Speed and Torque Control of Stepper Motor using Voltage and Current Control

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Abstract:
In this paper, Stepper motors provide fine control of rotation angle and speed through discrete excitation signals using voltage and current control. Micro-stepping enables higher precision through fractional excitation of step motor windings. Microcontrollers enable efficient and simple generation of discrete digital signals. Low cost and effective electronic utilities are realized with the use of microcontroller's and accompanying circuitry in conjunction. There are different driver topologies for step motor control, each having advantages and disadvantages for certain needs. Micro-stepping can be enabled using the H-bridge topology.

Keywords: *Electromechanical, Micro-stepping, PI-proportional-integral, PWM-pulse width modulation*

1. Introduction

A step motor control system is composed of three parts as shown in Figure 1. Apart from the motor itself, which performs the actual electromechanical conversion, a step motor control system includes a motor driver which is a piece of electrical circuitry that provides the required electrical signals to rotate or hold the step motor according to its control inputs. These control inputs are generated by a controller of the step motor control system. A step motor controller is the unit that produces input pulses for motor drivers to control an outer mechanical structure with step motors. A velocity profile is used to bring step motors into specified positions at specified time intervals. Input pulses brought to a step motor driver are used to control the number of steps or micro-steps to apply to the motor. Generally, these input pulses are converted into iterations using a look-up-table, which stores the amount of current to supply to each phase of the motor in a micro-stepping application.

2. Control Topology

The aim of current control is managing the power which is supplied to the step motor. Similar to position control, current can be controlled in either an open loop or closed loop fashion. Open loop current control refers to the control of the step motor without measuring the current flowing through the windings.

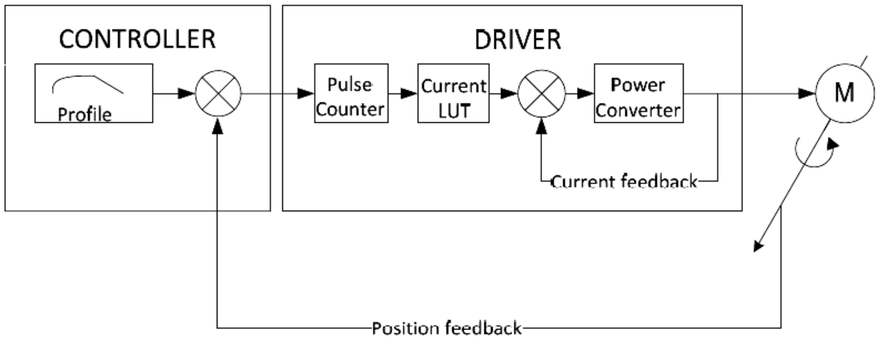


Fig.1 A Generalized Step Motor System with a Position and Current Feedback Path.

2.1 Voltage Control

One of the simplest of open loop control methods is the fixed voltage control, which is preferred for systems where torque demand of the system is not critical. Fixed voltage control method aims to provide a fixed amount of voltage, which is generally the rated voltage, to drive the motor and current limitation is left to the internal resistance of the motor. Fixed voltage control is ideal if low noise operation is needed and the system is operated under fixed conditions such as fixed motor speed or fixed load. In systems with a higher torque demand, fixed current control is employed where the motor is operated around the rated current. Fixed current control method refers to open loop current control as in the case in the fixed voltage control. This time, the voltage level applied to the windings is increased. As a result, output current of the driver can reach to the desired levels more rapidly and thus allows faster operation.

2.2 Current Control

Current control can be implemented in various ways. One approach is directly applying the rated voltage to the phase windings in a sequence in accordance with the desired excitation mode. This is the method mentioned as fixed voltage control. Another option is using a power source with a higher voltage than the rated voltage of the motor. Stepping this voltage down to the rated voltage is achieved either by applying linear control or by a pulse width modulation (PWM) chopper as shown in Fig.2.

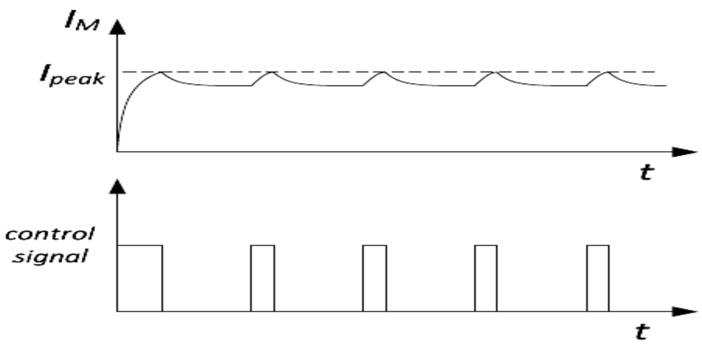


Fig. 2 Control of Motor Current with a PWM Chopper

2. Mathematical Model

The step motor can be modeled as a series L/R circuit. At the time of excitation (1) and (2), are valid where *Lm* and *Rm* are motor parameters and τ is the time constant of the circuit.

