International Journal of
Electrical and Computer System Design
www.ijecsd.com

Microstepping Mode for Stepper Motor Control

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Abstract—Extremely high-performance system for stepper motor control in a microstepping mode, which was designed and performed with a L292 specialized integrated circuits, made by SGS-THOMSON, Microelectronics Company. The microstepping control system improves the positioning accuracy, eliminates low speed ripple, and resonance effects in a stepper motor electrical drive. The same microstepping system is ideal for robotics, plotters, printers, X-Y tables and can facilitate the construction of very sophisticated positioning control systems while significantly decreasing component cost, board space design time and system cost. The same microstepping control system can be used for two single-phase DC motors, a variable reluctance motor and an AC biphasic motor's control.

Keywords— Stepper motor; Microstepping Mode; Variable Reluctance Stepper Motor; Permanent Magnet Stepper Motor; Hybrid Stepper Motor.

1. Introduction

Stepper motors are very versatile and an important member among the machines designed till today. With the help of stepper motors it has been possible to create a kind of revolution in the areas of robotics which is meant to carry parts, machines, materials etc[1-2]. Stepper motors also proved like a pole backbone not only in robotics areas but also in electro medical fields, basically in radiation therapy[3]. Stepper motors are externally commutated motors commonly used for positional task.A stepper motor suitable for use in a medical imaging environment has a cylindrical central gear having an external surface with circumferentially distributed and radially directed teeth[4-7].

Basically, Stepper motor comes in the category of Brushless DC Motor [5]. The rotor of the stepper motor rotates in step wise angular movements whenever its stator winding is energised by computer programming [6-8]. In a broad way the magnetic interaction which occurs between poles of the sequence wise energised stator windings and rotor poles causes the rotor to move[9]. Each of these rotations is called a step and the angle of each step is called step angle[10,11]. A stepper motor is actually a digital actuator whose input supply is in the pattern of programmed energization of the stator winding and whose output is in the pattern of step wise angular rotation [12].

2. Classification Of Stepper Motor

2.1 Variable Reluctance (VR) Stepper Motor

The variable reluctance stepper motors do not have any permanent magnet either on stator or rotor [13]. These motors consist of a primary pole stator with concentrated three or four phase winding and a salient pole rotor. The rotor is made from ferromagnetic laminations, carries no winding. The stator produces flux which causes the rotor movement through a single step so that reluctance seen by the stator field is minimum and the stator flux linkages are maximized for given stator currents [14].

In a 3 phase 6/2 pole variable reluctance motor there are six salient poles with concentrated series (or parallel) windings, so that stator has effectively three phase winding. The stator winding is excited from a dc source through a suitable electronic switching device. Suppose AA', BB' and CC' represent the respective coils of the stator. Therefore, when coils AA' are excited, the rotor is at a position say ϴ=0°. When coils AA' are de-energized and coils BB' are excited, the rotor moves through a step angle of 60° clockwise (CW). Further when current is withdrawn from coils BB' and coils CC' are excited, the rotor further moves through a step of 60° CW so that ϴ=120°. In this manner the rotor will complete one revolution through six steps. The step angle in this case is 60°.

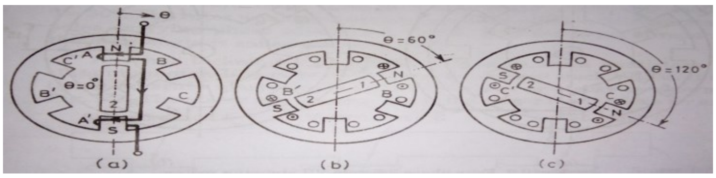

Figure: 1 Internal structure of Variable Reluctance (VR) Stepper Motors [2]

Generally, the magnitude of step angle is given by;

$$Step\ Angle = \frac{360°}{m * P}$$

Where: m - number of phase windings on the stator

P - number of rotor teeth or poles.

if A and B are excited simultaneously, then rotor would move through a step angle of 30° CW so that ϴ=30°. The rotor would now occupy a position midway between stator poles carrying phase windings A and B. This technique of reducing step angle is called micro-stepping. Lower values of step angle can be achieved by using a stepper motor with more poles on stator and teeth on rotor. For example, in a 4 phase 8/6 pole VRSM, the concentrated windings on diametrically opposite poles are connected in series (or parallel) so as to obtain an effective 4 phase winding on the stator. In this case the step angle is 15°.

