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Microstepping Bipolar Drive of Two-Phase Hybrid Stepping Motor on TMS320F2808 DSP

1. INTRODUCTION

Hybrid stepping motors are used in a wide variety of position controlled equipments such as plotters, CNCs, printers, robots, etc. because it can be easily operated in the open-loop fashion [1]. Full or half step switching scheme is normally selected if low-cost and low-precision requirements are wanted. In high precision applications, the microstepping scheme is however necessary to allow motor be rotated in a fraction of its full step angle. Two main advantages of this scheme have been well reported in literatures such as reduction of resonance behaviour [2],[4] and smooth movement with very low ripple torque [3]. In this note, the microstepping scheme with configurable fractional step is thus motivated to be implemented digitally using a fixed-point TMS320F2808 DSP from Texas Instruments, Inc. The discrete angle for discretized sinusoidal voltage commands is generated by ZOH module. The motor currents are controlled by using unipolar PWM technique. This implementing system is aimed for high-precision applications. Dual H-bridge circuit is primarily used to drive a two- phase hybrid stepping motor as shown in Fig. 1. Each phase winding is connected to each H-bridge circuit, thus four switching devices are independently controlled the proper voltage for each phase winding. The main advantage of this circuit topology is to allow the independent generation of bipolar voltage between two phases. In low-cost, low-precision applications, the conventional full or half step scheme is selected to implement without PWM technique. Then, the voltages applied to motor cannot be adjusted and the motor currents are eventually over the motor's rating at low speeds. Thus, the current control should always be included in the implementation.

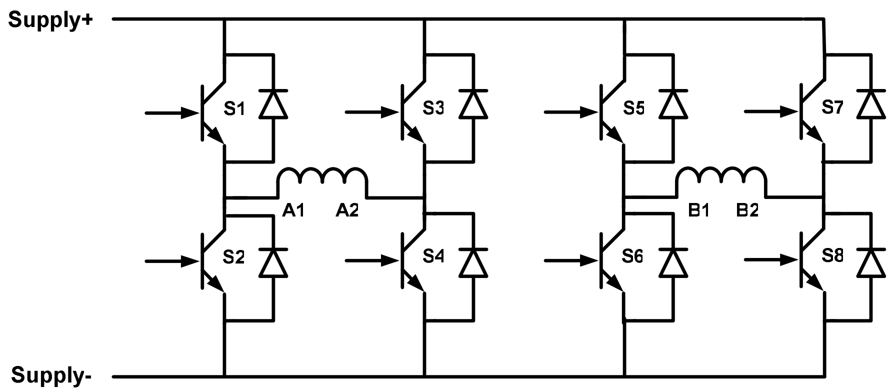

Fig.1 Dual H-bridge circuit connecting to a two-phase hybrid stepping motor

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2. MICROSTEPPING SCHEME WITH CURRENT CONTROLLED

Fig.2 shows the overall system of microstepping bipolar drive using TMS320F2808 DSP. Bipolar drive is well known its advantage of increased torque capability by 20%-30%, comparing with unipolar drive [4]. Notice that the reference variables are defined with a superscript * in this figure. In the system, the peak of two-phase motor currents is controlled by a PI controller. The output of this PI is the peak command voltage (v_p^*). The feedback of peak current is simply calculated from the measured phase–a and –b currents by the following:

$$i_p = \sqrt{i_a^2 + i_b^2} \qquad (1)$$

The continuous angle (θ_{con}) is discretized to be the discrete angle (θ_{disc}) by ZOH block. The number of fractional steps can be easily adjusted by this block. Then, this θ_{disc} will be used to compute the discreate sinusoidal command voltages with the peak determined by PI output expressed as follows:

$$v_a^* = v_p^* \cos\theta_{disc} \qquad (2)$$

$$v_b^* = v_p^* \sin\theta_{disc} \qquad (3)$$

Once the command voltages (2) and (3) are computed, then the duty cycle of each switching device in the dual H-bridge is determined by using unipolar PWM technique. Based on this technique, the command voltages are compared with a triangle signal (v_{tri}) with a fixed switching frequency and the rules of four switching device for phase-a are determined as follows:

$$\begin{aligned} &\text{when} \quad v_a^* > v_{tri}, \quad \text{S1 on and S2 off} \\ &\qquad \text{Otherwise, S1 off and S2 on} \\ &\text{when} \quad -v_a^* > v_{tri}, \quad \text{S3 on and S4 off} \\ &\qquad \text{Otherwise, S3 off and S4 on} \end{aligned} \qquad (4)$$

Similarly, the same rules are applied for other four switching devices (S5-S8) for phase-b winding, using phase-b command voltage (v_b^*). The main advantage of unipolar PWM technique is the reduction of ripple currents due to output voltages of double switching frequency.

