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SIMULATION OF HYBRID STEPPING MOTOR USING MATLAB-SIMULINK

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ABSTRACT

Recently, hybrid stepping motors are being used extensively over a wide range of application especially for precise positioning. This is due to their advantages of having higher efficiency, maintain very high resolution due to the small step angle and other advantages over other types of stepping motor. Therefore this project takes for granted to study their transient performance over various situations. This project is mainly based on modelling and simulation of two phase hybrid stepping motor. The presented model is able to perform the transient performance of the motor with three types of operation; two phases on, one phase on and half stepping. The model is developed in Matlab-Simulink at first and later is presented using the Graphical User Interface (GUI) in order to change the motors parameters independently during each simulation conducted. The GUI can be also used to show various results of simulation. The model described enables calculations of motor current and voltages as well as performing the speed and position responses for the rotor during each excitation. Using this model, it is capable of performing the simulations of hybrid stepping motor with various parameters. The simulations results are presented with a detail explanation on each part of the study conducted. The results show that hybrid stepping motor can be used for precise positioning especially when small step angle are required.

LIST OF SYMBOLS

p	: *number of rotor teeth*
S	: *steps per revolutions*
m	: *number of stator phases*
N	: *number of rotor pole pairs*
f	: *stepping rate*
ζ	: *damping ratio*
ω_n	: *natural frequency of oscillation (rad/s)*
θ_m	: *stepping angle*
ω	: *speed of rotation*
J	: *motor inertia*
B	: *viscous friction*
Km	: *motor Emf constant*
Φoj	: *location of the winding j*
τ	: *time constant*
Vj	: *supply voltage*
R	: *resistance of the winding*
L	: *inductance of the winding*
Ij	: *phase current*
K_d	: *amplitude of the release torque*
Tij	: *torque produces in each phases*
T'	: *stiffness of torque-angle characteristics*
t	: *time*

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CHAPTER 1
INTRODUCTION

1.0 INTRODUCTION

Traditionally a DC motor with servo is used for precise positioning. However in early 1960s many found that this was not very practical since the cost was very high and presented a series of disadvantages. When this problem arises they turn to stepper motor. Stepper motors as their name suggest they 'step' a little bit a time. They produce the highest torque at low speed. This is completely different from a DC motor where it produces low torque at low speed. Furthermore stepper motors have 'holding torque' characteristics which are not present in DC motors. Holding torque allows a stepper motor to hold its position firmly when not turning. In particular DC motors present the problem of mechanical wear of brushes whereas stepper motors do not have brushes at all.

Stepping motors are presently being used extensively over a wide range of application. Generally they are used in microcomputer, office and factory automation application and now they are widely used in robotics [33]. A stepper motor is an ideal incremental actuator for digital control system which can be run in open loop mode with sufficient accuracy. They can be controlled directly by computers, microprocessors or programmable digital controller. They are unlike most electric motors, where it can be viewed as electric motors without commutators. Since the hybrid stepper motor has higher efficiency, maintain very high resolution due to the small step angle and other advantages over the Variable Reluctance (VR) and Permanent Magnet (PM) types stepping motor, they are commonly used stepping motor in industry [33].

When the used of stepping motors in industry become wider, the user have nothing to refer to except the characteristics of the commercial catalogues. These catalogues however do not present a sufficient data that allows the user to do a very detail study of the motor. In order to carry out a detail study of its performance, a complete model of the motor is required.

1.1 OVERVIEW OF PROJECT

In this project a complete model for the analysis of stepping motor is presented. The model is developed for a two phase hybrid stepping motor which takes into account the electrical as well as the mechanical transients of the motor. The resulting mechanical and electrical differential equations are integrated directly. The model described enables calculation of motor currents and voltages besides speed and position in transient condition. Effect of motor parameters on its characteristics can be viewed for different operating conditions. These characteristics can be presented for half step and full step operation.

1.2 OBJECTIVES OF PROJECT

The objective of this project is to develop the mathematical model for a two phase hybrid stepper motor which represents the dynamic response of the motor. Based on this model, a complete open loop block diagram of two phase system is created. The input of the system is pulse command where two types of operations will be applied as an input to the system; full stepping and half stepping. The output of the system is the motor rotor position angle. An open loop system is developed using Matlab-Simulink in which perform the step responses for the stepper motor. This is shown by the rotor position angle of the motor. The study is mainly on the transient performance of the motor where varies of studies will be carried out to find the difference between one-phase on, two-phases on and half-stepping. Besides, this also enables to study currents, voltages and speed of the motor. Each time a command pulse is received, the motor rotor position will move one 'step'. Every one 'step' should be equal to the stepping angle of the motor. The output of the model will produce a number of step pulses which depends on the stepping rate of the motor where each step is completed very quickly usually in a few milliseconds.

