Microstepping Drives Approaches to Improve Machine Carriage/Conveyor Movement

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Abstract- **Due to the microstepping advantages, the research and development has been done to provide better technique and signal processing for microstepping drives for each type of stepper motor. This article will discuss on experiment on two techniques to provide microstepping for bipolar stepper motor. The study is focused on controlling microstepping using two methods; "ON","OFF" delay control signal (ODC) and "ON","OFF" with pulse width modulation control (OPWMC) signal. The purpose of the study is to improve the movement of the conveyor or carriage part of a machine which is driven by a bipolar stepper motor. The experiment is done on the carriage movement control with two type of driving style; direct winding control (DWC) and conductive control (CC). The performance is referred from the distance movement (axis) of the carriage machine (left-right/right-left). The results are show that the DWC with OPWMC technique give more precise movement from CC with ODC and DWC without OPWMC technique to correct the distance movement error and reducing the resonance occurred during stepper motor drives.**

Keywords: PWM fraction, Microstepping, Stepper Motor Control

I. Introduction

Several approaches and techniques have been done to control the stepper motor which has capability to move one step at a time, unlike conventional motors, which spin continuously. Most of works were done to control per-steps of stepper motor due to the setting point. Furthermore resonance problem is a major issue that needs to be reduced during the stepper motor driving. Therefore half wave stepping and microstepping (fraction of full wave stepping) has been introduced to solve that problem. Microstepping technique provides smooth movement at low speed, increasing stepping resolution and increasing torque at both low and high step-rates instead of decreasing resonance effect.

The main advantage of microstepping is giving the precise control of rotor stepping which contributes to the precise length of step for the motor shaft. Therefore this study takes the advantage of applying the microstepping technique with some approaches to solve the problem on the carriage or conveyor movement on the 2-axis mini plotting machine. Bipolar stepper motor is attached on the carriage part of the machine which is the important part of the machine on controlling x-axis part. Each step of shaft movement will give some effect the motion of x-axis of the machine to desire length (mm). In this study no encoder or sensor is used to correct the movement of x-axis of the machine. The distance movement of x-axis is measure by using the outer length measurer or ruler which is attached a long the arm of x-axis.

II. Microstepping Control

[1] A microstepping technique or also known as high torque microstepping alternately varied the current in to two windings of a stepping motor. This technique is implemented when one winding is powered while the current in the other winding is gradually dropped to zero, reversed and then ramped up again. Thus the sequence is repeated for other winding. Therefore this "ON"/"OFF" signal provides sinusoidal signal. As mentioned in the previous section, current control is important on controlling stepper motor in order to decrease the resonance effect. This current control will referred on how smoother stepper motor can be driven. In order to control the 'smoother motion', microstepping control technique is used. [2] When this control is applied the windings are energised with sinusoidal currents and increasing the step resolution. In addition this control technique improves the torque compensation, reduces the oscillations and resonance frequency or also namely subharmonic.

Therefore this study did some experiment on both regular stepping control and microstepping control to improve the performance of machine carriage arm movement which is driven using bipolar stepper motor. In addition those techniques have been modified due to the application requirement. As a result two technique has been created and implemented namely "ON","OFF" delay control signal (ODC) and "ON","OFF" with pulse width modulation control (OPWMC) signal. The main result for those techniques is to determine the distance of carriage due to the input from user or embedded system.

ODC technique is based on regular stepping control; full step control and half step control. This technique depends on the number steps of revolution (N_O) and its delay (T_O). N_O is depended on the manufactured motor step angle (Θ_M) (1). T_O is depend on the N_O value and the maximum speed of the motor in rotation per-minute (rpm). T_O will affect the speed of step revolution which is proportional to the degree steps of the stepper motor.

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$$N_o = \frac{360}{\theta_M} \quad (1)$$

$$T_o = \frac{60}{rpmN_o} \quad (2)$$

In order to deal with the carriage arm movement, 3 is used which is consider the circulation of gear (l_G) and desired distance, (d).

$$N_o = \frac{360d}{\theta_M l_G} \quad (3)$$

On the controller part, dual full bridge driver circuit are used to control each winding of bipolar stepper motor in the carriage arm of the machine (Fig. 2). Each winding will be given a clock wise (CW) signal, counter-clock wise (CCW) signal or shutdown signal by ignoring the tap/command signal, depends on the mode that needs to be controlled. The method of control allows to controls any two phase stepper motor with the same way.

