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DEPARTMENT OF MECHATRONICS ENGINEERING

19MCT204- Electrical Drives and Control

STEPPER MOTOR

A stepper motor is an electromechanical device it converts electrical power into mechanical power. Also, it is a brushless, synchronous electric motor that can divide a full rotation into an expansive number of steps. The motor's position can be controlled accurately without any feedback mechanism, as long as the motor is carefully sized to the application. Stepper motors are similar to switched reluctance motors. The stepper motor uses the theory of operation for magnets to make the motor shaft turn a precise distance when a pulse of electricity is provided. The stator has eight poles, and the rotor has six poles. The rotor will require 24 pulses of electricity to move the 24 steps to make one complete revolution. Another way to say this is that the rotor will move precisely 15° for each pulse of electricity that the motor receives.

Construction & Working Principle

The **construction of a stepper motor** is fairly related to a DC motor. It includes a permanent magnet like Rotor which is in the middle & it will turn once force acts on it. This rotor is enclosed through a no. of the stator which is wound through a magnetic coil all over it. The stator is arranged near to rotor so that magnetic fields within the stators can control the movement of the rotor.

Stepper Motor

The stepper motor can be controlled by energizing every stator one by one. So the stator will magnetize & works like an electromagnetic pole which uses repulsive energy on the rotor to move forward. The stator's alternative magnetizing as well as demagnetizing will shift the rotor gradually &allows it to turn through great control.

The **stepper motor working principle** is Electro-Magnetism. It includes a rotor which is made with a permanent magnet whereas a stator is with electromagnets. Once the supply is provided to the winding of the stator then the magnetic field will be developed within the stator. Now rotor in the motor will start to move with the rotating magnetic field of the stator. So this is the fundamental working principle of this motor.

Stepper Motor Construction

In this motor, there is a soft iron that is enclosed through the electromagnetic stators. The poles of the stator as well as the rotor don't depend on the kind of stepper. Once the stators of this motor are energized then the rotor will rotate to line up itself with the stator otherwise turns to have the least gap through the stator. In this way, the stators are activated in a series to revolve the stepper motor.

Driving Techniques

Stepper motor driving techniques can be possible with some special circuits due to their complex design. There are several methods to drive this motor, some of them are discussed below by taking an example of a four-phase stepper motor.

Single Excitation Mode

The basic method of driving a stepper motor is a single excitation mode. It is an old method and not used much at present but one has to know about this technique. In this technique every phase otherwise stator next to each other will be triggered one by one alternatively with a special circuit. This will magnetize & demagnetize the stator to move the rotor forward.

Full Step Drive

In this technique, two stators are activated at a time instead of one in a very less time period. This technique results in high torque & allows the motor to drive the high load.

Half Step Drive

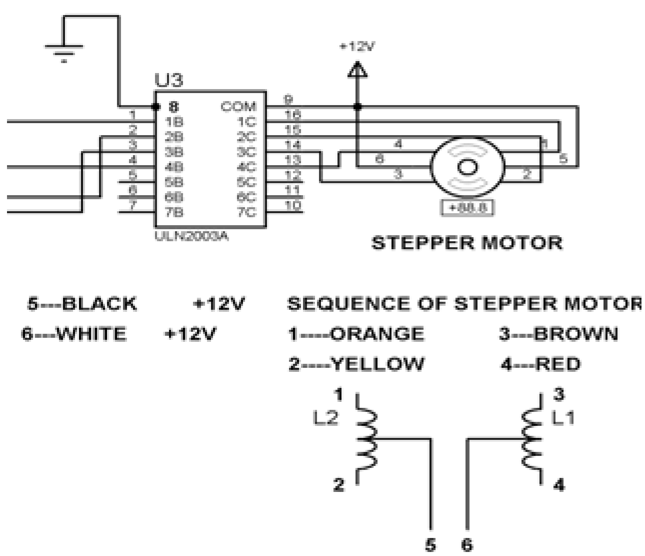
This technique is fairly related to the Full step drive because the two stators will be arranged next to each other so that it will be activated first whereas the third one will be activated after that. This kind of cycle for switching two stators first &after that third stator will drive the motor. This technique will result in improved resolution of the stepper motor while decreasing the torque.

