Adataptive Hysteresis Using Self-Training For Micro-Stepping

Prof. Dr. Mian Mohammad Saleem
Department of Electrical Engineering
[*]U.E.T., Lahore

Muhammad Saad Saleem
Research Associate
[†]K.I.C.S., U.E.T., Lahore

Abstract

Micro-Stepping is one of the most widely used technique for precision and smooth movements in stepper motors. This paper introduces a technique for micro-stepping other than [1]sine-cosine using self training. This technique involves feedback which simplifies the whole system. Complex hardware is replaced with intelligent software. This makes the whole system more adaptable to changing conditions.

KeyWords: Micro-Stepping, Stepper Motor, precision movement, encoder feedback, intelligent software

1 Introduction

Externally commutated motors have many advantages because of their compatibility with latest digital systems. Stepper motor is one of its kind. To achieve higher precision and smoothness, micro-stepping is used. We will employ a different technique other than sine-cosine micro-stepping. Some of the problems associated with sine-cosine technique are following:-

- The technique is usually used in open loop, hence accuracy cannot be assured when load is varying
- Errors incorporated with this technique like Detent effect, quantization error and error due to hysteresis in coils are very difficult to remove
- Effect of static friction makes this technique more vulnerable to errors when used in open loop

We have used feedback to make the whole system simple and reliable. Pulse width modulation is used for current control in coils using adaptive hysteresis technique. This technique is elaborated in following sections. Self training helps the system to adapt itself to different hardware and conditions. Different Component of this technique are explained as follows.

2 System Integration

The system required to implement adaptive hysteresis using self-training technique is shown in figure(1). It can be seen that micro-processor is acting like a brain of this system. It gets feedback from two sources. First one is current feedback from motor coils and second one is position feedback from mechanical shaft using optical encoder.

If encoder with large number of pulses per revolution is not available or it is very expensive then the shaft of the motor can be geared down using a belt. This way we can achieve better precision if the belt assembly doesn't have any backlash. Usually these encoders have two output lines. If the shaft moves clockwise, it sends pulses on first line and if the shaft moves counter clockwise, then it sends pulses on second line. These lines are connected to micro-processor, which generate two different interrupts so that micro-processor can know that motor has made a movement in a particular direction.

[*]University of Engineering and Technology, Lahore

[†]Khwarzimic Institute of Computer Science is a government institute for development of high tech projects in order to generate research and development activity in Pakistan

[1]It is a technique used to generate smooth movements in stepper motors. Current in motor coils behave like sine wave

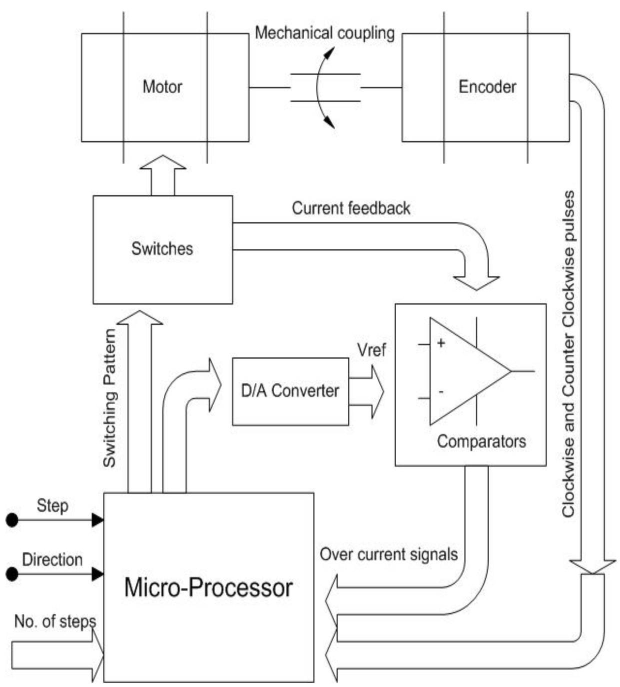

Figure 1: System diagram

[2]DAC generates a reference voltage for every phase. This reference voltage is compared with voltage across current sensing resistor. So by changing bit pattern, we can control current in each phase. Comparators provide over current signals, so that micro-processor can control current by using adaptive hysteresis technique. How much this reference voltage should be changed in order to reach desired position? We will answer this question by using self-training technique.