It is slightly different on OPWMC implementation. This technique is due to the "microstepping" concept which is modulated the pulse width modulation (PWM) and ODC signal in the half wave drive mode. This technique allows ODC technique to be "double" PWM control which is contributed to the smoother motion control. This technique is used to correct some error on the open loop control of distance movement (machine's carriage or conveyor). Furthermore this technique is depended on the bit resolutions or PWM resolution provided by the electronic circuit hardware or embedded system.

Due to this study, the machine is control by the controller set that has been designed using 8-bit microcontroller unit (MCU) and dual full bridge driver. The MCU provided two PWM pins with 8 bits resolution. In order to determine the value of duty cycle (D) in decimal, the N_O , step number (N_S) value and the bits resolution (B_R) of embedded system is needed. The value of duty cycle (D) can be determined by using (4).

$$D = \left(\cos\left(\frac{N_S \pi}{N_o + 1} \right) \right) \left((2 \wedge B_R) - 1 \right) \quad (4)$$

From (4), it shows that each N_S has a specific value of PWM duty cycle. If compares to the ODC approaches, each step number is due to the maximum speed of stepper motor or 100% of duty cycle. With OPWMC approaches each step number has specific value of D. The number of microsteps typically ranges from 4 to 32 microsteps per rated step size. It is depends on how much the B_R can be provided by the embedded system that has been used.

III. Stepper Motor Controller

For this machine, the PIC16F series microcontroller unit (MCU) is used as a core processor for the overall system. This MCU provides 8-bit PWM resolution with independent pins namely Enhanced Capture/Compare (ECCP) module. This module provides up to 8 bits PWM resolutions (0-255).

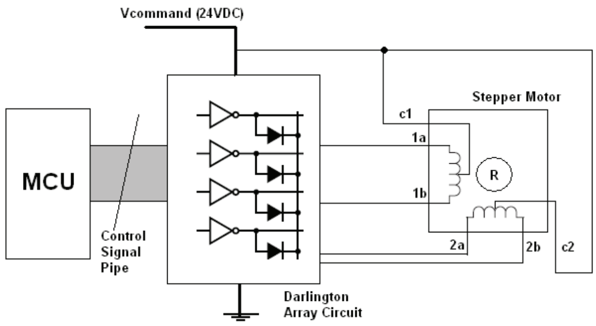

Fig.1 Stepper Motor Control with CC Method

For this machine two methods have been in the matter of experimental and research; direct winding control (DWC) and conductive control (CC). In first approaches, CC method has been used using Darlington array circuit driver which use tap wire in the stepper motor as a command (Fig. 1). The MCU on machine will control the Darlington circuit to release or unreleased the current flow through each winding of bipolar stepper motor. The basic control for full wave stepping mode using CC is show in Table 1.

TABLE I
EXAMPLE OF WINDING CONTROL USING CC APPROACHES (FULL WAVE STEPPING)

Winding 1		Winding 2	
1a	1b	2a	2b
HIGH	LOW	HIGH	LOW
LOW	HIGH	HIGH	LOW
LOW	HIGH	LOW	HIGH
HIGH	LOW	LOW	HIGH

This method is quit difficult to implement the OPWMC since the PWM needs to be modulated with the ODC signalling method on each winding. Therefore, DWC method has been used to make sure that OPWMC can be implemented to the machine's carriage control. This method will ignore all the tap or command wire on the stepper motor which is emphasised on controlling each winding in the bipolar motor (Fig. 2).

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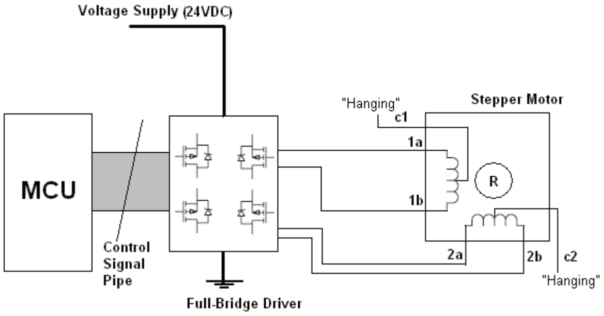

Fig. 2 Stepper Motor Control with DWC Method

DWC allows to control stepper motor direct through the winding without using the tap or command wire. In fact by using this approach, the control method is not same as CC method. Table 2 shows the method of control using DWC approaches to provide full wave stepping and half wave stepping.

