Simple Discussion on Stepper Motors for the Development of Electronic Device

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Abstract— This paper is designed and developed to have the general as well as basic knowledge about the modern electronic device named ‘Stepper motor’. A step motor can be viewed as a synchronous AC motor with the number of poles (on both rotor and stator) increased, taking care that they have no common denominator. Additionally, we have discussed about its characteristics, classification, operation, advantages and electric magnetic effects.

Index Terms— Electronic device, stepper motor, synchronous, rotor, stator, electric and magnetic effects.

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1 INTRODUCTION

Stepper motors can be viewed as electric motors without commentators. Typically all windings in the motor are part of the stator and the rotor is permanent magnet or in the case of variable reluctance motors, a toothed block of some magnetically soft material. All of the commutation must be handled externally by the motor controller, and typically, the motors and controllers are designed so that the motor may be held in any fixed position as well as being rotated one way or the other [1, 2]. Most stepping motors can be stepped at audio frequencies, allowing them to spin quite quickly and with an appropriate controller, they may be started and stopped "on a dime" at control orientations. For some applications, there is a choice between using servomotors and stepper motors. Both types of motors offer similar opportunities for precise positioning but they differ in a number of ways. Servomotors require analog feedback control systems of some type. Typically, this involves a potentiometer to provide feedback about the rotor position and the current position. In making a choice between stepper motors and servomotors, a number of issues must be considered; which of this will matter depends on the applications [2, 3]. For example, the repeatability of positioning done with a stepper motor depends on the geometry of the motor rotor, while the repeatability done with a servomotor generally depends on the stability of the potentiometer and other analog components in the feedback circuit. Stepper motors can be used in simple open look control system; these are generally adequate for system that operates at low accelerating with static loads, but closed look control may be essential for high acceleration, particularly if they involve variable loads. If a stepper motor in open look control system is over torque, all knowledge of rotor position is lost and the system must be reinitialized Servomotors are not subject to this problem. [4, 5].

For applications where precise measuring of a motors' rotor position is critical, a stepper motor is usually the best choice. Stepper motors operate differently than other motors; rather than voltage being applied and the rotor spinning smoothly, stepper motors turn on a series of electrical pulses to the motor's windings. Each pulse rotates the rotor by an exact degree. These pulses are called "steps", hence the name "stepper motor". Stepper motors are traditionally used in various motion control applications. Stepper motors are quite easy to wire and control. Stepper systems are economical to implement, intuitive to control, and have good low speed torque, making them ideal for many low power, computer-controlled applications. They can be for example interfaced to computer using few transistors and made to rotate using a small piece of software. Stepper motors provide good position repeatability. Stepper motors are used in robotics control and in computer accessories (disk drives, printers, scanners etc.).

Stepping motors come in a wide tune of angular resolution. The coarsest motors typically turn 90 degrees per step, while high resolution permanent magnet motors are commonly able to handle 1.8 or even 0.72 degrees per step. With an appropriate controller, most permanent magnet and hybrid motors can be run in half- steps, and some controllers can handle smaller fractional steps or micro steps [6].

2 COMMON CHARACTERISTICS OF STEPPER MOTORS

Stepper motors are not just rated by voltage. The following elements characterize a given stepper motor [5, 7]:

2.1 Voltage

Stepper motors usually has a voltage rating. This is either printed directly on the unit, or is specified in the motor's datasheet. Exceeding the rated voltage is sometimes necessary to obtain the desired torque from a given motor, but doing so may produce excessive heat and/or shorten the life of the motor.

2.2 Resistance

Resistance-per-winding is another characteristic of a stepper motor. This resistance will determine current draw of the motor, as well as affect the motor's torque curve and maximum operating speed.