Step, Direction and No. of steps signals come from the main micro-processor. Step signal generates an interrupt in micro-processor, which will move motor to next possible position. The direction is decided by direction bit. No. of steps bits are used when more than one movement has to be made with single interrupt. After manipulating all the data from feedback sources and previous state, the micro-processor generate a switching pattern to drive [3]H-Bridge circuits.

It is assumed that mechanical coupling is free from any backlash and encoder is free from errors.

3 Adaptive Hysteresis

We will explain the adaptive hysteresis technique using the H-Bridge circuit shown in fig(2). This H-bridge is sufficient for one phase of the motor. Switches A and B are mostly P-channel MOSFETs and C and D are N-channel MOSFETs. Resistor R is used as a current damping resistor. The current flows through this resistor when we need to decay it quickly. To choose the value of R , we need to satisfy equation(1) and equation(2).

$$I_{max}R < V_{DSS(BR)PNP} \tag{1}$$

$$I_{max}R < V_{DSS(BR)NPN} + V_{CC} \tag{2}$$

This circuit operates in four modes. In forward mode, A and C are on, in reverse mode, B and D are on, in slow decay mode (used in [4]PWM) C and D are on and in fast decay mode, all the switches are

[2]Digital to Analogue Converter

[3]A circuit consisted of four switches, mainly used to control D.C. and stepper motors

[4]Pulse Width Modulation

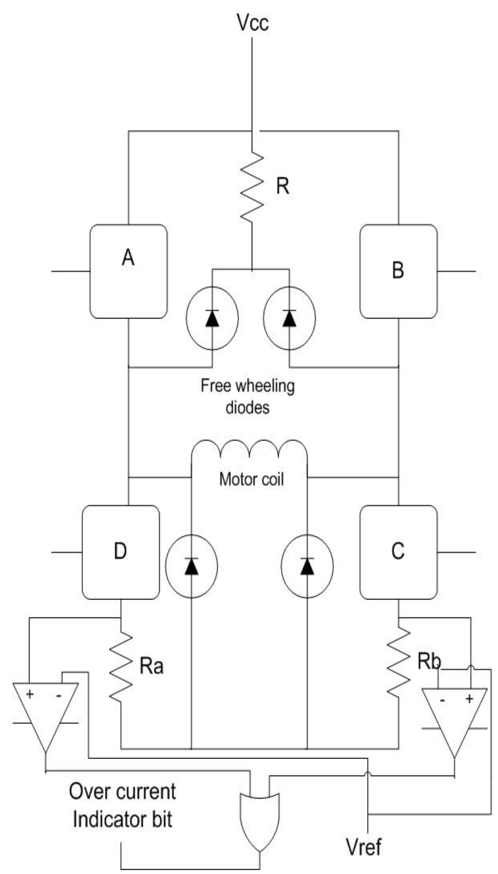

Figure 2: Typical H-Bridge Circuit

closed. In the last mode, current is forced to pass through resistor R and current is quickly decayed. Now when we say that the circuit is using PWM for current control in motor coil, this means that circuit is working in forward/reverse mode and then in slow decay mode.

If we assume that the inductors are not saturated then we can say that the magnetic flux produced by a coil is directly proportional to current. By changing current we can change magnitude of magnetic flux, and if we are exciting two or more than two phases at the same time, then by changing magnetic flux, we can change direction of the resultant flux.

