The Vector Control Research and Implementation of The Three-phase Hybrid Stepping Motor

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Abstract—This design using the vector control algorithm (SVPWM) to subdivide the three-phase stepper motor stator current, to reduce the step angle, to reduce low-frequency oscillations and noise of the stepper motor, to reduce the torque pulsation of the motor, and to improve the voltage utilization. The control algorithm is feasible by matlab simulation.

Keywords-three-phase hybrid stepper motors; SVPWM; current subdivision

I. INTRODUCTION

With the development of microprocessor technology and control algorithm, aiming at the phenomenon that the stepper motor is prone to oscillation in the low speed operation, a set of three-phase hybrid stepper motor drive system with DSP as the controller of the whole digital control was designed. The processor uses the digital signal processor TMS320F2812 of TI company, it’s main frequency can up to 150MHz, and it’s operation speed is very fast, it’s storage capacity is large, it can implement the complex control algorithm. Using pulse subdivision drive can realized the subdivision of stepper motor and reached the subdivision of the step angle, to reduce low-frequency oscillations and suppress noise. In view of the similarity between the SVPWM control algorithm and the pulse subdivision drive, the design uses SVPWM control algorithm to realize the subdivision of stator current of stepper motor, and make it approximate sine.

II. CONTROL PRINCIPLE OF THE SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)

The three-phase voltage type inverter circuit, at any time, just has only three switches turned on, and the same bridge arm of the upper and lower switch can’t be conducting at the same time. In turn, there are eight kinds of combination modes of the switch mode. Each set of patterns, corresponding to a voltage space vector. First assume that the upper bridge arm conducting and the lower bridge arm cut-off for state 1, the upper bridge arm cut-off and lower bridge arm conducting for state 0, so the inverter circuit of 8 kinds of combination modes are: 000 (V8), 001 (V5), 010 (V3) and 011 (V4), 100 (V1), 101 (V6), 110 (V2), 111 (V7). The motion trajectory of the 8 vectors in the form of the alpha and beta axes is shown in Figure 1.

SVPWM control want the flux linkage space vector vertex trajectory to be circular, it need control the voltage vector (or current vector) of the vertex trajectory be circular. However, the voltage vector is only 8, how to synthesis other voltage vector which amplitude is Udc and phase angle is any angle between 0 ~ 2\pi ? According to the principle of vector synthesis, the linear combination of the basic voltage space vector can be used to realize this. Assumed that to be synthesized vector is Us, and it falls on the first sector, synthesized by U1 and U2 two vector synthesis, and the angle with U1 is beta, commutation cycle is T, in a phase change cycle T, part time T1 in the work of the state U1, another part time T2 in U2 working state, the voltage space vector linear combination of vector diagram as shown in figure 2.
According to the principle of flux linkage, the satisfaction of the relationship is:

\[
U_s T = U_1 T_1 + U_2 T_2 = U_{dc} T_1 + U_{dc} e^{j\pi/2} T_2
\]

\[
= U_d [\left(\frac{T_1}{T} + \frac{T_2}{2T}\right) + j\frac{\sqrt{3}T_2}{2T}] 
\]

(1)

There decompose Us along the alpha beta coordinate system decomposition can get:

\[
U_s = U_d + jU_{\beta} = |U_s| \cos \beta + j |U_s| \sin \beta 
\]

(2)

Simultaneous (1), (2), according to the principle of equal real part and imaginary part respectively, we can get:

\[
\begin{align*}
T_1 &= \left(\frac{|U_s| \cos \beta}{U_{dc}} - \frac{|U_s| \sin \beta}{\sqrt{3}U_{dc}}\right) T \\
T_2 &= 2 \frac{|U_s| \sin \beta}{\sqrt{3}U_{dc}} T
\end{align*}
\]

(3)

Among them, the sum of T1 and T2 is less than T, in order to reduce the switching frequency of the power devices, reduce switching losses. The rest of the time by the two zero vector V7 and V8 each accounted for half, that is: T7=T8=1/2(T-T1-T2), and the switch tube conduction is also required in order. If adopt the way of seven-segment, in a switching cycle, the three-phase inverter switching sequence is: 000 (duration of T8/2), 100 (T1/2), 110 (T2/2), 111 (T7/2), 110 (T2/2), 100 (T1/2) and 000 (T8/2). This can meet the requirements of each phase change, only need to switch a switch, can greatly reducing the switching loss.

