An Introduction to Stepping Motors
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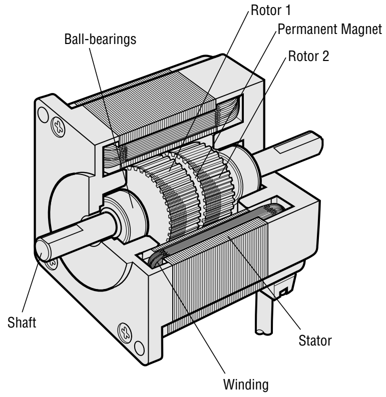
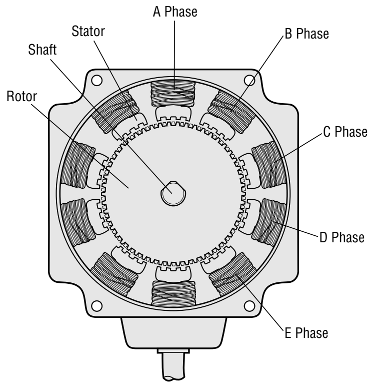
The Basics of Stepping Motors

Structure



Motor Structure Diagram 1: Cross-Section Parallel to Shaft



Motor Structure Diagram 2: Cross-Section Perpendicular to Shaft

The figures above show two cross-sections of a 5-phase hybrid stepping motor. Hybrid stepping motors are composed primarily of two parts, the stator and the rotor. The rotor in turn is comprised of three components: rotor 1, rotor 2 and the permanent magnet. The rotors are magnetized in the axial direction, with rotor 1 polarized north and rotor 2 polarized south.

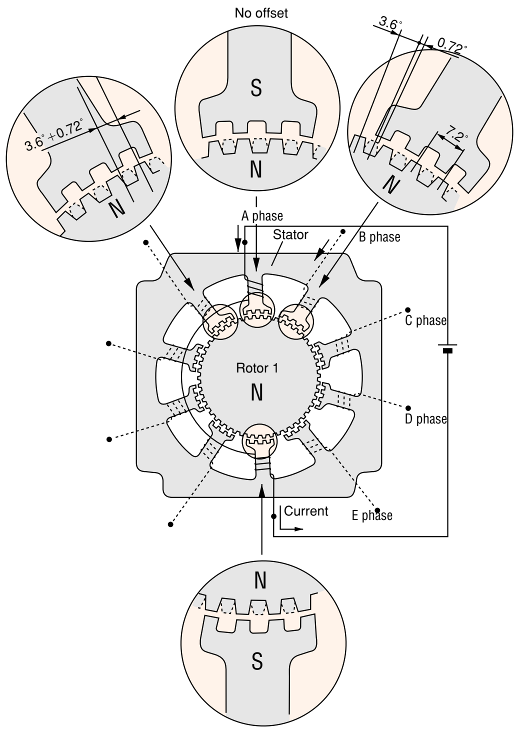
The stator contains 10 magnet poles with small teeth, each of which is wrapped in wire to form a coil. The coil is connected to the facing magnet pole and is wound so it becomes magnetized to the same pole when current is run through it. (Running a current through a given coil magnetizes the facing poles to the same magnetism, either north pole or south pole.) The two facing poles form a single phase. Since there are five phases, A through E, the motor is called a 5-phase stepping motor. There are 50 teeth on the outside of the rotor, with the teeth of rotor 1 and rotor 2 mechanically offset from each other by half a tooth pitch.

Excite: Send current through the motor coil.
Magnet pole: The projections of the stator, magnetized by excitation.
Teeth: The teeth of the rotor and stator.

Principles of Operation

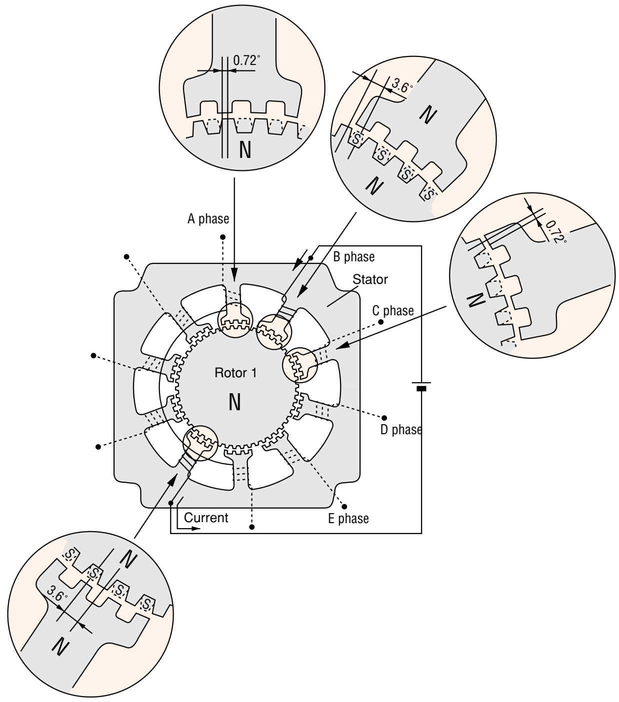
The following figure helps describe the relationship of the positions of the stator and rotor teeth when magnetized.