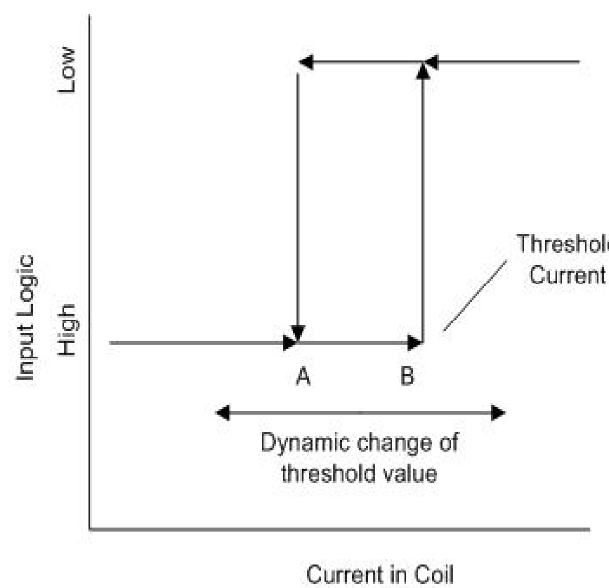

Figure 3: Graph between input logic and phase current

If for example, a given phase is operated in forward mode, then transistor A is switched on and off quickly such that the current is in our desired range. In order to ensure the level of current in coil, we use feedback. A reference voltage is compared with the voltage across the current sensing resistors. If voltage across any one of the resistors is greater than reference voltage, over current bit will be high. Two current sensing resistors are used because we want to know current level in first three modes of H-Bridge circuit. As soon as the over current bit becomes high, we shift the H-Bridge into slow decay mode. For how much time we should keep circuit in slow decay mode before going back to forward mode? To answer this question, look at figure(3).

In figure(3), the threshold point is shown. When the current in the coil reaches this point, the over current bit becomes high. This point can be varied dynamically by changing the reference voltage V_{ref}. This reference voltage can be generated by a DAC using R-2R ladder network. This makes it very easy to change the current in coil dynamically using software.

In figure(3), the difference in values of I_A and I_B is very critical. Increasing this value can make a varying magnetic field, which makes the total torque less. If other coils will also vary their magnetic field in this fashion, then their resultant will be difficult to handle. So we try to make this as little as possible. In making this difference small, we should understand some of the problems associated with it:-

- At higher frequencies, switching losses in transistors become significant
- High speed components are expensive, like diodes, resistors with very little inductance and high [5]MIPS micro-processors

4 Self Training

Self training process is used to predict current level in a coil for a desired position. When the system is turned on, it will try to determine that how many pulses it receives from an encoder between two full steps and then find the speed at which rotor can follow magnetic flux for a particular load. Once we will find this speed, we will always drive the motor less than this speed to ensure that rotor doesn't lag far behind the flux. This process will be repeated at least hundred times to ensure that rotor will follow flux smoothly.

This will help the system to guess when the next pulse will arrive. However, it is possible that due to changing load or other circumstances, this guess doesn't work then we have to make a remedy. Our software compensates this flaw.

[5]Million Instructions per Second

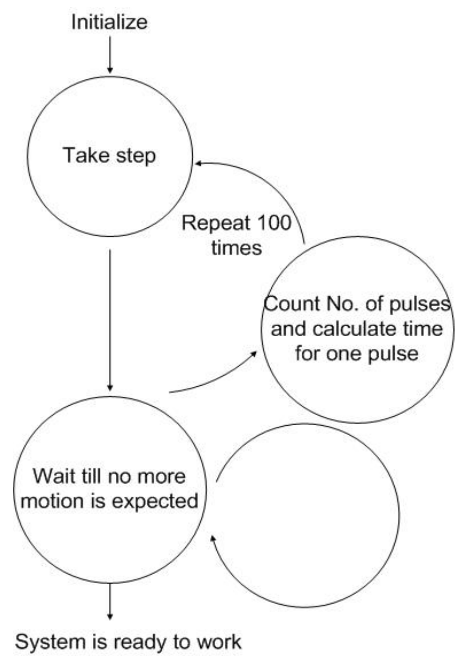

Figure 4: Self Training Process

5 Software

After the system knows something about the conditions under which it is running in self-training period, it starts its regular operation. Micro-processor monitors over current bits and using adaptive hysteresis technique, controls current in coils. If an encoder sends a pulse then that means rotor is moving. The micro-processor will make such changes so as to revert the change. This is important because if micro-processor will not revert it, the rotor will change its position to some undesired position. This is important in those conditions when system is trained for less load and when more load is applied, the rotor starts lagging magnetic flux. When micro-processor receives required number of pulses, it stops moving magnetic flux, but as rotor was lagging the rotor