2.2 Permanent Magnet (PM) Stepper Motor

The stator of a permanent magnet stepper motor consists of salient poles with concentrated windings, just like the stator of a VRSM. The rotor, as the name of this motor suggests, consists of permanent magnet poles. For the illustration of the working principle of PMSM an elementary form of 2 phase 4/2 pole stepper motor is considered here. The concentrated winding on diametrically opposite poles is connected in series so as to result in 2 phase winding on the stator. The rotor is magnetized to give two permanent magnets [15].

The working of this motor is like: -

Two coils AA' connected in series constitute phase A winding. When this winding is excited with current i_a, the stator produced poles attract the rotor permanent magnet poles so that their magnetic axis coincides. Let this exciting phase A winding be denoted by +A.

Now the current in phase A winding is reduced to zero while phase B winding is excited with current ib. Stator produced poles now attract the rotor poles causing a CW step rotation through Θ=90°. Let the exciting phase B winding be denoted by +B.

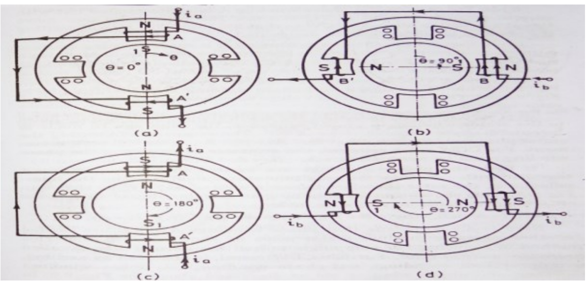

Figure: 2 Internal structure of Permanent Magnet (PM) Stepper Motor [2]

Now the phase winding A is again excited but with current opposite to Ia that is –Ia this time. Now rotor poles further move through a step of 90° CW so that Θ=180°. This step of exciting phase winding is denoted by –A.

Now the phase winding B is made to carry an exciting current opposite to that of Ib that is – Ib this time. The rotor again executes further step of 90° CW so that Θ=270°. This method of exciting phase B winding be designated as –B. For further 90° CW step phase winding B is de-energized and phase winding A is energized. This shows that four steps complete one revolution of the rotor movement. So here by the application of each current pulse to the stator winding in proper sequence, the rotor can be made to execute discrete angular steps of 90°. Sequence of exciting the stator phase winding is +A,+B,-A,-B,+A….for CW rotor movement. For CCW rotor rotation, sequence of exciting stator phase winding is +A,-B,-A,+B,-B .If both the stator windings are excited in the sequence +A together with +b, then the resultant stator field is along the interpolar axis, the rotor therefore moves a step of 45° CW. This shows for obtaining the angular step of 45° CW the switching sequence should be as +A, (+A+B), +B, (+B-A), -A, (-A-B), -B, (-B+A), +A. This method of reducing step angle to half the normal step is called half step mode of excitation. This is achieved by exciting in proper sequence, one phase winding, one- and two-phase winding together, one phase winding and so on as described above. In PMSM even with zero exciting currents, some torque is produced tending to align the permanent magnet poles with the stator teeth; this however is not the case in VRSM. PMSM therefore have the advantage of developing some torque to maintain if the drive circuitry fails. PMSM have the disadvantage that smaller steps are not feasible because of the difficulties encountered in their construction.

2.3 Hybrid Stepper Motor (HSM)

The combination of PM and VR stepper motor comes in the category of Hybrid stepper motor. HSM incorporate an axial permanent magnet at the two ends of which are coupled with two similar ferromagnetic stacks. These two ferromagnetic stacks having same number of teeth. The first end of these homogeneous stack acquires north magnetic polarity whereas at the other end it acquires south magnetic polarity. Both the ferromagnetic stacks comprise of an angle wise displacement of one half of the rotor tooth pitch. The primary pole of stator structure which is constant from one side to other side of the stator pole design. The stator poles carry concentrated winding like other types of stepper motors [16].

For understanding the hybrid stepper motors an illustration is given here:

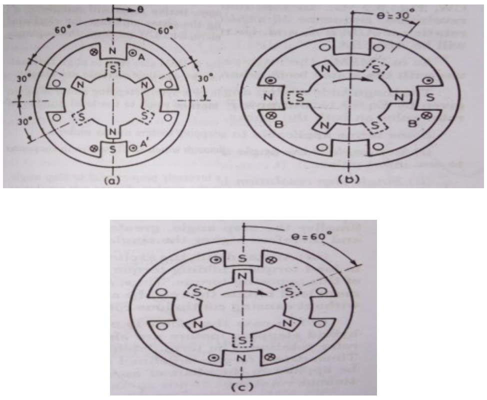

Figure: 3 Internal Structure of Hybrid Stepper Motor (HSM) [2]