TABLE II
EXAMPLE OF WINDING CONTROL USING DWC APPROACHES (FULL WAVE STEPPING)

Winding 1		Winding 2	
1a	1b	2a	2b
1a→ 1b		OFF	
OFF		2a→ 2b	
1a←1b		OFF	
OFF		2a←2b	

Besides that, this method is more efficient than CC and easy to design for high current capacity. In this project, the 10A, 600V Metal Oxide Field Effect Transistor (MOSFET) has been used as gates for current flow control in each bridge stages.

IV. PERFORMANCE & ANALYSES

In this project, several experiments have been done to evaluate the performance of the machine carriage or conveyor movement to compare each approaches and the effect of microstepping to the carriage movement. The experiment is not only considered the mechanical part but also electrical part.

Four experiments were done; movement with CC approach (M1), movement with DWC approach (M2), movement with DWC-OPWM 16 microsteps approach (M3) and movement with DWC-OPWM 32 microsteps approach (M4). All movement were driven under the full wave stepping mode. Fig. 4 shows the example of PWM for carriage of the machine with M3 and M4 driven. M3 and M4 was drive with Winding 1 of Stepper Motor with 100% duty cycle and Winding 2 of Stepper Motor with varied duty cycle followed (4). As seen in Figure 3, each 'ON/OFF' signal at Winding 2 is modulated with varied PWM signal.

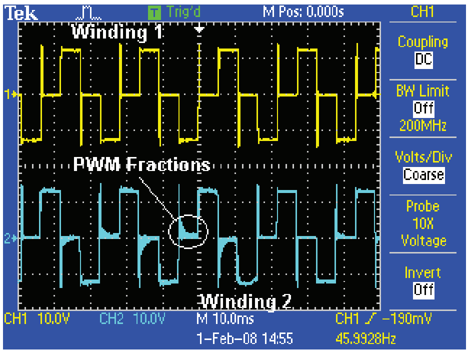

Fig.3 Example of Signal at each Winding for M3

As shown in Fig. 4, M2 and M3 show good performance which is same as a set point respectively. However M1 and M4 perform poor results error occurred on some carriage steps. About 0.8% error on first step of carriage for M1 has contributed to the other error on the next steps. It can be seen on the step 8 and 9 for M1. It is different to M4 which the error is major than M1. Even though M4 is done with microsteps approach, high jerky on shaft contributes to the step error on the carriage movement. On first step of M4, carriage of the machine has out of line setting about 4% makes other step experienced some error such 2.2% and 3.8% for step 3 and step 8 of carriage step respectively.

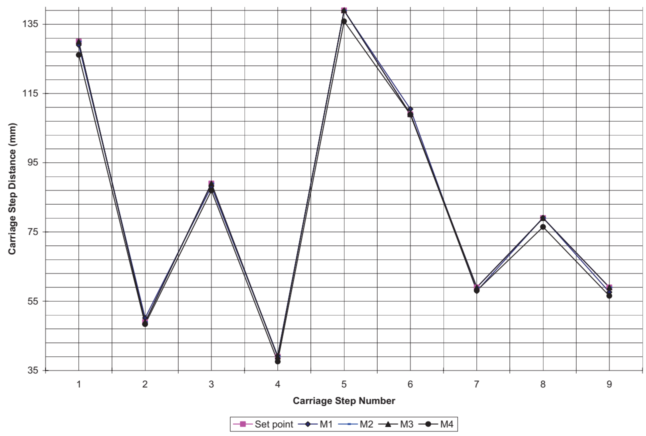

Fig. 4 Carriage Step Distance (mm) versus Carriage Step Number

M3 mode drive has been selected as drive method for this machine. Although this drive is quite slow compares to M2 mode but M3 drive mode has microsteps element which reduce the resonance effect and the movement is smoother than M2 mode drive. In mechanical point of view the precision movement between M2 and M3 mode drive is same.

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V. CONCLUSION

Based on the experiment results, the microstepping approach does not affect much on the precision of carriage movement for the machine. However in electrical point of view, this technique do contribute to current fluctuation which is average were reduced about 0.1 A during drives. Furthermore the motion is quite slow for DWC with OPWM compares to DWC without OPWM signalling element such M2 drive mode.

Unwanted jerky can be occurred and gives ‘cogging’ on the stepper motor such M4 drive mode if number of microsteps is used in driven stepper motor with OPWM signal is too high. We need to know the capability of MCU inside the controller and number of phase of stepper motor. In this case, bipolar stepper motor or two phase stepper motor has been used to drive machine carriage and 8-bit MCU is used in controller design. Therefore the maximum number of step should be used in drive is 16 steps. Thus only 16 variation of PWM duty cycle should be generated using (4).

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