1.3 OUTLINE OF PROJECT

This dissertation is divided into several sections which illustrates the outline of the project. Each section is explained in details in order to give an overall idea of the project. The sections are as follows:

CHAPTER 1 Present the introduction, overview and objectives of the project

CHAPTER 2 Discuss the background theory of stepper motor. This includes the types of stepper motor, advantages and disadvantages of the Hybrid motor compared to Variable Reluctance, principle of operation, mode of operation and its system.

CHAPTER 3 Explain in detail the dynamic model of stepper motor and to come out with a model for a two phase Hybrid stepper motor.

CHAPTER 4 Introduce project method in order to achieve the project objectives. Project planning is also included in this section where a proper schedule is prepared in Gantt Chart format so that each part of the project can be finished in a specific time.

CHAPTER 5 Present the project result. This section covers the results and comments. Calculations are also included as part of the discussion on the achieved results.

CHAPTER 6 Conclusion and future plan.

CHAPTER 2
LITERATURE REVIEW

2.0 INTRODUCTION

Recently, many applications related to positioning systems are being implemented with hybrid stepper motors. They are the most commonly used stepping motors in robotic industries since they have higher efficiencies, maintain very high resolution due to small stepping angle and other advantages over the variable reluctance and permanent magnet motor. It is known that there are several major areas of interest in motion control in robotics, speed and position regulation, speed and position tracking or torque control. Based on these reasons, then the hybrid stepper motor has been chosen for study purposes in this project.

2.1 APPLICATIONS AND CHARACTERISTICS OF STEP MOTOR

A stepper motor is the best choice when consider precise measuring of a motors rotor position. It also can be useful for application where the motor may be starting and stopping, while the force acting against the motor remains present. This eliminates the need for a mechanical brake mechanism. A wide range of stepper motor is now available in the market and can be found in any piece of electromechanical equipment such as VCR, DVD, computer printers, luxury car and etc.

However the most important factor in choosing a stepper motor for a given application is the 'degree per step' (step angle) characteristics. Stepping angles are mostly in the range of 1.8°-90° with torque ranging from 1μNm up to 40 Nm in a motor suitable for machine tool applications [22]. At present nearly all small angle steppers are small and of the hybrid type. At lower efficiencies with available voltages, a smaller step motors can be driven effectively. However there is a serious problem when larger size step motor with larger winding time constant is considered; where the full output power is rarely achieved at higher operating speed because of efficiency consideration and voltage limitation.

Apart from step angle, static torque is one of the most important parameter. It is understood that [20] for a given static torque the best motor would be the one which was cheapest, smallest and had the lowest static power consumption. From this information, as far as applications are concerned, one can determine suitable types of step motor. As a conclusion, the following elements characterize a given stepper motor;

(i) Voltage: sometimes it is necessary to exceed the rated voltage to obtain the desired torque which in other side will shorten the motor's life.
(ii) Resistance: the resistance determines the current draw of the motor, which also affect the motor's torque curve and maximum operating speed.
(iii) Step angle: the number of degrees the rotor will rotate for each full step.

2.2 TYPES OF STEPPER MOTOR

The types of motor determine the type of drivers and the type of translator used. Basically there are two categories of stepper motor:

2.2.1 PERMANENT MAGNET (PM)

There are commonly two types of permanent magnet motors; unipolar and bipolar stepper motor. These types of motors are relatively easy to control. They tend to 'cog' when the rotor is twisted. Usually they have only two independent winding with or without center taps. All the exciting winding is housed on salient poles forming the stator, while the rotor is usually passive salient pole structure with a number of poles on it different from those on the stator [10]. Most PM motors can be in half steps with an appropriate controller and be able to handle 1.8 or 0.72 degrees per step.

2.2.2 VARIABLE RELUCTANCE (VR) and HYBRID

This type of motor sometimes referred to as hybrid motor where both types utilize the reluctance principle. However, there are differences between them, firstly in term of method to produce the magnetic fields and secondly, in term of step angles. In Hybrid motor a permanent magnet is fitted in the rotor. These two separate sources will produce magnetic fields. This is completely different in VR motor where the fields are produced solely by sets of stationary current carrying windings. When consider the step angles, the hybrid is best suited when small angles (e.g. 1.8°, 2.5°) are required while VR type is suitable for the larger step angles (e.g. 15°, 30°, 45°).