1. When Phase A is Excited



When phase A is excited, its poles are magnetized south and attract the teeth of rotor 1, which are magnetized north, while repelling the teeth of rotor 2, which are magnetized south, which balances it to a stop. The teeth of the phase B poles, which are not excited, are misaligned with the south-polarized teeth of rotor 2 so they are offset by 0.72˚.

2. When Phase B is Excited



When the excitation switches from phase A to phase B, the phase B poles are magnetized north, attracting the south polarity rotor 2 and repelling the north polarity of rotor 1. In other words, when excitation switches from phase A to phase B, the rotor rotates 0.72˚. As excitation shifts from phase A, to phase B, to phase C, to phase D, to phase E, phase A, the stepping motor rotates in precise 0.72˚ steps. To rotate it in reverse, reverse the excitation order to phase A, phase E, phase D, phase C, phase B, phase A.

The high (0.72˚) resolution is created by the mechanical offset of the stator and rotor structures, which is why positioning can be performed accurately without the use of an encoder or other sensor. Since the only factors that might decrease stopping precision are variations in the processing precision, assembly precision, and DC resistance of the coil, a high stopping precision of ±0.05° (with no load) is achievable. The driver performs the role of switching the phases, and its timing is supplied by the pulse signal input to the driver.
In the example above, excitation proceeds one phase at a time, but for the most effective use of the coils, four or five phases should be excited simultaneously.

Characteristics

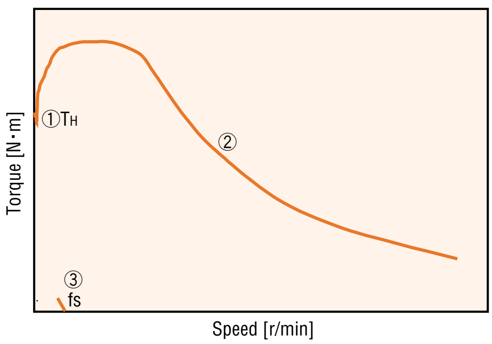
When using a stepping motor it must be determined that the motor characteristics are suited to the required load. The two main characteristics of stepping motor performance are:

- Static Characteristics:
  Those relating to the changes in angle that take place when the stepping motor is stopped or during motor standstill.
- Dynamic Characteristics:
  Those relating to speed and torque when the stepping motor starts or is rotating.

1. Dynamic Characteristics

(1) Speed – Torque Characteristics

This is the most common characteristic for expressing stepping motor performance. On the graph of this characteristic, the horizontal axis expresses pulse speed while the vertical axis expresses torque.
Pulse speed equals the pulse rate, which the number of pulses per second. In stepping motors, the number of revolutions per minute is proportional to pulse speed.



Speed – Torque Characteristics

The speed-torque characteristics are determined by the motor and driver, so they vary greatly based upon the type of driver used.

① Holding Torque (T_H)

The holding torque is the maximum holding power (torque) the stepping motor has when power is being supplied but the motor is not rotating (rated current).

② Pullout Torque

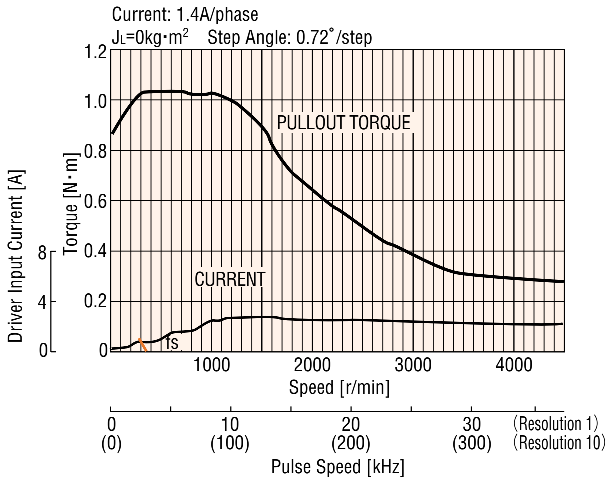
Pullout torque is the maximum torque that can be output at a given speed. When selecting a motor, be sure the required torque falls within this curve.