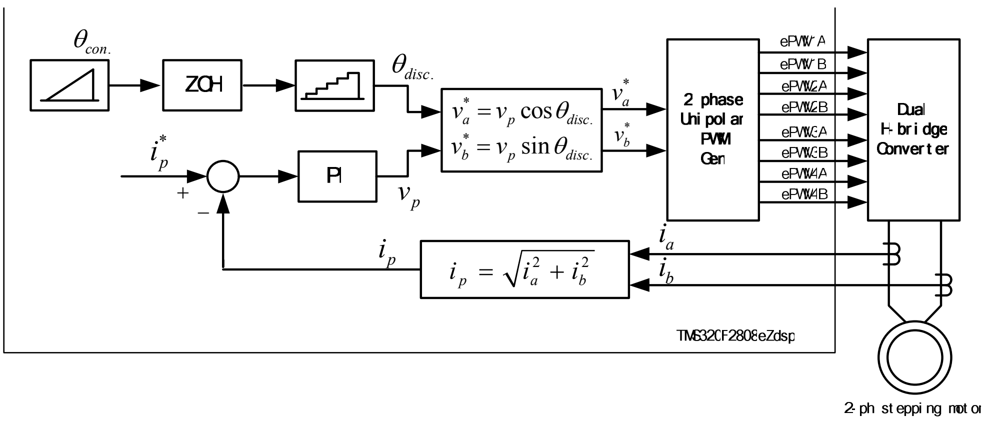

Fig.2 Overall system using DSP

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3. EXPERIMENTAL RESULTS

The overall system shown in Fig. 2 is implemented on a fixed-point TMS320F2808 DSP based controller with 100MHz system clock [5]. A photograph of overall hardware setup is shown in Fig. 3. In this system, the switching frequency (or triangle signal frequency) is set at 10 kHz. This frequency is also the frequency of interrupt service routine (ISR) where overall algorithms are executed. Two measured currents are also sampled with this frequency and then converted to digital format using 12-bit ADC unit of DSP. The DSP controller is configured to generate the 1-μsec dead time for upper and lower switching devices to avoid short through or cross conduction on current through these two switches. The two-phase stepping motor is rated 3A and 1.8^{o} step angle. The Code Composer Studio (CCS) V3.1 is used as DSP development tool and it is capable to plot the graphs of any variables in the codes during run-time [6]. Fig. 4 shows a screen capture of CCS with graphs. Thus, some experimental results in this note are conveniently obtained from CCS graphs.

