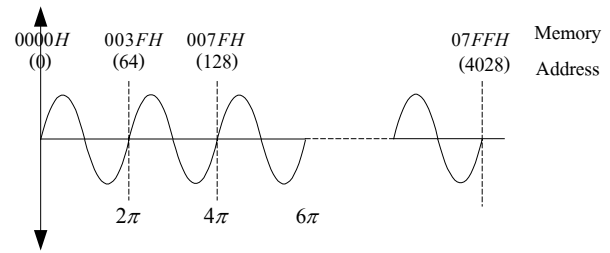


Fig. 3. The 4028 segments of 64 sinusoidal signals.

Since there are 64 periods of sinusoidal signal, the total segments are then equal to 4028 segments. After being modulated with saw tooth signal, the SPWM can be shown in the Fig. 4.

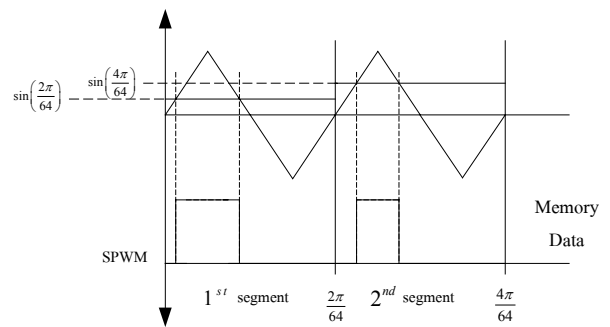


Fig. 4. 1<sup>st</sup> segment and 2<sup>nd</sup> segment of SPWM.

Table 4 Memory map of SPWM data.

Memory Address	Q <sub>0</sub>	Q <sub>1</sub>	Q <sub>2</sub>	Q <sub>3</sub>	Q <sub>4</sub>	Q <sub>5</sub>	Q <sub>6</sub>	Q <sub>7</sub>
0000H	SPWM of R Phase	SPWM of S Phase	SPWM of T Phase	Sine Signal	Cosine Signal	Pulse1	Pulse2	Toggle
0001H								
0002H								
64=2 <sup>6</sup> =003FH								
0040H	SPWM of R Phase	SPWM of S Phase	SPWM of T Phase	Sine Signal	Cosine Signal	Pulse1	Pulse2	Toggle
007FH								
0080H	SPWM of R Phase	SPWM of S Phase	SPWM of T Phase	Sine Signal	Cosine Signal	Pulse1	Pulse2	Toggle
00BFH								
07C0H	SPWM of R Phase	SPWM of S Phase	SPWM of T Phase	Sine Signal	Cosine Signal	Pulse1	Pulse2	Toggle
07FFH	SPWM of R Phase	SPWM of S Phase	SPWM of T Phase	Sine Signal	Cosine Signal	Pulse1	Pulse2	Toggle

The modulation signal is first transformed to binary file and then programmed to the ROM memory, which can be shown the table 4. The output signal is a digital signal and its frequency is controlled by the counter2. The output signals consist of 3 groups of signal: Three-Phase Drive, Two-Phase Drive and Step Drive

Three -Phase Drive

The output signals  $Q_0, Q_1$  and  $Q_2$  are designed for three-phase drive where

- $Q_0$  is a SPWM of R phase
- $Q_1$  is a SPWM of S phase
- $Q_2$  is a SPWM of T phase

Two-Phase Drive

The output signals  $Q_3$  and  $Q_4$  are designed for two-phase drive where

- $Q_3$  is a SPWM of Sine Signal
- $Q_4$  is a SPWM of Cosine Signal

Step Drive

The output signals  $Q_5, Q_6$  and  $Q_7$  are designed for step drive where

- $Q_5$  is an output signal of Pulse1
- $Q_6$  is an output signal of Pulse2
- $Q_7$  is an output signal of Toggle Pulse

3.2 Driver System

The Driver system consists of counter1, counter2 and ROM. The block diagram of the driver system can be shown in Fig. 5.

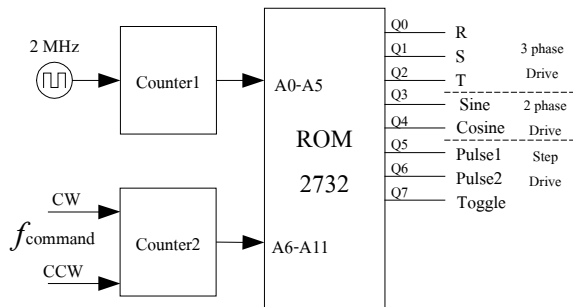


Fig. 5. Block Diagram of Driver System.

Counter1 is connected to pins  $A_0$  to  $A_5$  to decode the SPWM data while counter2 is connected to pin  $A_6$  to  $A_{11}$  to control the frequency of SPWM signal. The driver circuit is a hybrid as shown in Fig. 6.

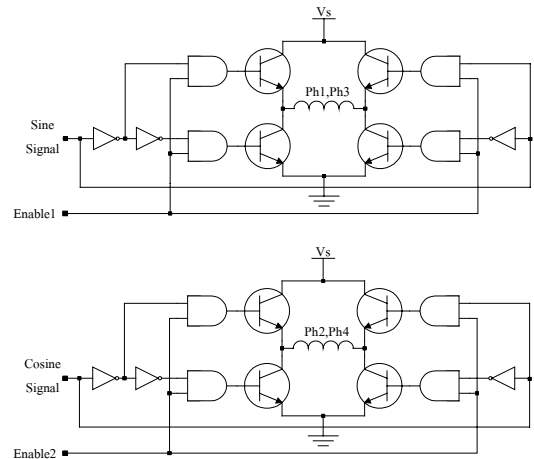


Fig. 6 The driver circuit

The driver circuits are connected to the four-phase PM stepping and driven by two-phase drive. The Ph1 and Ph3 are connected in parallel and driven by sine signal. The Ph2 and Ph4 are connected in parallel and driven by cosine signal.