suppose north pole is at front end and south pole is at far end. The current i_a energized with phase winding A, N pole at A and S pole at A' are induced on stator. Pole at A attracts S pole of far end and pole at A' attracts N pole of front end. The flux linkage increases on the rotor side dur to equilibrium orientation. This equilibrium orientation of rotor design maximizes the flux linkages with phases winding A, flux reaches to maximum. For turning the rotor clockwise through a step, de-energizing of phase winding A and exciting of phase winding B is done so that N pole at B and S pole at B' are induced on stator. Pole at B attracts S pole of rear end and pole at B' attracts N pole of front end, so a step angular rotation become 30° CW. In the next equilibrium position, maximum flux linkages are now linked with phase winding B. If excitation is removed from phase winding A, pole on A attracts front N pole and pole at A' attracts rear S pole. This gives rise to a further step angle movement of 30° CW. In this manner 12 steps will complete one revolution. Sequence of exciting the phase winding for clockwise rotation is ABA'B'A and therefore for CCW rotation, the sequence will be AB'A'BA. As in PMSM, the rotor poles in HSM also tend to align themselves with the stator teeth when stator exciting current is absent.

The problems related to low frequency oscillation, resonance at low-speed and dynamic stability are closely associated with non-linear grouping of control system attached with the motor and output load which is complex and unpredictable. As this allowed technique upgrade the stepper motor behaviour, the position response has been observed. At present, the details on the orientation of rotor, summarized by the current waveform of the steeper motor can be apply in positioning along with output obtained from position optical encoder. Simultaneously, the control in micro-stepping system contributes in the magnification of resolution and superior motion stability. Taking into considerations the above-mentioned aspects, the author presents in this paper the bipolar command in micro-stepping mode of SM with two L292 specialized integrated circuits.

3 MICROSTEPPING MODE

The technique to avoid the issues related to stepper motor while still maintain their open-loop advantages is to employ them in the microstepping mode. In this mode each of the steps is subdivided into "microsteps" [8].

A common way to control the angle of the torque phasor is by applying to the motor's phase's two periodic waveform+s shifted by 90 electrical degrees.

suppose the phase current equations;

$$I_a = I_o \cos \theta_e$$
$$I_b = I_o \sin \theta_e \qquad \text{eq. 1}$$

where θ_e= electrical position & I_o = current per phase.

The resulting torque generated by the corresponding phases would then be:

$$MA = K_m I_a = K_m I_o \cos \theta_e$$
$$MB = K_m I_a = K_m I_o \sin \theta_e \qquad \text{eq. 2}$$

where K_m = torque constant of the motor.

Substituting eq.1 into eq.2 & performing vector summation the resulting total generated torque measured on the motor shaft is indicated by:

$$MO = \sqrt{MA^2 + MB^2} = K_m I_o$$

Note that in this case we have zero torque ripple.

Using this technique one can theoretically achieve infinite resolution with any SM. Since the drive current waveforms are sinusoidal instead of square, the step-to-step oscillations are removed and the associated velocity ripple. In an actual application, the extent to which these things are true depends on how the two sinusoidal reference waveforms are generated. This improves performance at low rotational speeds and help in reducing resonance problems. An example of the required phase currents for full step and four micro steps per step operation are shown in Fig. 5 respectively.

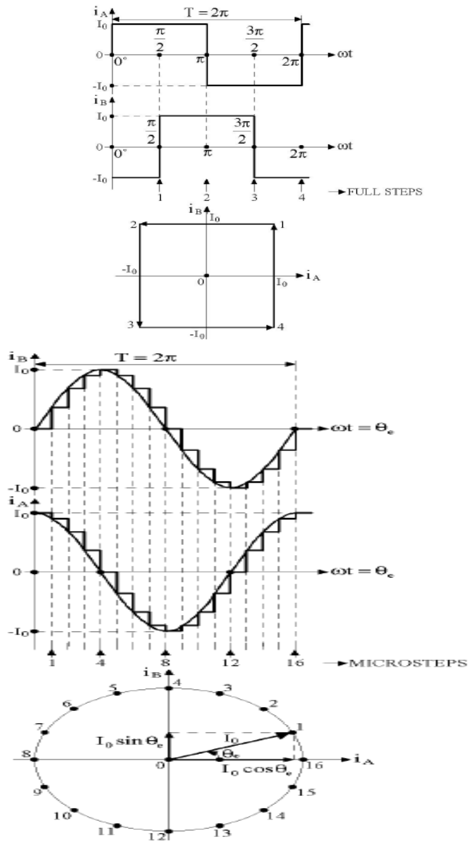

Figure: 4 Four Microstep Step Drive Waveforms[7]