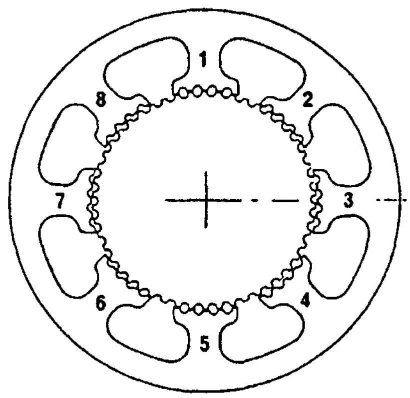

Figure 2.1: Hybrid stepping Motor with 1.8°- step [20]

The VR motor normally comes out with three or four windings with a common return. Every of its winding is placed in one stator, which has multiple teeth. The rotor has equal number of teeth as the stator; this combination will form one unit. Many units will form multi-stack motor. The popularity of this type motor become increases as it provides a flexibility to suit many application which requires fast response.

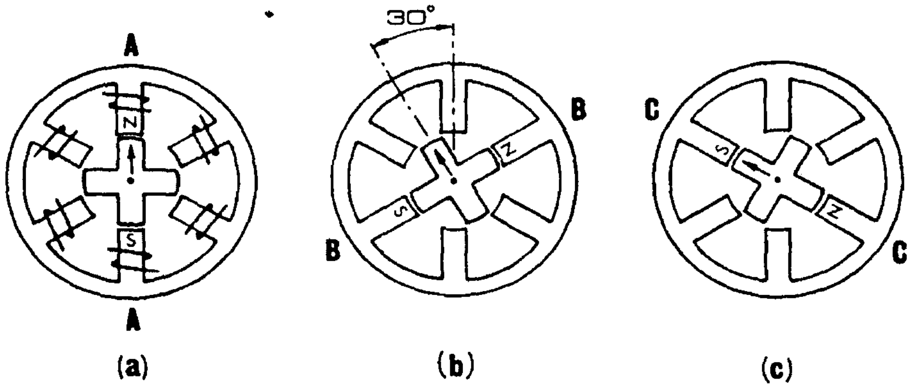

Figure 2.2: VR stepping Motor with 30°- step [22]

2.3 ADVANTAGES AND DISADVANTAGES OF HYBRID MOTOR

a) Advantages

(i) Step angle is normally small; therefore the higher the number of teeth is required. As a result, lower mmf is required to achieve the limiting value of torque.

(ii) In term of torque production mechanism, hybrid has advantage of having smaller stator compared to the same rotor size of VR. This is because in hybrid, mmf is divided between stator and rotor poles while in VR, mmf is located at stator alone. So hybrid motor requires smaller size of stator with a lower static power.

b) Disadvantages

(i) An equivalent VR motor has a stator similar to that of the hybrid, but the rotor is homogeneous. In VR rotor, there is no permanent magnet and the teeth are in line through out so it is simpler and cheaper compared to hybrid.

(ii) In term of torque production mechanism, hybrid needs a bipolar supply to develop its full output. However VR motor only needs a unipolar supply.

2.4 PRINCIPLE OF OPERATION

The objective of this section is to mention about the principle operation of a stepper motor. The principle which discussed in this section is more concentrate on hybrid stepper motor. The hybrid stepper motors combine the principle operation of the Variable Reluctance (VR) and Permanent Magnet (PM) motors.

Basically the principle on which stepper motors is based is very simple. It consists of permanent magnet, known as the rotor and the electromagnet on the stationary portion that surrounds the motor is called the stator. The rotor can move clockwise or anti clockwise. To move the rotor clockwise the upper electromagnet is deactivated and the right electromagnet is activated, so the rotor can move 90 degrees clockwise, aligning itself with the active magnet. This process is repeated in the same manner at the south and west electromagnet until once again reach the starting portion. In this case, assume that the motor resolution is 90 degrees, where resolution can be defined as degrees per step.

The torque in hybrid step motor is produced by the interaction of the field produce by rotor and stator. The rotor field is produced by permanent magnet and hence stays constant. The torque which acts to align the field and permanent magnet is called reluctance torque [22]. This is the torque which causes the rotor in a stepper motor to step.

2.5 MODE OF OPERATIONS

Basically there are three types of operations; full stepping, half stepping and micro stepping. Full stepping can be performed with one phase on or two phases on. One phase on (single stepping) is the simplest and most widely used mode of operations. A brief description on how all of this type of mode will operate will be explained below. For the sake of simplicity, the explanation will be based on the 90 degrees two phase stepper motor.

2.5.1 FULL STEPPING – ONE PHASE ON

In this mode only one phase is excited at a time. When phase A is energized the rotor is at a rest position ($\theta = 0$). Phase A is switch off immediately when the phase B is energized instead. In this situation, the current is transferred instantaneously from phase A to phase B. Therefore the rotor will move 90 degrees clockwise. Since the torque is clockwise for the whole 90 degrees, the rotor will be accelerating all the time, and overshoot at the 90 degrees position. Later the torque reverses and the rotor experiences a braking torque which brings it to rest. This process is repeated in the same manner by switching on phase A and switching off phase B until the rotor complete a full 360 degrees rotation.