2.3 Degrees Per Step

This is often the most important factor in choosing a stepper motor for a given application. This factor specifies the number of degrees the shaft will rotate for each full step. Half step operation of the motor will double the number of steps/revolution, and cut the degrees-per-step in half. For unmarked motors, it is often possible to carefully count, by hand, the number of steps per revolution of the motor. The degrees per step can be calculated by dividing 360 by the number of steps in 1 complete revolution Common degree/step numbers include: 0.72, 1.8, 3.6, 7.5, 15, and even 90. Degrees per step are often referred to as the *resolution* of the motor. As in the case of an unmarked motor, if a motor has only the number of steps/revolution printed on it, dividing 360 by this number will yield the degree/step value [7].

3 DIFFERENT TYPES OF STEPPER MOTOR

Stepper motors may be classified by their drive topology, motor construction and stepping pattern. The drive topology of stepper motors is an important criterion for choosing a motor. Here are two main topologies to mention, unipolar and bipolar driving.

3.1 Unipolar Motor

Unipolar stepping motors, both Permanent magnet and hybrid stepping motors with 5 or 6 wires are usually wired as shown in the schematic in Figure 2.1, with a center tap on each of two windings. In use, the center taps of the windings are typically wired to the positive supply.

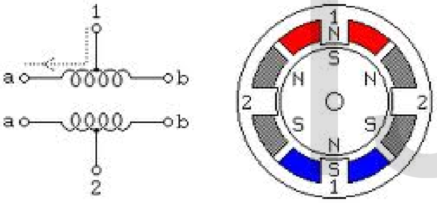


Figure1 - Schematic diagram of unipolar stepper motor

The motor cross section shown in Figure1 is of a 30 degree per step permanent magnet or hybrid motor. Motor winding number 1 is distributed between the top and bottom stator pole, while motor winding number 2 is distributed between the left and right motor poles.

For higher angular resolutions, the rotor must have proportionally more poles. The 30 degree per step motor in the figure is one of the most common permanent magnet motor designs, although 15 and 7.5 degree per step motors are widely available. Permanent magnet motors with resolutions as good as 1.8 degrees per step are made, and hybrid motors are routinely built with 3.6 and 1.8 degrees per step, with resolutions as ne as 0.72 degrees per step available. As shown in the figure, the current flown from the center tap of winding 1 to terminal a causes the top stator pole to be a north pole while the bottom stator pole is a south pole. This attracts the rotor into the position shown.

To rotate the motor continuously, we just apply power to the two windings in sequence. Assuming positive logic, where a 1 means turning on the current through a motor winding, the following two control sequences will spin the motor illustrated in Figure1 clockwise 24 steps or 2 revolutions:

The two halves of each winding are never energized at the same time. Both sequences shown above will rotate a permanent magnet one step at a time. The top sequence only powers one winding at a time, as illustrated in the figure above; thus, it uses less power. The bottom sequence involves powering two windings at a time and generally produces a torque about 1.4 times greater than the top sequence while using twice as much power.

Winding la 10001000100010001000l001 *Winding lb 001000100010001000l000100* *Winding 2a 010001000100010001000l000* *Winding 2b 000100010001000l000100010* *time --->*	*Winding la 11001 1001 10011001 1001 1001* *Winding lb 0011001100110011001100110* *Winding 2a 0110011001100110011001100* *Winding 2b 1001100110011001100110011* *time --->*

The step positions produced by the two ssequences above are not the same; as a result, combining the two sequences allows half stepping, with the motor stopping alternately at the positions indicated by one or the other sequence. The combined sequence is as follows:

Winding 1a 1100000111000001110000111

Winding lb 0001110000011100000111000O

Winding 2a 0111000001110000011100000l

Winding 2b 0000011100000111000001110O
time --->

To control the stepper, apply voltage to each of the coils in a specific sequence. The sequence would go like this:

Step	**wire 1**	**wire 2**	**wire 3**	**wire 4**
1	**High**	**low**	**High**	**Low**
2	**Low**	**high**	**High**	**Low**
3	**Low**	**high**	**Low**	**High**
4	**High**	**low**	**Low**	**High**

To control a unipolar stepper, a Darlington Transistor Array is used. The stepping sequence is as shown above. Wires 5 and 6 are wired to the supply voltage.