③ Maximum Starting Frequency (f_S)

This is the maximum pulse speed at which the motor can start or stop instantly (without an acceleration or deceleration period) when the frictional load and inertial load of the stepping motor are 0. Driving the motor at greater than this pulse speed requires gradual acceleration or deceleration. This frequency drops when there is an inertial load on the motor. (See the description of inertial loads and starting frequency on the next page.)

The following figure shows the speed torque characteristics of the 5-phase stepping motor/driver unit **RK566BC**.

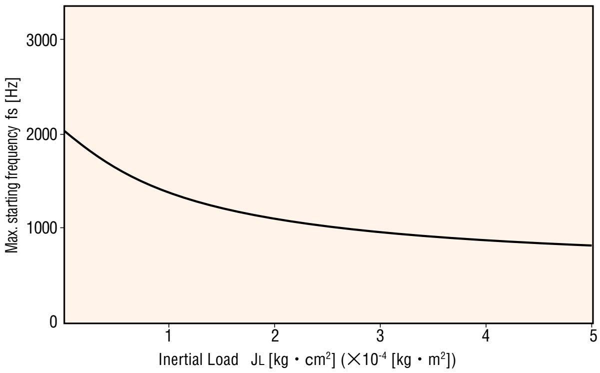
RK566BC



(2) Inertial Load-Starting Frequency Characteristics

The figure below illustrates the changes in starting frequency caused by inertial load. Since the stepping motor rotor and the equipment have their own inertia, lags and advances occur on the motor axis during instantaneous start and stops. These values change with the pulse speed, but the motor cannot keep up with pulse speeds beyond a certain point and missteps result. The pulse speed just before a misstep occurs is called the maximum starting frequency.

RK566BC



Inertial Load-Starting Frequency Characteristics

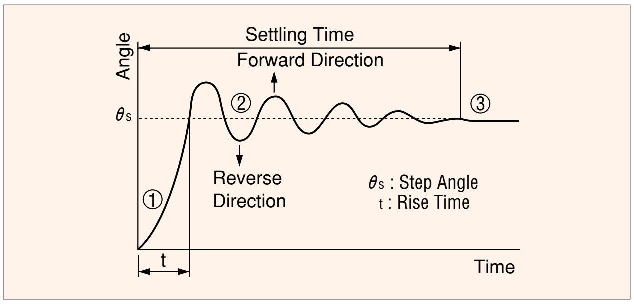
Changes in maximum starting frequency with load inertia may be approximated by the following formula.

$$f = \frac{f_S}{\sqrt{1 + \frac{J_L}{J_O}}} \text{ [Hz]}$$

f_S : Maximum starting frequency (Hz) of the motor
f : Maximum starting frequency (Hz) when applying load inertia
J_O : Rotor inertia (kg·m^2)
J_L : Load inertia (kg·m^2)

(3) Vibration Characteristics

When no pulse signal is input to driver, the stepping motor stops with a holding brake force equivalent to the maximum value of holding torque. As pulses are input, the motor operates in a repeating stepwise manner as shown below.

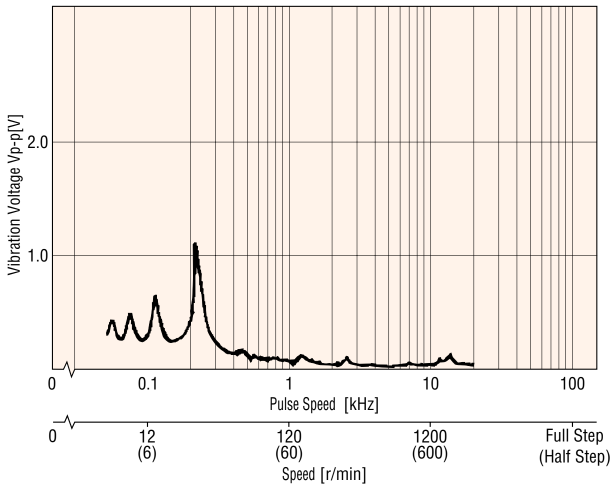


Single step response

① When a pulse signal is input, the motor accelerates towards the next step angle.
② Due to the influence of the rotor inertia and the load inertia, the motor overshoots a certain angle, returns in the opposite direction, and then repeats this action.
③ After the motor has repeated sufficient damping oscillations, it stops at the set position.

A step-like movement that produces this kind of damped vibration is the cause of vibration at low speeds. The graph of vibration characteristics below shows the characteristics indicating the extent of vibration while the stepping motor is running.