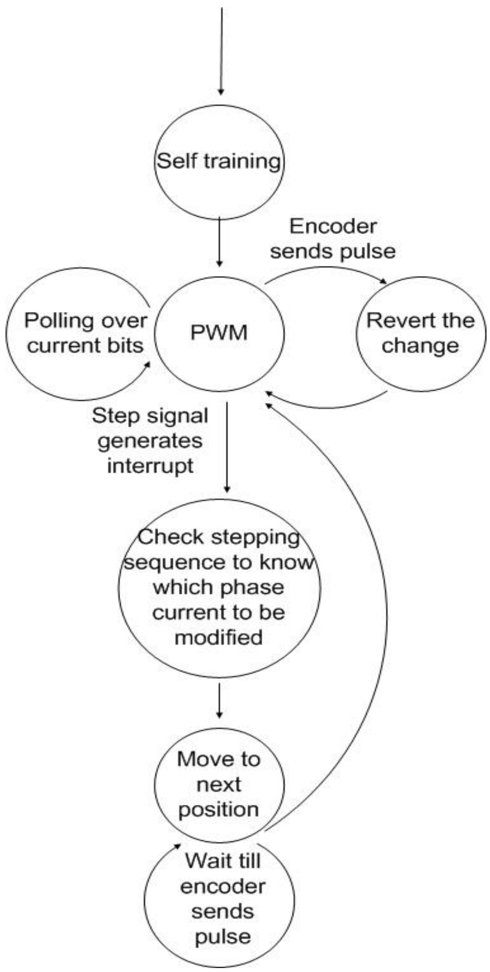

Figure 5: Software flow chart

reaches a position ahead of the desired position after sometime. This makes system vulnerable to errors if we don't use this technique.

When micro-processor receives a step pulse, it shifts magnetic flux in the direction determined by direction bit. The micro-processor checks that which phase current has to be changed by checking previous phase sequence and after checking direction bit it decides that current should increase or decrease in a particular phase. Current is increased or decreased by varying reference voltage V_{ref}. The system waits till required number of pulses are received from encoder and then goes back to initial PWM state.

6 Conclusions

Sine-Cosine micro-stepping provides constant torque. In our adaptive hysteresis self-training technique, we don't need to use this technique as the desired current level is automatically adjusted using feedback. So many errors and problems associated with sine-cosine micro-stepping are removed.

One of the areas which require extensive work is improvement of self training. If this technique becomes more mature then it is possible that the motor is trained with an encoder of less number of pulses per revolution and then system will be operated in open loop. This can save cost significantly.

It can be appreciated that by using above stated approach, the motor can be operated in varying load conditions without any expensive hardware and without sacrificing accuracy. The approach can be easily used in commercial drives of externally commutated motors as electrical hardware and high MIPS microprocessors are inexpensive and easily available.

Acknowledgment

I want to thank Dr. Iqbal Gondal from Monash University, Australia, whose help and encouragement helped me to complete this paper.

References

[1] Douglas, W. Johns, *Control of Stepping Motors,* (The University of IOWA, 1995).

[2] Yeadon, W. H. and Yeadon, A.W. *Handbook of Small Electric Motors,* (McGraw-Hill, 2001).

[3] Takashi, Kenjo, *Stepping motors and their microprocessor controls,* (Oxford University Press, c1984.).

[4] P.P., Acarnley, *Stepping motors: a guide to modern theory and practice,* (P. Peregrinus on behalf of the IEE, 1984, c1982).

[5] Raskin, Chuck, *Designing With Motion Handbook,* (Newnes 5th edition, March 1, 1997).

[6] Valentine, Richard, *Motor Control Electronics Handbook,* (McGraw-Hill Professional, May 1, 1998).

[7] Keljik, Jeff and Alerich, Walter N. *AC/DC Motors, Controls, and Maintenance,* (Delmar Learning; 7 edition, January 22, 2001).

[8] Piech, Zbigniew and Plech, Zbigniew J. and Gieras, Jacek F. *Linear Synchronous Motors: Transportation and Automation Systems,* (CRC Press, September 29, 1999).