Micro Stepping

This technique is most frequently used due to its accuracy. The variable step current will supply by the stepper motor driver circuit toward stator coils within the form of a sinusoidal waveform. The accuracy of every step can be enhanced by this small step current. This technique is extensively used because it provides high accuracy as well as decreases operating noise to a large extent.

Stepper Motor Circuit & Its Operation

Stepper motors operate differently from DC brush motors, which rotate when voltage is applied to their terminals. Stepper motors, on the other hand, effectively have multiple toothed electromagnets arranged around a central gear-shaped piece of iron. The electromagnets are energized by an external control circuit, for example, a microcontroller.



Stepper Motor Circuit

To make the motor shaft turn, first one electromagnet is given power, which makes the gear's teeth magnetically attracted to the electromagnet's teeth. At the point when the gear's teeth are thus aligned to the first electromagnet, they are slightly offset from the next electromagnet. So when the next electromagnet is turned ON and the first is turned OFF, the gear rotates slightly to align with the next one and from there the process is repeated. Each of those slight rotations is called a step, with an integer number of steps making a full rotation.

In that way, the motor can be turned by a precise. Stepper motor doesn't rotate continuously, they rotate in steps. There are 4 coils with a 90^{o} angle between each other fixed on the stator. The stepper motor connections are determined by the way the coils are interconnected. In a stepper motor, the coils are not connected. The motor has a 90^{o} rotation step with the coils being energized in a cyclic order, determining the shaft rotation direction.
The working of this motor is shown by operating the switch. The coils are activated in series in 1-sec intervals. The shaft rotates 90^{o} each time the next coil is activated. Its low-speed torque will vary directly with current.

Types of Stepper Motor

There are three main types of stepper motors, they are:

- Permanent magnet stepper
- Hybrid synchronous stepper
- Variable reluctance stepper

Permanent Magnet Stepper Motor

Permanent magnet motors use a permanent magnet (PM) in the rotor and operate on the attraction or repulsion between the rotor PM and the stator electromagnets.

This is the most common type of stepper motor as compared with different types of stepper motors available in the market. This motor includes permanent magnets in the construction of the motor. This kind of motor is also known as tin-can/can-stack motor. The main benefit of this stepper motor is less manufacturing cost. For every revolution, it has 48-24 steps.

Variable Reluctance Stepper Motor

Variable reluctance (VR) motors have a plain iron rotor and operate based on the principle that minimum reluctance occurs with minimum gap, hence the rotor points are attracted toward the stator magnet poles.

The stepper motor like variable reluctance is the basic type of motor and it is used for the past many years. As the name suggests, the rotor's angular position mainly depends on the magnetic circuit's reluctance that can be formed among the teeth of the stator as well as a rotor.

Hybrid Synchronous Stepper Motor

Hybrid stepper motors are named because they use a combination of permanent magnet (PM) and variable reluctance (VR) techniques to achieve maximum power in small package sizes.

The most popular type of motor is the hybrid stepper motor because it gives a good performance as compared with a permanent magnet rotor in terms of speed, step resolution, and holding torque. But, this type of stepper motor is expensive as compared with permanent magnet stepper motors. This motor combines the features of both the permanent magnet and variable reluctance stepper motors. These motors are used where less stepping angle is required like 1.5, 1.8 & 2.5 degrees.

How to Select a Stepper Motor?

Before selecting a stepper motor for your requirement, it is very significant to examine the torque-speed curve of the motor. So this information is available from the designer of the motor, and it is a graphical symbol of the torque of the motor at a specified speed. The motor's torque-speed curve should match closely the necessities of the application; or else, the expected system performance cannot be obtained.