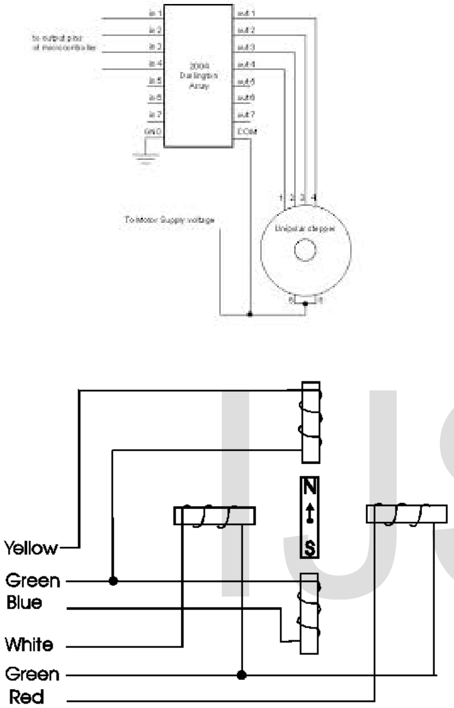


Figure2 - Basic Connections of Unipolar Stepper Motor (the electrical equivalent stepper motor)

3.2 Bipolar Motor

Bipolar permanent magnet and hybrid motors are constructed with exactly the same mechanism as is used on unipolar motors, but the two windings are wired more simply, with no center taps. Thus, the motor itself is simpler but the drive circuitry needed to reverse the polarity of each pair of motor poles is more complex. The schematic in Figure3 shows how such a motor is wired, while the motor cross section shown here is exactly the same as the cross section shown in Figure2.

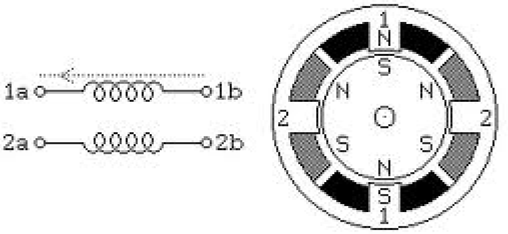


Figure3 - Schematic diagram of bipolar stepper motor

The drive circuitry for such a motor requires an H-bridge control circuit for each winding. Briefly, an H-bridge allows the polarity of the power applied to each end of each winding to be controlled independently. The control sequences for single stepping such a motor are shown below, using + and symbols to indicate the polarity of the power applied to each motor terminal:

```
Terminal la +---+---+---+--- ++--++--++--++--
Terminal lb --+---+---+---+- --++--++--++--++
Terminal 2a -+---+---+---+-- -++--++--++--++-
Terminal 2b ---+---+---+---+ +--++--++--++--+
            time --->
```

These sequences are identical to those for a unipolar permanent magnet motor, at an abstract level, and that above the level of the H-bridge power switching electronics, the control systems for the two types of motor can be identical. Many full H-bridge driver chips have one control input to enable the output and another to control the direction. Given two such bridge chips, one per winding, the following control sequences will want the motor identically to the control sequences given above:

```
Enable      1 1010101010101010  111111111111111
Direction    1 lx0x1x0x1x0x1x0x  1100110011001100
Enable      2 0101010101010101  1111111111111111
Direction    2 xlx0x1x0x1x0x1x0  0110011001100110
            time --->
```

To distinguish a bipolar permanent magnet motor from other 4 wire motors, measure the resistances between the different terminals. It is worth noting that some permanent magnet stepping motors have 4 independent windings, organized as two sets of two. Within each set, if the two windings are wired in series, the result can be used as a high voltage bipolar motor. If they are wired in parallel, the result can be used as a low voltage bipolar motor. If they are wired in series with a center tap, the result can be used as a low voltage unipolar motor [8].