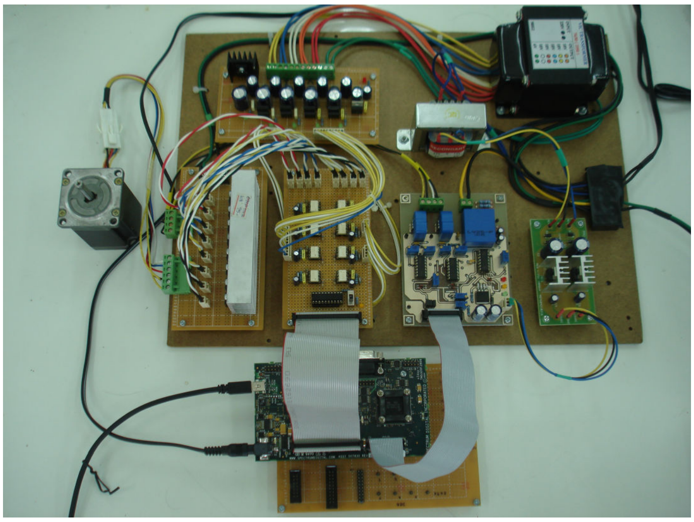

Fig.3 Overall hardware setup

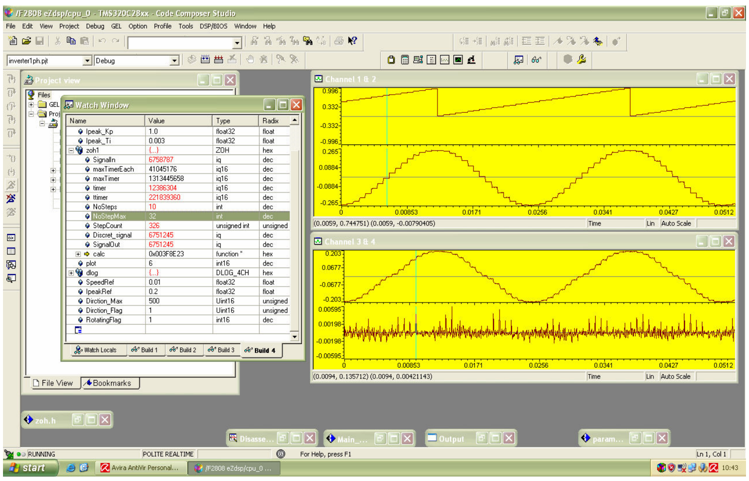

Fig 4. CCS screen capture with graphs during run-time

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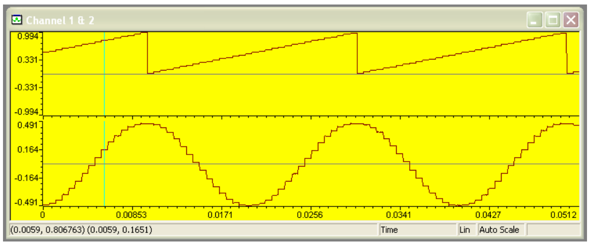
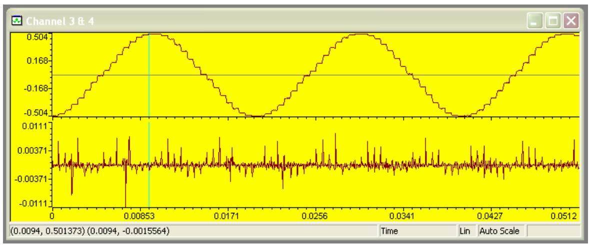
Figs 5 through 7 show the captured CCS graphs of discrete angle, reference current, feedback current, and current error when the step precision is configured by ZOH block for precision = 1/8, 1/16, and 1/100 step, respectively. As seen from these figures, the current is successfully controlled with a peak of 0.5 per-unit (base current of 2A) regardless of the step precision. The current errors in Figs. 7(b), 8(b), and 9(b) are shown to validate the successful implementation of current control. As the fractional step reduced, the current waveforms become less and less discretized and eventually sinusoidal. When the currents are sinusoidal waveforms, then the smooth rotation of stepping motor is obtained with small ripple torque. This is a necessary requirement in high precision applications.

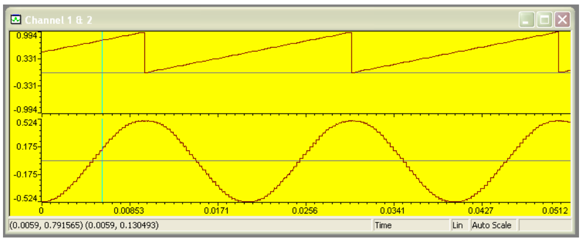


(a) discrete angle and reference current

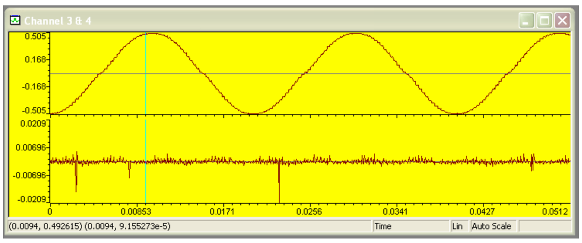


(b) feedback current and current error

Fig. 5 Responses for precision =1/8 step.



(a) discrete angle and reference current



(b) feedback current and current error

Fig.6 Responses for precision = 1/16 step.