Types of Wiring

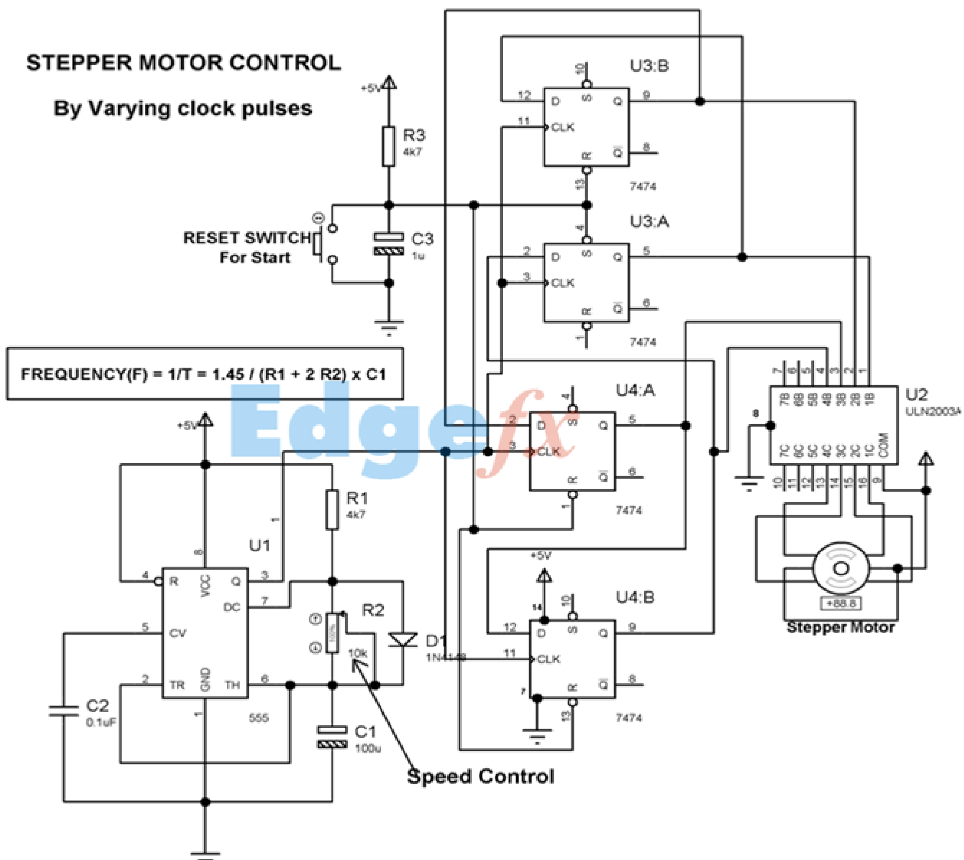
The stepper motors are generally two-phase motors like unipolar otherwise bipolar. For each phase in a unipolar motor, there are two windings. Here, center-tapped is a common one lead in between two windings toward a pole. The unipolar motor has 5 to 8 leads.

In the construction, where the common of two poles are divided however center-tapped, this stepper motor includes six leads. If the two-pole center taps are short inside, then this motor includes five leads. Unipolar with 8 leads will facilitate both series & parallel connection while the motor with five lead or six lead has stator coil's series connection. The operation of the unipolar motor can be simplified because while operating them, there is no requirement of reversing the flow of current within the driving circuit which are known as bifilar motors.

In a bipolar stepper motor, for each pole, there is a single winding. The direction of supply needs to change through the driving circuit so that it will become complex so these motors are called unifilar motors.

Stepper Motor Control by Varying Clock Pulses

Stepper motor control circuit is a simple and low-cost circuit, mainly used in low power applications. The circuit is shown in the figure, which consists of 555 timers IC as a stable multi-vibrator. The frequency is calculated by using the given relationship. Frequency = 1/T = 1.45/(RA + 2RB)C Where RA = RB = R2 = R3 = 4.7 kilo-ohm and C = C2 = 100 μF.



Stepper Motor Control by Varying Clock Pulses

The output of the timer is used as a clock for two 7474 dual 'D' flip-flops (U4 and U3) configured as a ring counter. When power is initially switched on, only the first flip-flop is set (i.e. Q output at pin 5 of U3 will be at logic '1') and the other three flip-flops are reset (i.e. the output of Q is at logic 0). On receipt of a clock pulse, the logic '1' output of the first flip-flop gets shifted to the second flip-flop (pin 9 of U3).

Thus, logic 1 output keeps shifting circularly with every clock pulse. Q outputs of all the four flip-flops are amplified by Darling-ton transistor arrays inside ULN2003 (U2) and connected to the stepper motor windings orange, brown, yellow, black to 16, 15,14, 13 of ULN2003 and the red to +ve supply.