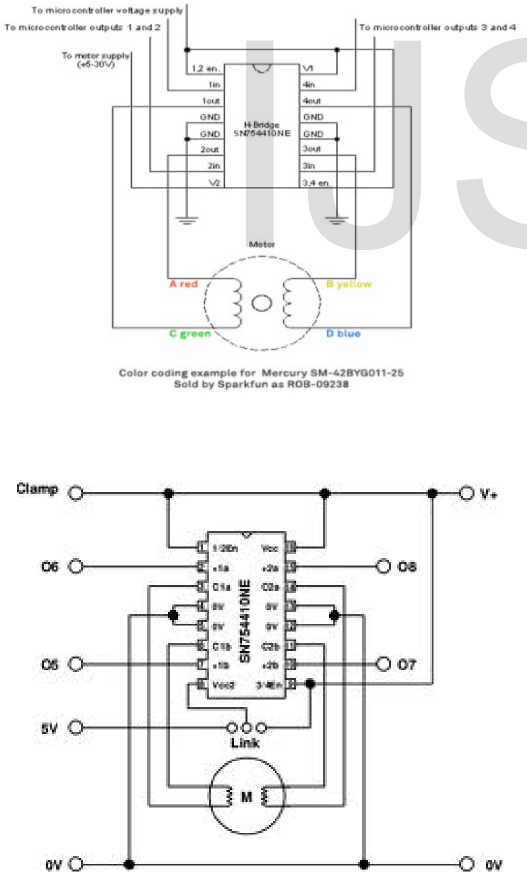
Like other motors, stepper motors require more power than a microcontroller can give them, so we'll need a separate tower supply for it. Ideally we'll know the voltage from the manufacturer, but ii not, get a variable DC power supply, apply the minimum voltage (hopefully 5V or so), apply voltage across two wires of a coil (e.g. I to 2 or 3 to 4) and slowly raise the voltage until the motor is difficult to turn. It is possible to damage a motor this way, so don't go too far. Typical voltages for a stepper might be 5V, 9V, 12V, 24V. Higher than 24V is less common for small steppers, arid frankly, above that level it's best not to guess.

To control a bipolar stepper motor, we have to give the coils current using to the same steps as for a unipolar stepper motor. However, instead of using four coils, you use the both poles of the two coils, and reverse the polarity of the current. The easiest way to reverse the polarity in the coils is to use a pair of H-bridges. The L293D dual H-bridge has two H-bridges in the chip, so it will work nicely for this purpose.

Once the motor stepping in one direction, stepping in the other direction is simply a matter of doing the steps in reverse order. Knowing the position is a matter of knowing how many degrees per step, and counting the steps and multiplying by that many degrees. So for examples, if you have a 1.8-degree stepper, and it's turned 200 steps, then it's turned 1.8 x 200 degrees, or 360 degrees, or one full revolution. There are several different types of 3tepper motor construction. These include variable reluctance, permanent magnet, and hybrid permanent magnet.

3.3 Variable Reluctance Motor

The Variable Reluctance Motor (VRM) is a type of motor with significant industrial relevance. Although it is usually used as a "stepper-motor," in products such as computer printers, it can be made to behave like a servomotor if properly controlled. In this mode, it has a number of advantages over the typical brushed servomotor, including a larger torque-to-mass ratio, better thermal characteristics (the windings are in the stator, on the outside of the motor), brushless operation, and a less expensive construction. However, it is challenging to control the VRM in this manner because it is highly nonlinear, and it requires electronic commutation.



