SELECTION AND CALCULATION OF STEPPER MOTORS FOR CNC

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Introduction. A stepper motor, also known as step motor or stepping motor, is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any position sensor for feedback (an open-loop controller), as long as the motor is carefully sized to the application in respect to torque and speed.

Brushed DC motors rotate continuously when DC voltage is applied to their terminals. The stepper motor is known for its property of converting a train of input pulses (typically square waves) into a precisely defined increment in the shaft’s rotational position. Each pulse rotates the shaft through a fixed angle.

Stepper motors effectively have multiple "toothed" electromagnets arranged as a stator around a central rotor, a gear-shaped piece of iron. The electromagnets are energized by an external driver circuit or a micro controller. To make the motor shaft turn, first, one electromagnet is given power, which magnetically attracts the gear's teeth. When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet. This means that when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to align with the next one. From there the process is repeated. Each of those 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 angle [1, p 48-50].

The circular arrangement of electromagnets is divided into groups, each group called a phase, and there is an equal number of electromagnets per group. The number of groups is chosen by the designer of the stepper motor. The electromagnets of each group are interleaved with the electromagnets of other groups to form a uniform pattern of arrangement. For example, if the stepper motor has two groups identified as A or B, and ten electromagnets in total, then the grouping pattern would be ABABABABAB.

Electromagnets within the same group are all energized together. Because of this, stepper motors with more phases typically have more wires (or leads) to control the motor.

When choosing a stepper motor for CNC, it is necessary to start with the planned scope of use of the machine and technical characteristics. Below are the selection criteria, classification of the most popular engines and examples of calculation.

Figure 1 – Stepper motors

How to choose a stepper motor for CNC: criteria

• Inductance. You should calculate the square root of the winding inductance and multiply it by 32. The value obtained should be compared with the voltage of the power supply for the driver. The differences between these numbers should not differ much. If the supply voltage is 30% higher, the motor will heat up and make noise. If less, the torque will drop too fast. High inductance will potentially provide the opportunity for more torque. However, this requires a driver with a high supply voltage.

• Graph of torque versus speed. Allows you to determine whether the selected engine meets the conditions in the specification.

• Geometric parameters. The length of the engine, the flange and the diameter of the shaft are important here.

You should also pay attention to the ohmic resistance of the phases, the rated current in the phase, the moment of inertia of the rotor, the maximum static synchronizing torque [2, p. 5-6].

Motor type

An important criterion is the type of stepper motor for the CNC machine. Widespread bipolar, unipolar and three-phase models.

Each of them has its own features:

1. Bipolar motors.

Bipolar motors have a single winding per phase. The current in a winding needs to be reversed in order to reverse a magnetic pole, so the driving circuit must be more complicated, typically with an H-bridge arrangement (however there are several off-the-shelf driver chips available to make this a simple affair). There are two leads per phase, none are common.

A typical driving pattern for a two coil bipolar stepper motor would be: A+ B+ A− B−. I.e. drive coil A with positive current, then remove current from coil A; then drive coil B with positive current, then remove current from coil B; then drive coil A with negative current (flipping polarity by switching the wires e.g. with an H bridge), then remove current from coil A; then drive coil B with negative current (again flipping polarity same as coil A); the cycle is complete and begins anew.

Static friction effects using an H-bridge have been observed with certain drive topologies.

Dithering the stepper signal at a higher frequency than the motor can respond to will reduce this "static friction" effect.

A bipolar stepper motor with gear reduction mechanism used in a flatbed scanner [3, p. 7].

Because windings are better utilized, they are more powerful than a unipolar motor of the same weight. This is due to the physical space occupied by the windings. A unipolar motor has twice the amount of wire in the same space, but only half used at any point in time, hence is 50% efficient (or approximately 70% of the torque output available). Though a bipolar stepper motor is more complicated to drive, the abundance of driver chips means this is much less difficult to achieve.