The common point of the winding is connected to the +12V DC supply, which is also connected to pin 9 of ULN2003. The color code used for the windings is may vary from make to make. When the power is switched on, the control signal connected to the SET pin of the first flip-flop and CLR pins of the other three flip-flops goes active 'low' (because of the power-on-reset circuit formed by the R1-C1 combination) to set the first flip-flop and reset the remaining three flip-flops.

On reset, Q1 of IC3 goes 'high' while all other Q outputs go 'low'. An external reset can be activated by pressing the reset switch. By pressing the reset switch, you can stop the stepper motor. The motor again starts rotating in the same direction by releasing the reset switch.

Difference between Stepper Motor and Servo Motor

Servo motors are suitable for high torque & speed applications whereas the stepper motor is less expensive so they are used where the high holding torque, acceleration with low-to-medium, the open otherwise closed-loop operation flexibility is required. The difference between the stepper motor and servo motor includes the following.

Stepper Motor	**Servo Motor**
The motor which moves in discrete steps is known as the stepper motor.	A servo motor is one kind of closed-loop motor that is connected to an encoder to provide speed feedback & position.
Stepper motor is used where control, as well as precision, are main priorities	Servo motor is used where the speed is the main priority
The overall pole count of the stepper motor ranges from 50 to 100	The overall pole count of servo motor ranges from 4to 12
In a closed-loop system, these motors move with a consistent pulse	These motors need an encoder to change pulses to control the position.
Torque is high in less speed	Torque is low in high speed

Positioning time is faster throughout short strokes	Positioning time is faster throughout long strokes
High-tolerance movement of inertia	Low-tolerance movement of inertia
This motor is suitable for low rigidity mechanisms like pulley and belt	Not suitable for less-rigidity mechanism
Responsiveness is high	Responsiveness is low
These are used for fluctuating loads	These are not used for fluctuating loads
The adjustment of gain/tuning is not required	The adjustment of gain/tuning is required

Stepper Motor vs DC Motor

Both the stepper and dc motors are used in different industrial applications but the main differences between these two motors are a little bit confusing. Here, we are listing some common characteristics between these two designs. Each characteristic is discussed below.

Characteristics	**Stepper Motor**	**DC Motor**
Control Characteristics	Simple and uses microcontroller	Simple and no extras required
Speed Range	Low from 200 to 2000 RPMs	Moderate
Reliability	High	Moderate
Efficiency	Low	High
Torque or Speed Characteristics	Highest Torque at Fewer Speeds	High Torque at Fewer Speeds
Cost	Low	Low

Parameters of Stepper Motor

The stepper motor parameters mainly include step angle, steps for each revolution, steps for each second, and RPM.

Step Angle
The step angle of the stepper motor can be defined as the angle at which the motor's rotor turns once a single pulse is given to the stator's input. The resolution of the motor can be defined as the number of steps of the motor and the number of revolutions of the rotor.

Resolution = Number of Steps/Number of Revolution of the Rotor
The motor's arrangement can be decided through the step-angle & it is expressed within degrees. The resolution of a motor (the step number) is the no. of steps which make within a single revolution of the rotor. When the step-angle of the motor is small then the resolution is high for the arrangement of this motor.

The exactness of the arrangements of the objects through this motor mainly depends on the resolution. Once the resolution is high then the accuracy will be low.

Some accuracy motors can create 1000 steps within a single revolution including 0.36 degrees of step-angle. A typical motor includes 1.8 degrees of step angle with 200 steps for each revolution. The different step angles such as 15 degrees, 45 degrees, and 90 degrees are very common in normal motors. The number of angles can change from two to six and a small step angle can be attained through slotted pole parts.

Steps for Each Revolution
The steps for each resolution can be defined as the number of step angles necessary for a total revolution. The formula for this is 360°/Step Angle.

Steps for Each Second
This kind of parameter is mainly used for measuring the number of steps covered within each second.

Revolution per Minute
The RPM is the revolution per minute. It is used to measure the frequency of revolution. So by using this parameter, we can calculate the number of revolutions in a single minute. The main relation between the parameters of the stepper motor is like the following.