Color coding example for Mercury SM-42BYG011-25
Sold by Sparkfun as ROB-09238

Figure 4 - Basic connection of bipolar stepper motor (H-Bridges)

3.4 Permanent Magnet Motor

The mentioned advantage of high speed permanent magnet motors and generators can only be achieved by using high quality motor elements. The reason for that is that due to the high rotational speeds, the centrifugal forces on the rotating motor part (rotor) can be very high leading the materials to the edge of mechanical stress resistivity. Failures in motor elements can result in crashes affecting the environment or at least damage the system, where the generator or motor is built in. To prevent this, various physical aspects need to be calculated in a challenging development process, taking electromagnetic, thermal, mechanical stress and structure dynamic aspects into account. The applied computational methods need to be combined with a long experience, to extend actual operation limitations with keeping safety in mind as highest priority. Furthermore, the interaction of the rectifier and the permanent magnet motor needs to be known, because the rectifier has a deep impact on heating, noise, clogging, and efficiency of the motor. Especially the interaction of various converter systems with a high speed motor element demands very specific knowledge and experience. Hence tests of above described applications are crucial to succeed. They require an intense relation between the power electronic and high speed permanent magnet motor specialists. Furthermore the infrastructure enabling performance tests are highly complex and usually not available on the market. Very often the related costs exceed by far the costs incurred during the whole development process of a new motor element product line.

3.5 HYBRID PERMANENT MAGNET MOTOR

The hybrid stepper motor is the most widely used and combines the principles of the permanent magnet and the variable reluctance motors. The hybrid stepper motor is more expensive than the permanent magnet stepper motor but provides better performance with respect to step resolution, torque and speed. The hybrid stepper motor combines the best features of both the permanent magnet and variable reluctance type stepper motors. The rotor is multi-toothed like the variable reluctance motor and contains an axially magnetized concentric magnet around its shaft. The teeth on the rotor provide an even better path, which helps guide the magnetic flux to preferred locations in the air gap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the variable reluctance and permanent magnet types [7].

4 HOW STEPPER MOTOR WORKS

Motion Control, in electronic terms, means to accurately control the movement of an object based on either speed, distance, load, inertia or a combination of all these factors. There are numerous types of motion control systems, including; Stepper Motor, Linear Step Motor, DC Brush, Brushless, Servo, Brushless Servo and more. This document will concentrate on Step Motor technology.

In Theory, a Stepper motor is a marvel in simplicity. It has no brushes, or contacts. Basically it's a synchronous motor with the magnetic field electronically switched to rotate the armature magnet around [2].

Stepper motors consist of a permanent magnet rotating shaft, called the rotor, and electromagnets on the stationary portion that surrounds the motor, called the stator. Figure9 illustrates one complete rotation of a stepper motor. At position 1, we can see that the rotor is beginning at the upper electromagnet, which is currently active (has voltage applied to it). To move the rotor clockwise (CW), the upper electromagnet is deactivated and the right electromagnet is activated, causing the rotor to move 90 degrees CW, aligning itself with the active magnet. This 9rocess is repeated in the same manner at the south and west electromagnets until we once again reach the starting position. [13].