An 8-lead stepper is like a unipolar stepper, but the leads are not joined to common internally to the motor. This kind of motor can be wired in several configurations:

- Unipolar.
- Bipolar with series windings. This gives higher inductance but lower current per winding.
- Bipolar with parallel windings. This requires higher current but can perform better as the winding inductance is reduced.
- Bipolar with a single winding per phase. This method will run the motor on only half the available windings, which will reduce the available low speed torque but require less current

Figure 2 – Bipolar hybrid stepper motor

2. Unipolar motors.

A unipolar stepper motor has one winding with center tap per phase.
Each section of windings is switched on for each direction of magnetic field. Since in this arrangement a magnetic pole can be reversed without switching the direction of current, the commutation circuit can be made very simple (e.g., a single transistor) for each winding. Typically, given a phase, the center tap of each winding is made common: giving three leads per phase and six leads for a typical two-phase motor. Often, these two-phase commons are internally joined, so the motor has only five leads [4, p. 10].

A microcontroller or stepper motor controller can be used to activate the drive transistors in the right order, and this ease of operation makes unipolar motors popular with hobbyists; they are probably the cheapest way to get precise angular movements. For the experimenter, the windings can be identified by touching the terminal wires together in PM motors. If the terminals of a coil are connected, the shaft becomes harder to turn. One way to distinguish the center tap (common wire) from a coil-end wire is by measuring the resistance. Resistance between common wire and coil-end wire is always half of the resistance between coil-end wires. This is because there is twice the length of coil between the ends and only half from center (common wire) to the end. A quick way to determine if the stepper motor is working is to short circuit every two pairs and try turning the shaft. Whenever a higher than normal resistance is felt, it indicates that the circuit to the particular winding is closed and that the phase is working.

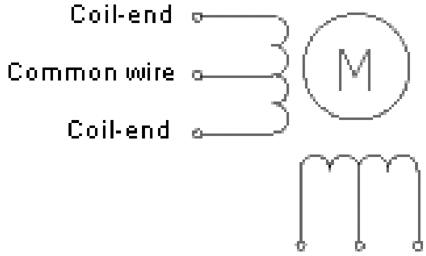

Figure 3 – Unipolar stepper motor coils

3. Higher-phase count stepper motors

Multi-phase stepper motors with many phases tend to have much lower levels of vibration. While they are more expensive, they do have a higher power density and with the appropriate drive electronics are often better suited to the application.


Figure 4 – Four-phase stepper motors

Examples of calculations of stepper motors for CNC

Determine the forces acting in the system [5, p. 1-2].

It is necessary to determine the force of friction in the guides, which depends on the materials used.

For example, the coefficient of friction is 0.2, the weight of the part - 300 kgf, the weight of the table - 100 kgf, the required acceleration – 2m/s2, the cutting force - 3,000 N.

To calculate the friction force, you need to multiply the coefficient of friction by the weight of the moving system.

For example:

$$0.2*9.8*(100+300)=785\ N$$

To calculate the force of inertia you need to multiply the mass of the table with the part by the required acceleration.

For example:

$$400*2=800\ N$$

To calculate the total force of resistance must add the forces of friction, inertia and cutting.

For example:

$$785+800+3000=4585\ N$$

Reference: the resistance force must be developed by the table drive on the ball screw nut.

Calculate the power

The formulas below are presented without taking into account the inertia of the shaft of the stepper motor and other rotating mechanisms.

Therefore, for greater accuracy, it is recommended to increase or decrease the acceleration requirements by 10%.

To calculate the power of the stepper motor should use the formula F = ma, where:

•F is the force in Newtons needed to set the body in motion;

•m - body weight in kg;

• a- the required acceleration m/c2.

To determine the mechanical power, it is necessary to multiply the force of resistance by speed.

There are calculators for automatic power calculation.

Calculation of the speed reduction

Determined on the basis of the nominal speed of the servo and the maximum speed of the table. For example, the speed of movement is 1,000 mm / min, the pitch of the propeller is 10 mm. Then the speed of rotation of the screw of the screw should be (1 000/10) 100 revolutions per minute.