III. IMPLEMENTATION OF SVPWM CONTROL ALGORITHM

Because the traditional SVPWM control algorithm to determine the vector in which sector is more complex, the amount of computation is relatively large, so we use the improved SVPWM algorithm. This method is much more than the traditional method of a transformation from the alpha beta coordinate system to the GH coordinate system. Can be found through observation, every sector of SVPWM is 60 degrees, so in gh coordinates (gh coordinates is 60 DEG coordinates, and alpha beta coordinate system is the vertical coordinate system - 90 degree coordinate system), all are integers, therefore the calculation of the sector is more convenient. The control algorithm steps are as follows:

(1) Make the transformation from dq to alpha beta coordinate: To limit the vector length, limit

\[
U_r = \sqrt{U_{rd}^2 + U_{rq}^2} \quad \text{to (inscribed circle radius)} \quad \frac{U_{dc}}{\sqrt{3}}. \quad \text{Which Udc represents the DC side power supply voltage. And then carry out the transformation of dq to alpha beta, The relationship between the dq axis and the alpha beta axis in the ABC coordinate system is shown in figure 3, The starting position of the space vector in the figure refers to the amount of ABC coordinate system, which has a sinusoidal form.}
\]

(2) Make the transformation from alpha beta to gh coordinate: The definition of the basic vector of the two coordinate system is shown in figure 4.
The transformation matrix of alpha beta to gh coordinate transformation is:

\[
\begin{pmatrix}
u_{ar} \\ v_{br}
\end{pmatrix} = \begin{pmatrix}
1 & -\frac{1}{\sqrt{3}} \\ 0 & \frac{2}{\sqrt{3}}
\end{pmatrix} \begin{pmatrix}
u_{ar} \\ v_{br}
\end{pmatrix} = \begin{pmatrix}
1 & -\frac{2}{3} & -\frac{1}{3} \\ 0 & \frac{2}{3} & -\frac{1}{3}
\end{pmatrix} \begin{pmatrix}
u_{ar} \\ v_{br}
\end{pmatrix}
\]

(4)

\[
= \frac{2}{3} \begin{pmatrix}
1 & -1 & 0 \\ 0 & 1 & -1
\end{pmatrix} \begin{pmatrix}
S_{rg} \\ S_{rh}
\end{pmatrix}
\]

Among them, Srx=0, 1 (when the upper bridge arm conducting and the lower bridge arm cut-off for state 1, the upper bridge arm cut-off and lower bridge arm conducting for state 0), Thus, the vector length in the gh coordinate system is 2Udc/3.

(3) Divide sector: \( (u_{2rg}, u_{2rh}) \) is the value of the reference space vector in the gh coordinate system for the corresponding two level. And then determine the sector in the two level, Determine the phase transition time.

IV. THE SIMULATION AND VERIFICATION

This simulation uses the SIMULINK MATLAB simulation module. Because of the SIMULINK simulation library, there are a wealth of circuit components models, mathematical functions and transfer functions and other modules, and is widely used in the field of power electronics and motor control areas. The simulation block diagram of the vector control system of the three-phase hybrid stepper motor includes 3S/2S transformation module, 2S/2R module, PI controller, the core of the SVPWM algorithm module, the inverter bridge module and the motor module. The block diagram of the system is shown in figure 5.

The simulation model of the system is simulated to test the effect of this control scheme. When the fine fraction is different, the control effect of the stepper motor is greatly different. When the fine fraction is 50, the step angle is 0.024 degrees; when the fine fraction is 1000, the step angle is 0.0012 degrees. The stepper motor three-phase stator current wave line is shown in figure 6 when the fine fraction is 50 and figure 7 when the fine fraction is 1000.
Can be seen from the figure 6 and figure 7: when the fine fraction is 50, the waveform of the output current is very significant, when the fine fraction constantly increases, the waveform will become more and more smooth, when the fine fraction is 1000, the three phase stator current waveform is very close to the sine wave.

It is showed that the effect of stepper motor current can be achieved by using this vector control scheme.

CONCLUSION

After referring to the related data, this paper designs a set of three-phase hybrid stepping motor driver based on TMS320F2812. Uses the SVPWM control algorithm to step into the motor stator current subdivision, when the fine fraction is large enough, stator current waveform nearly sinusoidal, To realize the segmentation of step angle, weaken the low-frequency oscillation and noise of stepper motor, to improve the voltage utilization.

REFERENCES