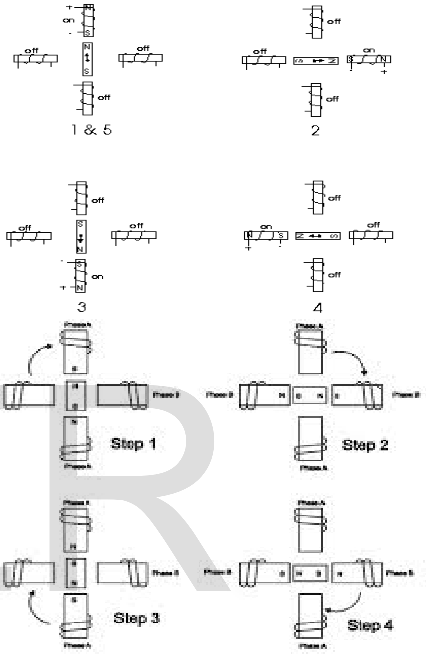


Figure 9 - Rotation of Stepper Motor

In the above example, we used a motor with a resolution of 90 degrees or demonstration purposes. In reality, this would not be a very practical motor for most applications. The average stepper motor's resolution -- the amount of degrees rotated per pulse -- is much higher than this. For example, a motor with a resolution of 5 degrees would move its rotor 5 degrees per step, thereby requiring 72 pulses (steps) to complete a full 360 degree rotation. We may double the resolution of some motors by a process known as "half-stepping". Instead of switching the next electromagnet in the rotation on one at a time, with half stepping we turn on both electromagnets, causing an equal attraction between, thereby doubling the resolution. As we can see in Figure10, in the first position only the upper electromagnet is active, and the rotor is drawn completely to it. In position 2, both the top and right electromagnets are active, causing the rotor to position itself between the two active poles. Finally, in position 3, the top magnet is deactivated and the rotor is drawn all the way right. This process can then be repeated for the entire rotation.

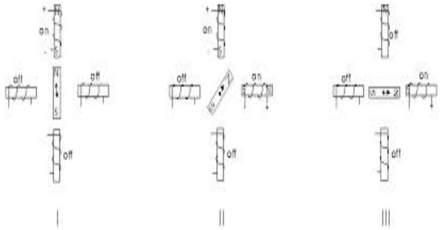


Figure10 - Position of electromagnet in stepper motor

There are several types of stepper motors. 4-wire stepper motors contain only two electromagnets; however the operation is more complicated than those with three or four magnets, because the driving circuit must be able to reverse the current after each step. For our purposes, we will be using a 6-wire motor [3].

Unlike our example motors, which rotated 90 degrees per step, real-world motors employ a series of mini-poles on the stator and rotor to increase resolution. Although this may seem to add more complexity to the process of driving the motors, the operation is identical to the simple 90-degree motor we used in our example. An example of a multiple motor can be seen in Figure11. In position 1, the north pole of the rotor's permanent magnet is aligned the south pole of the stator's electromagnet. Note that multiple positions aligned at once. In position 2, upper electromagnet is deactivated and next one to its immediate left is activated, causing the rotor to rotate a amount of degrees. In this example, after eight steps the sequence respects [8].

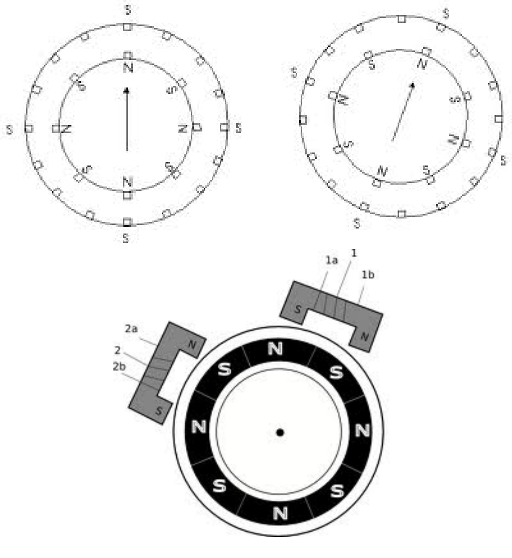


Figure11 - Multiple steppers motor

4.1 Electromagnetic Issues

In a permanent magnet or hybrid stepping motor, the magnetic field of the motor rotor changes with changes in shaft angle. The result of this is that turning the motor rotor induces an AC voltage in each motor winding. This is referred to as the counter EMF because the voltage induced in each motor winding is always in phase with and counter to the ideal waveform required to turn the motor in the same direction. Both the frequency and amplitude of the counter EMF increase with rotor speed, and therefore, counter EMF contributes to the decline in torque with increased stepping rate. Variable reluctance stepping motors also induce counter EMF! This is because, as the stator winding pulls a tooth of the rotor towards its equilibrium position, the reluctance of the magnetic circuit declines. This decline increases the inductance of the stator winding, and this change in inductance demands a decrease in the current through the winding in order to conserve energy. This decrease is evidenced as a counter EMF.