$$V_{bus} = L_m \cdot \frac{di}{dt} + R_m \cdot i \qquad \text{... (1)}$$

$$\mathcal{T} = \frac{L_m}{R_m} \qquad \text{... (2)}$$

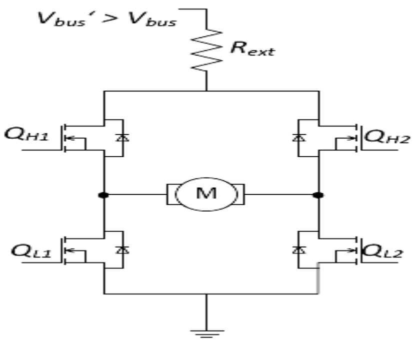
The more dominant the inductive behavior, the lower the slew rate of the output is. Time constant of the drive is increased by adding a series resistor.

$$L_m = L_m \cdot \frac{di}{dt} + (R_m + R_{ext}) \cdot i \qquad \text{... (3)}$$

$$\mathcal{T} = \frac{L_m}{R_m + R_{ext}} \qquad \text{... (4)}$$

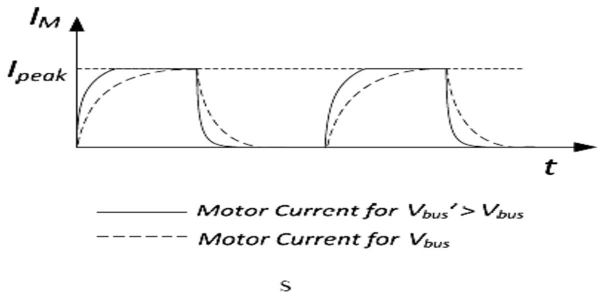
3. Control of Stepper Motor

It is possible to have a higher bus voltage than in the former case. *V'bus* > *Vbus* is applied to the windings. The new circuit with added *Rext* and the output current are given in Figure 16 (a) and (b) respectively.



(a)

Fig. 3 L/R Drive Circuit



(b)

Fig. 3 Switching Response of its Output Current

Step motor systems that incur a varying amount of torque from their load can utilize closed loop current control, where output current is measured and adjusted according to torque demands. Closed loop current control offers a better performance compared to open loop current control. Closed loop current control can be achieved with peak detection where the peak value of the phase current over many steps is detected and regulated by adjusting the duty cycles of the PWM signals accordingly. Achieving this type of regulation is possible with a PWM chopper on a full-bridge topology. A low starting reference value is selected and the duty cycle of the PWM signal is gradually increased until the maximum measured current value is equal to the rated current of the motor. The measured maximum current is sampled for each electrical cycle and the fixed current control is implemented continuously. As a result, motor performance under variable speed conditions significantly increases. This method also has the advantage of operability with different step motor types. Prior tuning specific to the motor type is not required. PI control is a generic framework for process output manipulation and can be utilized for matching step motor current to specific waveforms. In a PI step motor controller system, the difference, or error, between measured and desired instantaneous current, also called the set-point, is collected and summed with its integral to generate a PI output as shown in Figure 4. A negative PI output invokes an inhabitation of output current and a positive output leads to a boost.

It is also possible to adjust the whole shape of the current waveform with closed loop current control where system measures the winding currents forces them to follow a reference pattern.

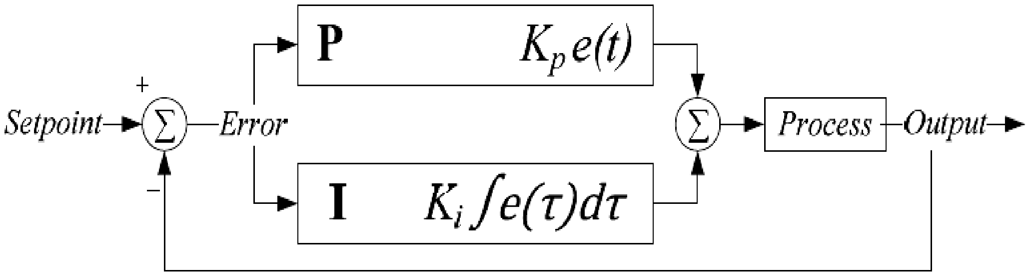


Fig. 4 Block Diagram of PI Control

A step motor driver utilizing a closed loop PI current controller can gradually adjust its operation according to the PI block output, e.g. by altering the duty cycle of its PWM generator. Shutting off current supplies to the motor on negative PI output is another option.

4. Conclusion

It has been found that L/R drive circuits are also referred to as constant voltage drives because a constant positive or negative voltage is applied to each winding to set the step positions it is winding current, not voltage that applies torque to the stepper motor shaft. The current I in each winding is related to the applied voltage V by the winding inductance L and the winding resistance R. Chopper drive circuits are referred to as constant current drives because they generate a somewhat constant current in each winding rather than applying a constant voltage. On each new step, a very high voltage is applied to the winding initially. The current in each winding is monitored by the controller, usually by measuring the voltage across a small sense resistor in series with each winding.

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