Steps for Each Second = Revolution per Minute x Steps per Revolution / 60

Stepper Motor Interfacing with 8051 Microcontroller

Stepper motor interfacing with 8051 is very simple by using three modes like wave drive, full step drive & half step drive by giving the 0 & 1 to the motor's four wires based on which drive mode we have to choose for running this motor.

The remaining two wires must be coupled to a voltage supply. Here the unipolar stepper motor is used where the four ends of the coils are connected to the primary four pins of port-2 in the microcontroller using the ULN2003A.

This microcontroller doesn't supply sufficient current to drive the coils so the current driver IC likes ULN2003A. ULN2003A must be used and it is the collection of 7-pairs of NPN Darlington transistors. The designing of the Darlington pair can be done through two bipolar transistors which are connected for achieving maximum current amplification.

In ULN2003A driver IC, input pins are 7, output pins are 7, where two pins are for power supply & Ground terminals. Here 4-input & 4-output pins are used. As an alternative to ULN2003A, L293D IC is also used for amplification of current.

You need to observe two common wires & four coil wires very carefully or else the stepper motor will not turn. This can be observed by measuring the resistance through a multimeter but the multimeter won't display any readings among the two phases of wires. Once the common wire & other two wires are in the equal phase then it must show a similar resistance whereas the two coils finish points in the similar phase will demonstrate the double resistance as compared with resistance among common point as well as one endpoint.

Troubleshooting

- Troubleshooting is the process to check the motor status whether the motor is working or not. The following checklist is used to troubleshoot the stepper motor.
- First, verify the connections as well as the code of the circuit.
- If it is ok, next verify that the motor gets proper voltage supply or else it simply vibrate however not revolve.
- If the voltage supply is well, then verify the endpoints of the four coil which is allied to ULN2003A IC.
- First, discover the two general endpoints & fix them to 12v supply, after that fix the residual four wires to IC ULN2003A. Until the stepper motor gets started, attempt all possible combinations. If the connection of this is not proper then this motor will vibrate in place of revolving.

Can Stepper Motors Run Continuously?

Generally, all the motors run or rotate continuously but most of the motors cannot stop while they under power, When you try to restrict the shaft of a motor when it is under power supply then it will burn or break.

Alternatively, stepper motors are designed to make a discrete step, then wait there; again step and stay there. If we want to make the motor stay in a single location for less time before stepping again then it will look like rotating continuously. The power consumption of these motors is high but the power dissipation mainly occurs once the motor is stopped or designed poorly then there is a chance for overheating. Because of this reason, the motor's current supply is frequently decreased once the motor is in a holding position for a longer time.

The main reason is, once the motor is rotating, its input electrical power part can be changed to mechanical power. When the motor is stopped while it is rotating, then all input power can be changed into heat on the inside of the coil.

Advantages

The **advantages of stepper motor** include the following.

- Ruggedness
- Simple construction
- Can work in an open-loop control system
- Maintenance is low
- It works in any situation
- Reliability is high
- The rotation angle of the motor is proportional to the input pulse.
- The motor has full torque at standstill.
- Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 – 5% of a step and this error is noncumulative from one step to the next.
- Excellent response to starting, stopping, and reversing.
- Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.
- The motor's response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.
- It is possible to achieve very low-speed synchronous rotation with a load that is directly coupled to the shaft.
- A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

The **disadvantages of stepper motor** include the following.

- Efficiency is low
- The Torque of a motor will declines fast with speed
- Accuracy is low
- Feedback is not used for specifying potential missed steps
- Small Torque toward Inertia Ratio
- Extremely Noisy
- If the motor is not controlled properly then resonances can occur

- Operation of this motor is not easy at very high speeds.
- The dedicated control circuit is necessary
- As compared with DC motors, it uses more current

Applications

The **applications of stepper motor** include the following.

1. **Industrial Machines** – Stepper motors are used in automotive gauges and machine tooling automated production equipment.
2. **Security** – new surveillance products for the security industry.
3. **Medical** – Stepper motors are used inside medical scanners, samplers, and also found inside digital dental photography, fluid pumps, respirators, and blood analysis machinery.
4. **Consumer Electronics** – Stepper motors in cameras for automatic digital camera focus and zoom functions.