The reactance (inductance and resistance) of the motor windings limits the current flowing through them. Thus, by ohms law, increasing the voltage will increase the current, and therefore increase the available torque. The increased voltage also serves to overcome the counter EMF induced in the motor windings, but the voltage cannot be increased arbitrarily! Thermal, magnetic and electronic considerations all serve to limit the useful torque that a motor can produce. The heat given off by the motor windings is due to both simple resistive losses, eddy current losses, and hysteresis losses. If this heat is not conducted away from the motor adequately, the motor windings will overheat. The simplest failure this can cause is insulation breakdown, but it can also heat a permanent magnet rotor to above its curie temperature, the temperature at which permanent magnets lose their magnetization. This is a particular risk with many modern high strength magnetic alloys.

Even if the motor is attached to an adequate heat sink, increased drive voltage will not necessarily lead to increased torque. Most motors are designed so that, with the rated current flowing through the windings, the magnetic circuits of the motor are near saturation. Increased current will not lead to an appreciably increased magnetic field in such a motor!

Given a drive system that limits the current through each motor winding to the rated maximum for that winding, but uses high voltages to achieve a higher cutoff torque and higher torques above cutoff, there are other limits that come into play. At high speeds, the motor windings must, of necessity, carry high frequency AC signals. This leads to eddy current losses in the magnetic circuits of the motor, and it leads to skin effect losses in the motor windings. Motors designed for very high speed running should, therefore, have magnetic structures using very thin laminations or even nonconductive ferrite materials, and they should have small gauge wire in their windings to minimize skin effect losses. Common high torque motors have large-gauge motor windings and coarse core laminations, and at high speeds, such motors can easily overheat and should therefore be derated accordingly for high speed running. It is also worth noting that the best way to demagnetize something is to expose it to a high frequency-high amplitude magnetic field.

Running the control system to spin the rotor at high speed when the rotor is actually stalled, or spinning the rotor at high speed against a control system trying to hold the rotor in a fixed position will both expose the rotor to a high amplitude high-frequency field. If such operating conditions are common, particularly if the motor is run near the curie temperature of the permanent magnets, demagnetization is a serious risk and the field strengths (and expected torques) should be reduced accordingly.

5 ADVANTAGES

A wide range of rotational speeds can be utilized with a stepping motor since the speed of a stepping motor is proportional to the frequency of the input pulses from your controller. Precise open-loop positional control is possible with a stepper motor without any feedback mechanism. Very low speed rotation is possible with a load that is coupled directly to the shaft of the stepping motor. A stepping motor is quite reliable because there are no contact brushes. Generally, the life of a stepper motor is determined by the life of the stepper motor bearing. A stepper motor is very good at starting, stopping and reversing direction. A stepper motor is very good in providing precise positioning and repeatability of movement.

5.1 Conveyors

Common motor requirements for conveyors include:
-LowVibration
- Stopping Precision
- Ability to withstand harsh environments
- Acceleration, deceleration capability
- Position retention
Stepper motors, AC motors and Brushless motors are commonly used for high-precision feed and digital control. The FPW Series of dust-resistant, watertight AC motors are available when environmental elements are a factor.

5.2 Linear Operation

The movement distance per rotation of the thread is determined by the thread pitch, so the significant points are the resolution and stepping precision. Our linear actuators offer all-in-one linear motion systems. Or you can build your own linear motion system using one of our standard rotary systems combined with a linear mechanism. When you need more than 200 stopping points per rotation of the lead screw, consider a motor first. We recommend the RK series microstep stepper motor and driver system, which is one of our standard stepper motor products. We suggest a AC reversible motor or electromagnetic brake motor with an electronic brake pack for lower resolution applications. If variable speed is required we recommend the AC motor or brushless DC motor speed control system.