4. THE EXPERIMENTAL RESULTS

The experimental results show the SPWM signal of ROM and speed response of the stepping motor.

4.1 SPWM signal

The SPWM signals of the ROM consist of 3 groups of signal: Three-Phase Drive, Two-Phase Drive and Step Drive, which can be shown in the Fig. 7, Fig.8 , and Fig.9 respectively.

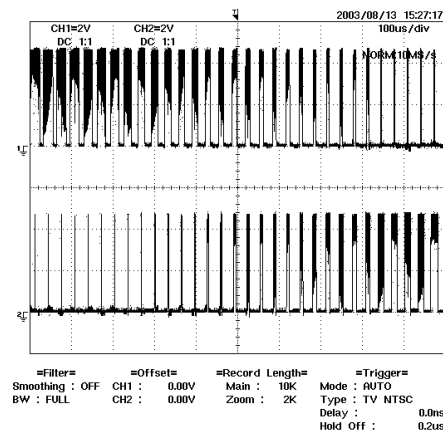


Fig. 7 The SPWM signal of R phase and S phase.

The SPWM signals of R phase are 120 electrical degree out of phase compared with S phase. The duty cycle and the frequency of signal depend on the counter1 and counter2, respectively.

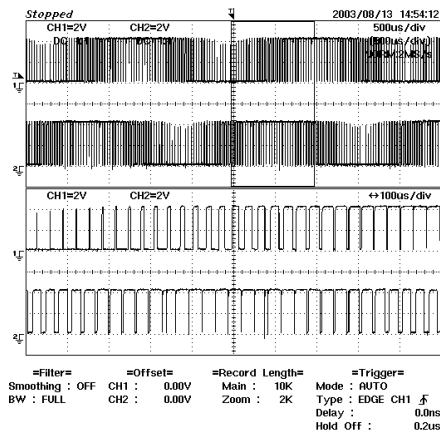


Fig. 8 (a) before feeding to RC circuit

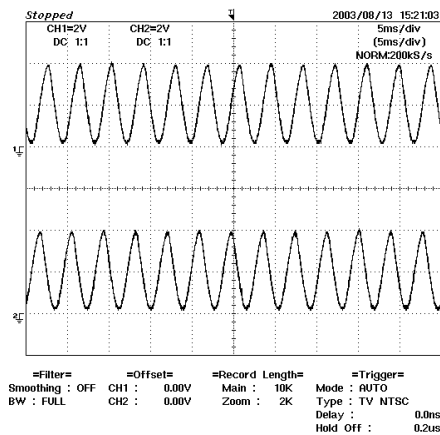


Fig. 8 (b) after feeding to RC circuit

Fig. 8. The sine and cosine SPWM signals for Two-phase drive

The Fig. 8 shows sine and cosine SPWM signals for Two-phase. From Figure 8(a), SPWM signals are sine, cosine, and their expansion, respectively.

Figure 8(b) represents the sine and cosine SPWM signals after feeding to RC circuit. The waveform can be shown as the sinusoidal signal. The frequency of sinusoidal signal depends on the f command.

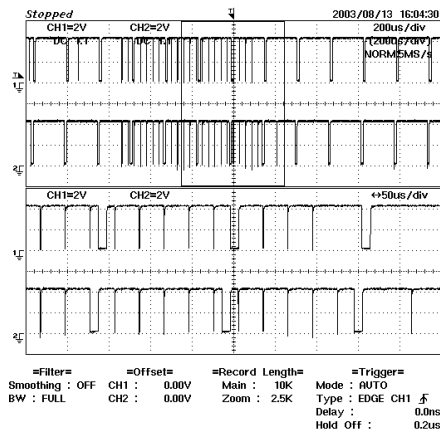


Fig. 10 The Pulse1 and Pulse2 signals

The pulse1 and pulse2 are designed to step drive. The pulse1 is 90 electrical degree out of phase compared with pulse2. The signal frequency is varied in case of counter2.

#### 4.2 Speed Response

The speed response is performed on the stepping motor with the resolution of 200 step per revolution. The sine and cosine signals are fed to the driver. The experiment is performed to vary frequency of f command. The response in Fig. 11 shows that the speed of the stepping motor depends on the frequency of f command.

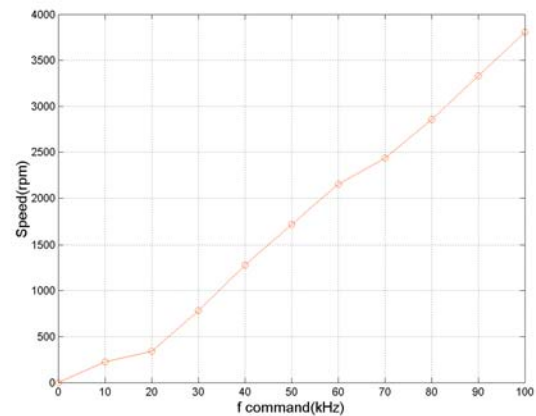


Fig. 11 Speed response of stepping motor

### 5. CONCLUSION

The programmable ministep drive is a technique to transform SPWM signal to the binary file before saving to the ROM. The data output of ROM is programmed to many patterns: Three-phase drive, Two-phase drive and Step drive. The frequency of f command can be varied the SPWM signal and control the speed of stepping motor. The experimental results of this technique show the improvement of the speed response and the smoothness of the step motion.

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