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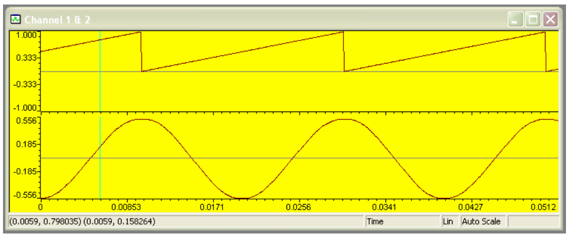
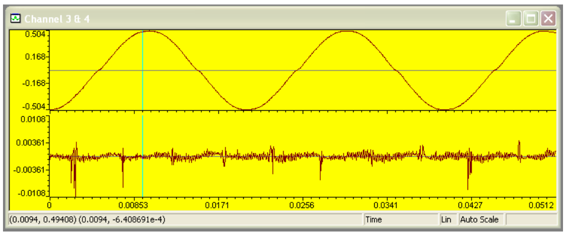


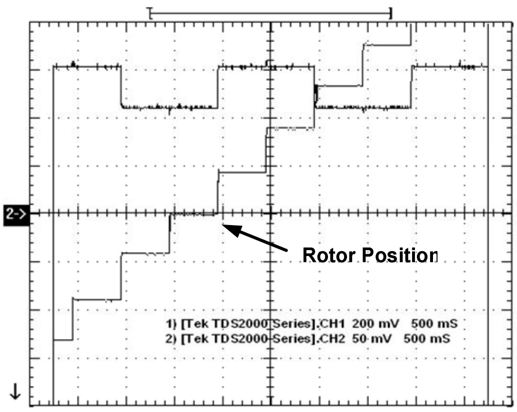
(a) discrete angle and reference current



(b) feedback current and current error

Fig. 7 Responses for precision = 1/100 step.

In Fig. 8, the phase-a current and rotor position of stepping motor are shown for (a) full step, (b) 1/8 step, and (c) 1/100 step. The experiments are tested under the same peak current controlled and same stepping rate. As seen in this figure, the peak of current is always constant for three different step precisions because of successful current control. However, the movement of rotor is extremely smooth for precision = 1/100 step, comparing with full step of 1.8^{o} (Fig. 10(a)) and 1/8 step (Fig 10(b)) precisions.



(a) full step

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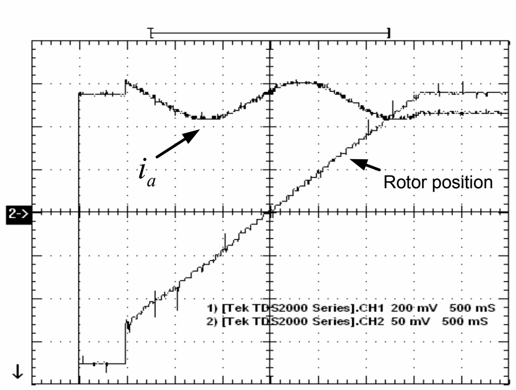
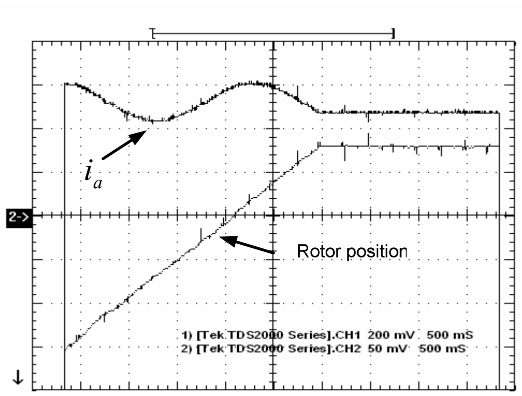


(b) 1/8 step



(c) 1/100 step

Fig. 8 Phase current and rotor position responses for different precisions

4. CONCLUSION

Microstepping is a drive technique of stepping motor that allows the smooth movement of rotor in a fraction of motor’s full step angle. It is necessary in high precision applications. This note presents a digital implementation of microstepping bipolar drive system with the current controlled on a practical fixed-point TMS320F2808 DSP. The dual H-bridge converter is designed to drive the two-phase stepping motor. The fractional step can be easily configurable by ZOH block, creating the discrete angle. Then, this angle is used to calculate the discreatized sinusoidal voltage commands. Based on experimental results, the implementation of proposed system is accomplished. The rotor position is very smoothly moved for precision = 1/100 step while motor currents are successfully controlled at different stepping rates.

5. REFERENCES

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