5.3 Rotational Operation

For Rotational Operation applications, resolution and stopping precision are the most important points. The RK Series of 5-phase microstep stepper motor systems may also be suitable for your needs. If an overrun of less than 1 rotation (motor alone) is required, try an AC induction motor, AC reversible motor, or electromagnetic brake motor with an electronic brake pack. If speed control is a primary requirement, the BLU series BLDC motor and driver system offers AC input and easy operation, while the BLH series BLDC motor and driver system offers DC input and a compact size. Both the BLU and BLH use brushless DC motors for long life and low maintenance. The ES speed controller combined with an AC compact motor is simple to use. If high frequency starting and stopping are required, clutch and brake motors may be the best fit. With a clutch and brake motor, the motor runs continuously and the load is started and stopped by switching the clutch and brake on and off, enabling continual operation of 100 cycles per minute.

5.4 Other Mechanisms

When high speed operation and high resolution are required, a stepper motor is the best solution. The closed loop Alpha STEP step motor and driver system offers short, accurate moves and closed loop feedback. Our microstepping step motor and driver systems offer high precision and very low vibration. For speed stability, brushless DC motor speed control systems offer a wide range of solutions, such as the BLH series, BLU series, BLF series, BX series or FBLII series. Easy-to-use AC speed control motor systems and SB50 brake packs can be combined with an AC compact motor to meet a wide variety of application requirements.
If high frequency starting and stopping are required, clutch and brake motors may be the best fit. With a clutch and brake motor, the motor runs continuously and the load is started and stopped by switching the clutch and brake on and off, enabling continual operation of 100 cycles per minute. For low speed, high torque applications, we recommend the SMK series of low speed synchronous motors. If the application incorporates a rack & pinion mechanism, the LS series of linear heads connected to AC motors is recommended.

5.5 Cooling Applications

A fan is a device that creates airflow by using a motor to rotate blades. Cooling fans are essential in the smooth operation of many sophisticated machines, such as electronic equipment. The ORIX fan line includes AC and DC axial flow fans for ventilation and cooling, centrifugal blowers for local cooling, and cross flow fans for a wide, uniform sheet of air. The ORIX fan line incorporated specially designed fan blades for increased air pressure, increased static pressure, high airflow and low noise.

6 LIMITATIONS

Stepper motors have their limitations. They are available in limited power (less than one horse power) and their rotation speed is limited (usually maximum speed limit is about 2000 rpm). The energy efficiency of stepper motors is low and stepper motor systems have tendency to have resonances, which needs to be avoided. Stepper motors have characteristic holding torque (ability to hold the position) and pullout torque (ability to move to the next position). Other torques can be difficult to achieve. Therefore, precise torque control is difficult with steppers. Because of open-loop nature of stepper motor controlling, they are not very good to be used with varying loads. It is possible for a stepper motor to lose steps if it is loaded too much. Steppers are not recommended for high-speed or high-power applications, or for applications requiring precise torque control. The stepper motors typically have a rated voltage at what they can work without overheating. Operating, the motor at this voltage limits the maximum speed and torque at high speed Hi Torque at Top Speed is achieved over-voltage of the motors with current limiting. Using power resistors or a chopper drive to keep current at the desired level can do the current limiting.

7 CONCLUSION

A step motor can be viewed as a synchronous AC motor with the number of poles (on both rotor and stator) increased, taking care that they have no common denominator. Additionally, soft magnetic material with many teeth on the rotor and stator cheaply multiplies the number of poles (reluctance motor). Modern steppers are of hybrid design, having both permanent magnets and soft iron cores.

To achieve full rated torque, the coils in a stepper motor must reach their full rated current during each step. Winding inductance and reverse EMF generated by a moving rotor tend to resist changes in drive current, so that as the motor speeds up, less and less time is spent at full current — thus reducing motor torque. As speeds further increase, the current will not reach the rated value, and eventually the motor will cease to produce torque [3].

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