RK566BC



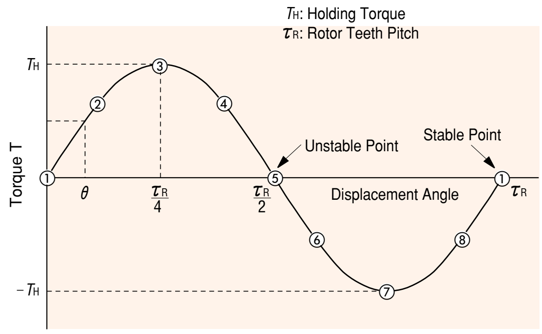
Vibration Characteristics

Rotation becomes smoother as the vibration level decreases. There is an area around 200 Hz where vibration is most pronounced, and should be avoided.

2. Static Characteristics

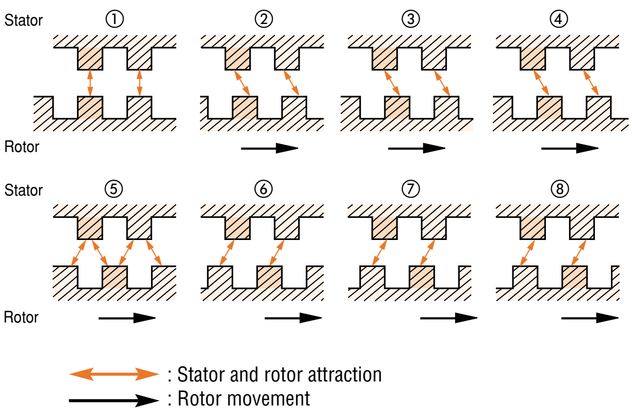
(1)Angle-Torque Characteristics

Angle-torque characteristics are the relationship between the angular displacement of the rotor and the torque which is applied to the shaft when energizing the motor with rated voltage. The curve for this characteristic is shown below.



Angle - Torque Characteristics

The illustrations below show the relationship of the positions of rotor and stator teeth at the numbered points in the diagram above.



When held stable at point ①, external application of a force to the motor shaft will produce a torque T (+) to the left trying to return the shaft to stable point ① and the shaft will stop when the external force equals this torque. ② If additional external force is applied, there is an angle at which the torque produced will hit a maximum. This torque is the holding torque T_H. ③ When that external force is exceeded, the rotor moves to an unstable point ⑤ and beyond, producing a torque in the same direction as the external force T(−), so it moves to the next stable point ① and stops.

Stable points:

Locations where the rotor stops, with stator and rotor teeth exactly aligned. These points are extremely stable and the rotor will always stop there if no external force is applied.

Unstable points:

Locations where the stator and rotor teeth are half a pitch out of alignment. They are extremely unstable. A rotor at these locations will move to the next stable point to the left or right if even the slightest external force is applied.

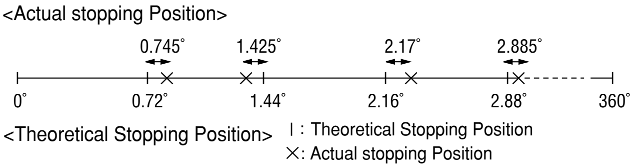
(2) Step Angle Accuracy

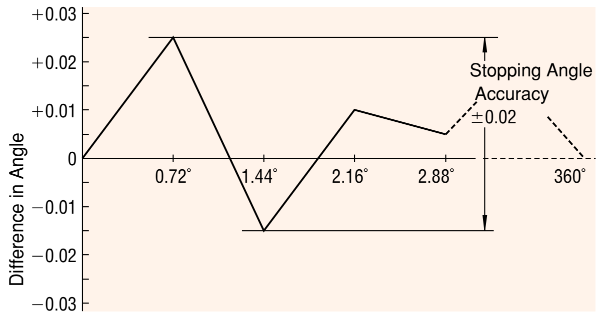
Under no-load conditions the stepping motor can maintain a step angle accuracy within ±0.05° *. This slight error arises from difference in the mechanical precision of the stator and rotor teeth and variations in the electrical precision of the DC resistance of the stator coil.
Step angle accuracy of the stepping motor is mainly expressed by the stopping angle accuracy described below.

* For the **PMC** series ±0.08°.
For the **2-Phase PK-J** type ±0.03°.

●Stopping Accuracy

This refers to the difference between the rotor's theoretical stopping position and its actual stopping position. A given rotor stopping point is taken as the starting point, then the stopping angle error is the difference between the maximum (+) value and the minimum (−) value when measuring each step of a full rotation.