To calculate the reduction factor, take into account the nominal speed of the servo.

For example, they are equal to 5,000 rpm. Then the reduction will be equal to (5,000/100) 50.

Ratings and specifications

Stepper motors' nameplates typically give only the winding current and occasionally the voltage and winding resistance. The rated voltage will produce the rated winding current at DC: but this is mostly a meaningless rating, as all modern drivers are current limiting and the drive voltages greatly exceed the motor rated voltage.

Datasheets from the manufacturer often indicate Inductance. Back-EMF is equally relevant, but seldom listed (it is straightforward to measure with an oscilloscope). These figures can be helpful for more in-depth electronics design, when deviating from standard supply voltages, adapting third party driver electronics, or gaining insight when choosing between motor models with otherwise similar size, voltage, and torque specifications.

A stepper's low-speed torque will vary directly with current. How quickly the torque falls off at faster speeds depends on the winding inductance and the drive circuitry it is attached to, especially the driving voltage.

Steppers should be sized according to published torque curve, which is specified by the manufacturer at particular drive voltages or using their own drive circuitry. Dips in the torque curve suggest possible resonances, whose impact on the application should be understood by designers.

Step motors adapted to harsh environments are often referred to as IP65 rated.

The US National Electrical Manufacturers Association (NEMA) standardises various aspects of stepper motors. They are typically referred with NEMA DD, where DD is the diameter of the faceplate in inches multiplied by 10 (e.g., NEMA 17 has a diameter of 1.7 inches). There are further specifiers to describe stepper motors, and such details may be found in the ICS 16-2001 standard (section 4.3.1.1).

Classification of stepper motors for CNC

Soviet models

In machine tools, inductor-type stepper motors made in the USSR are often used. We are talking about the DSHI-200-2 and DSHI-200-3 models. They have the following characteristics:

Table 1 – Sovietmodels

Parameters	DSHI-200-2	DSHI-200-3
Power consumption	11.8 watts	16.7 watts
Step processing error	3%	3%
Maximum static moment	0.46 nt	0.84 nt
Maximum pickup purity	1,000 Hz	1,000 Hz
Supply voltage	30 in	30 in
Supply current in phase	1.5 A	1.5 A
Single step	1.8 hail	1.8 hail
Weight	0.54 kg	0.91 kg

When choosing, you should pay attention to the presence of an OS index. This is a special edition with military approval. Has a higher quality of workmanship than conventional models.

Chinese models

Examples of Chinese CNC stepper motors and their characteristics are presented below.

Table 2 – Chinesemodels

Parameter	Model		
	JKM Nema 17 42mm Hybrid Stepper Motor	JK42HS48-2504	JK42HS40-1704
Length mm	48	40	34
Phase supply current, A	2.5	1.7	1.33
Single step (angular movement), deg	1.8	1.8	1.8
Weight, kg	0.34	0.32	0.22

The main advantage of Chinese-made motors are their price and competitive parameters and characteristics.

Other examples bipolar stepper motors for CNC

Table 3 – Other examples bipolar stepper motors for CNC

Parameters	Model		
	86HS156-5004	57HS76-3004	42HS48-1704A
Phase supply current, A	5	3	1.7
Single step (angular movement), deg	1.8	1.8	1.8
Inductance, mH	6	3.5	2.8
Shaft diameter	14	8	5

These are the best and most promising options for using power stepper motors in low-power three-dimensional printing systems.

Conclusions

Based on the results of the work performed, the following conclusions were made:

1) A literature search showed that there are three main types of electric motors used in electromechanical complexes for three-dimensional printing: synchronous with permanent magnets; direct current motors of classical design; stepper motors;

2) Comparative analysis of stepper motors showed that for inexpensive systems the most appropriate for use are bipolar stepper motors. This significantly reduces the cost of the control system and power part (driver);

3) DC motors provide the highest values of the overload capacity in terms of power and torque;

4) Synchronous motors with permanent magnets (BLDC) should be used as a powerful electric drive of industrial systems and in the case of high requirements for positioning accuracy.

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