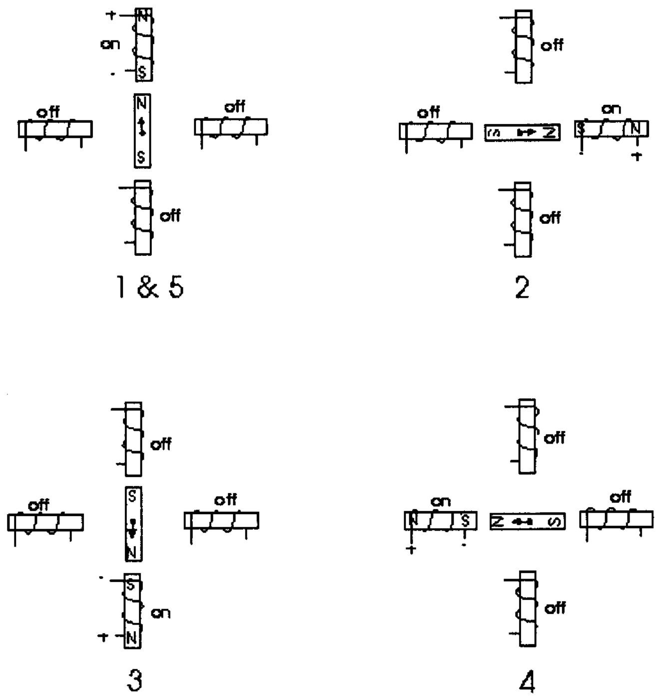

Figure 2.3: One phase on [18]

2.5.2 FULL STEPPING -TWO PHASE ON

In two phases on mode, two phases are excited simultaneously. When phase A and B are energized, the movement of rotor will produce torque from both phases. This movement will take full step but the rotor comes to its equilibrium positions at midpoint between the full step positions. Advantages of this mode are in providing a greater holding torque and much better damped single step response then the one phase on mode. This type of mode is suitable for hybrid motor since it needs bipolar supply to develop its full output.

2.5.3 HALF STEPPING

With half stepping both phases are energized, causing an equal attraction between them, thereby doubling the resolution. The phases are excited alternately in one phase on and two phases on modes. This causes the rotor to advance in step of half the full step angle. In the first position only the upper phase is energized and the rotor is drawn completely to it. Later both phases are energized causing the rotor to position between the two active poles. Finally the top phase is deactivated and the rotor is drawn all the way right. This process then will be repeated for the entire rotation. When compared to all type of operation, half stepping has advantages on doubling the resolution and producing a smoother rotor rotation where it permits the effective stepping angle to be halved.

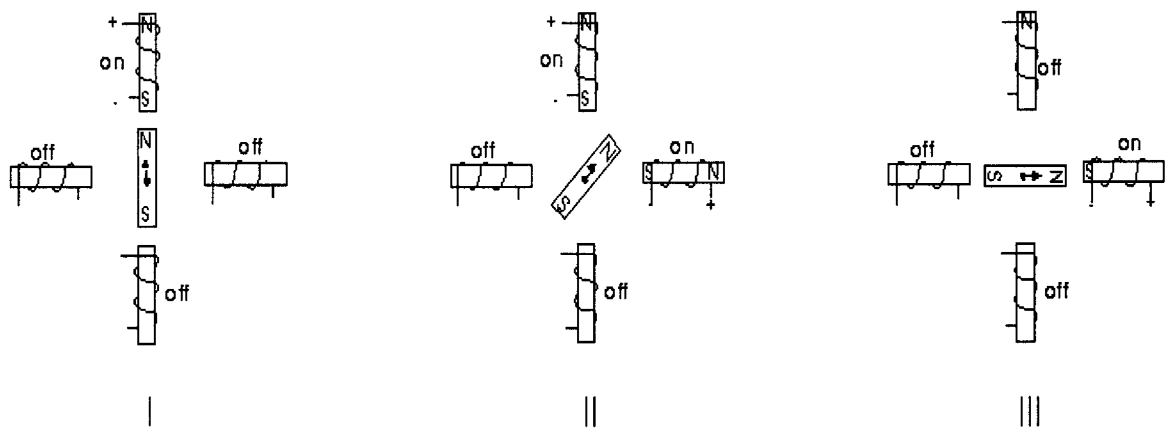

Figure 2.4: Half Stepping Mode [18]

2.5.4 MINI STEPPING

The technique is used when smaller than one degree step angle are demanded. In some applications, a very fine resolution is required for example in pointing of antennas. In this situation, this type of technique is used in order to reduce the step angle to a very small angle.