The stopping angle accuracy is ±0.05° *, but only under no load. In actual applications, there is always frictional load. The angle precision in such cases is produced by the angular displacement caused by angle-torque characteristics based upon the frictional load. If frictional load is constant, the angle of displacement is constant for rotation in one direction. When operating from both forward and reverse, however, double the displacement angle is produced by the round trip.
When stopping precision is required, always position from one direction only.

* For the **PMC** series ±0.08°.
For the **2-Phase PK-J** type ±0.03°.

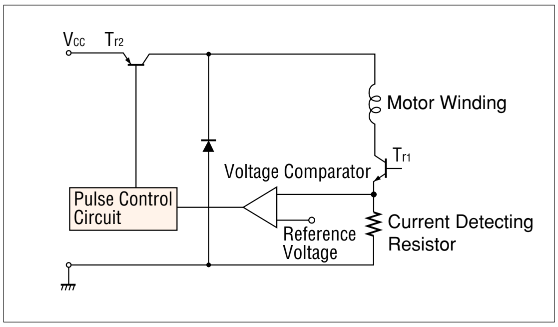
AC Input Drivers and DC Input Drivers

There are two ways of driving stepping motors: constant-current drive is and constant-voltage drive. The circuitry of constant-voltage drive are simpler, but it is harder to achieve torque at high speeds. For that reason, constant-voltage drives are used less often as equipment speeds have increased.
Constant-current drive is currently the most commonly used drive method, since it provides excellent torque at high speeds. All Oriental Motor stepping motors use constant-current drivers.

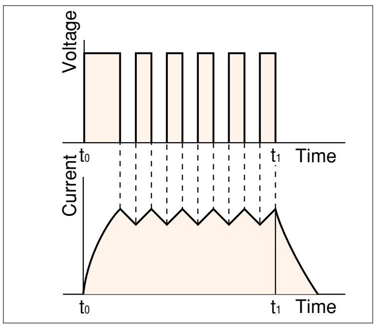
1. An introduction to constant-current drivers

Stepping motors rotate by the switching of current flowing through several coils. When the speed increases, the switching also becomes faster and the current rises cannot keep up, so torque drops. By chopping a DC voltage that is far higher than the motor's rated voltage, a constant current can be kept flowing to the motor even at high speeds.

The current flowing to the motor coil is compared to the reference voltage. When the detection resistor voltage is lower than the reference voltage (when it hasn't reached the rated current), the switching transistor (Tr_2) stays on. When it is higher than the reference voltage (when it exceeds the rated current), Tr_2 goes off. The current is controlled so that the rated current is always flowing.



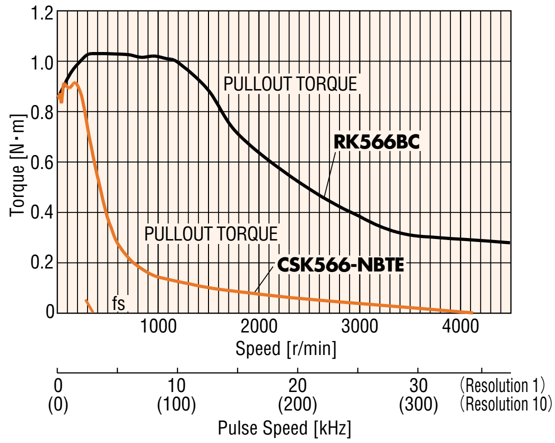
Basic circuit for constant current chopper driver



Relationship between voltage drive and constant current drive

2. The difference between AC input and DC input characteristics

A stepping motor is driven by a DC voltage applied through a driver. In the case of Oriental Motor's 24V DC input drivers, 24V DC is applied to the motor; in the case of AC200V-230V input, the input is rectified to DC and then approximately 140V DC is applied to the motor.
This difference in the voltages applied to the motors appears as a difference in the torque characteristics in the high speed region. This is because the higher the applied voltage, the faster the rise of current flowing through the motor coil, so that a fixed current can flow even in the high speed region. Thus, the AC input unit has superior torque characteristics throughout, from the low speed region to the high speed region, and a large speed ratio can be obtained.
It is recommended that this motor be used together with an AC input unit that can respond to a variety of conditions.



Comparison of characteristics of AC input unit and DC input unit

3. Selecting a Power Supply Transformer

The AC input driver is designed to be used with single-phase power in the range 200V-230V. When using power whose voltage is outside this range, use a transformer to drop the voltage to 200V-230V single phase.

Transformer capacitance [VA] = Driver power voltage [V] × Driver input current [A]

The driver input current of the stepping motor can be found in the specifications or in the speed-torque characteristics.