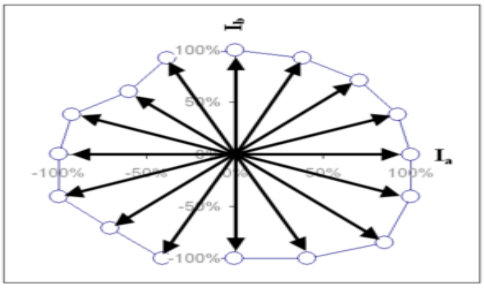

Figure: 5 Phase Diagram of Microstepping Mode [9]

4 EXTENDING THE DYNAMIC RANGE TOWARDS LOWER FREQUENCIES

When running a stepper motor at low frequencies. in half- or full-step mode. the movement becomes discontinuous, shows more ringing, and generates vibrations and noise. The stepping frequencies where this happens are below the system natural frequency. Here microstepping offers a easy and safe way to extend noiseless stepping frequencies down towards 0Hz. Normally it is not necessary to use smaller steps than 1⁄32-full-step. With this small electrical step angle the energy transferred to the rotor/ electrical step is only 0.1% of the fullstep energy. The deviation of the microstepping positions from a straight line is due to the use of uncompensated sine/cosine profiles.[11]

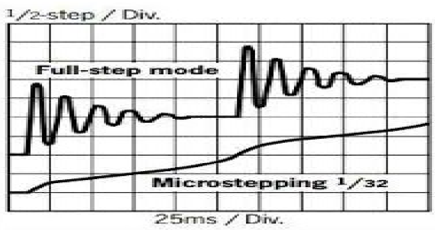

Figure: 6 Rotor Position As a Function of Microstepping Mode [6]

5 MICROSTEPPING SYSTEM DESCRIPTION

The stepper motor bipolar control in microstepping mode is shown in Figure 7. In this diagram the two-phase stepper motor in microstepping mode and a two L292 switch-mode driver commands are shown. This mode is can be acquiring if the input current will be sinusoidal as is feasible in the two phases of the motor.

The two sinusoidal current waveforms which are 90 degrees out of phase gives correct command. For achieve this target it has to be applied to the L292 driver's inputs (V_{sin} and V_{cos}) two reference oscillating signals (SINE & COSINE) gained with the help of the two electronically programmable memories (EPROM) and the two digital to analog converters (CNA1 and CNA2), related to the desired Kv step division coefficient:

$$iFA = \sin\frac{n\,\pi}{2\,K\,v}$$

$$iFB = \cos\frac{n\,\pi}{2\,K\,v}$$

$$n = 0,1,2,3\,...,4K_v - 1$$

An up/down counter is used to generate the most appropriate address location in EPROM's. The command pulses from a PULSE GENERATOR, positive-edge actives, are used to maximize or minimize the counter. At the end for multi tour potentiometer programming the pulse frequency can be modify thus motor speed is adjust according to requirement.

The Block diagram of electronic scheme digital command is shown in Figure 8. The two reversible and synchronous counters I_2 and I_3 of 74193 type are actually EPROMs capacity of 2K X 8 used to register the data. The two-position switch K3 established the counter mode (rotation sense). The CLOCK signal is also established. The LM555 timer (I_1) used for inducing automatically (AUTO) oscillatory signal and P_1 multi-tour potentiometer is use to modify the frequency. The B_1 push button used manually (MAN).

The LM555 timer IC is used to attend oscillatory signal verified by means of the START/STOP signal fed by means of the two-position switch K_1. The digit wise data comparable to SINE and COSINE is recorded on the I_1 and I_5 EPROMs severally of M2716 type. This digit wise data is exchanged in analog output through two digital to analog converters) 16 and 18 respectively of DAC08 type with resolution of 8 bit. The reference voltage V_{REF} = 1OV is essential for the two 8 bit digital to analog converters is established by the TL431 stabilizing circuit (I_{10}). The digital to analog converters are utilzed in bipolar configuration, such thing being achieved by means of the two TLO8 1 type operational amplifiers, I_7 and I_9 respectively. The controlling system ensures two operating modes:

$$microstepping\ with\ K_v = 4(\frac{4*\ microsteps}{step});$$

$$microstepping\ with\ K_v = 64(\frac{64*\ microsteps}{step});$$

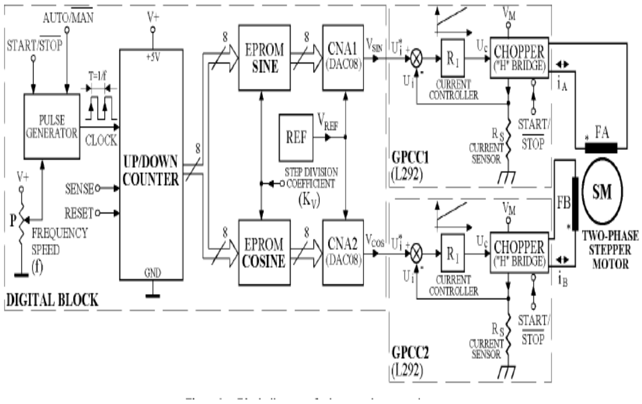

Figure: 7 Block Diagram of Microstepping Control System [7]

In the Figure. 10 is shown electrical scheme of power stage. The two-constant current programmable generator is generalized with the I1 and I2 specialized integrated circuits of L292 type, made by SGS-THOMSON, microelectronics Company.

The current sense resistors R_{s1} = R_{s2} = R_s should be high precision types (maximum tolerance ±2%) and the recommended value is

$$R_s = \frac{0.044\ IVINI}{I_0}$$

with IVINI < 9. 1V and II0I < 2A.

The proper operation of the constant current programmable generators is also ensured (and) by the ultra-fast diodes D_1 D_8 of BYW29 (PHILIPS) type. At the same time, the ($R_5 = R_{12}$) ($C_5 = C_{10}$) anti-oscillating group is also provided.

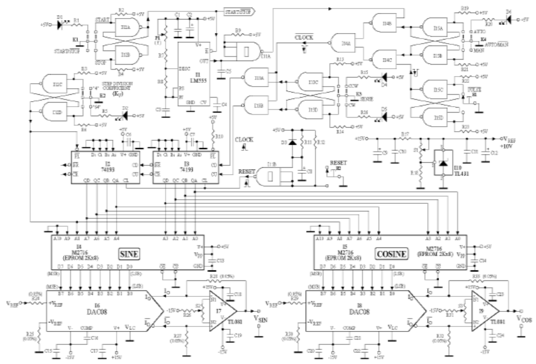

Figure: 8 Electronic Scheme of The Digital Command Block[7]

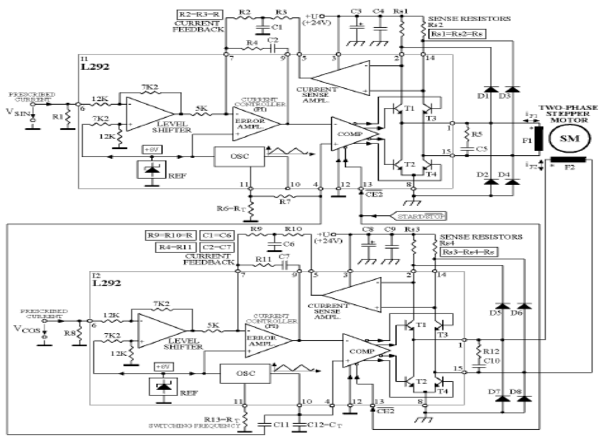

Figure: 9 Electronic Scheme of The Power Stage[7]

6 APPLICATIONS OF STEPPER MOTORS

Instrumentation Applications:-

There are essentially low torque applications in which the torque ranges from a few gm-cm to a maximum of 1 kg-cm. Typical examples of such applications are quartz watches, remote camera shutter operations, clocks on railway platforms, mechanical D/A converter etc.

Applications in computer peripherals:-

This important class of application of stepper motors is characterized by the phrase “High performance high volume”. The motors employed in these applications have medium torque rating that is 1-2 kg-cm. Typical examples are line printers, floppy disk drive, digital X-Y plotter, magnetic tape transport, paper tape drive etc.

Applications in office equipments:-

Typical examples of stepper motor applications in this field are electronic typewriter, facsimile (Xerox) machine.

Robotics:-

Stepper motors are very popular for the reason of its applications in robotics. Stepper motors are popular as an actuator for activating joints of various types of robots.

Electro-medical Applications:-

Stepper motors are widely used in X-ray machines, radiation therapy units, CAT-scanners, ultrasound scanners etc., which require precise positioning.

Miscellaneous Applications:-

These include nuclear reactor, aerospace and various industrial applications.

7 CONCLUSIONS

The last progress both in control in motor drive domain imposes on the researchers a continuous reorientation in order to solve the design problems with the newest technical means. Stepper motor with a microstepping mode system are resonances are reduced, noise generation is considerably reduced, very high step resolution, bipolar switching operation, precise X-Y-Z position and rotation control.

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