Stepping Motor

■ Applications

Mobile equipment

Digital cameras, Mobile equipments, PDA, etc.

Office automation equipment

Printers, facsimiles, Typewriters, Photocopiers, FDD head drives, CD-ROM pickup drives, Scanners, etc.

Audio-visual equipment

Video cameras, Digital cameras, etc.

Measuring instruments

Automotive odometers, Various integrating meters and counters

Game equipment

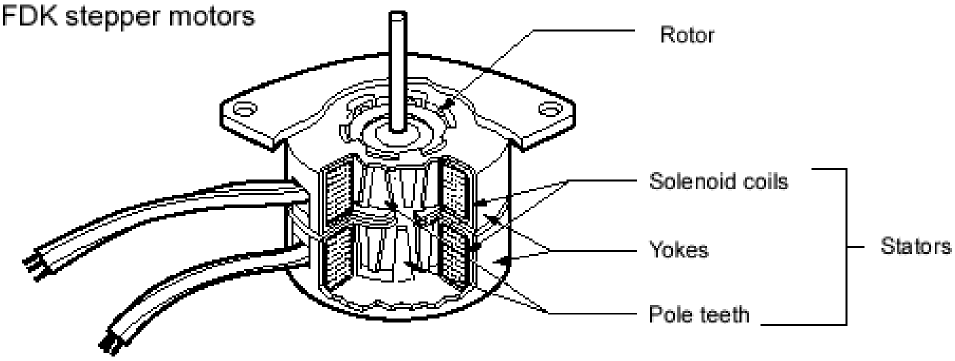
Pachinko machines, etc.

■ Structure and operation

Stepper motors convert electric pulses into incremental mechanical motions. FDK's stepper motors have a claw-pole yoke structure with a cylindrical permanent magnet rotor, as illustrated below. These motors rotate when a rotating magnetic field is generated and when the rotor magnet is synchronized with the rotating magnetic field.

Specifically, a rotating field is generated by applying alternating current to the solenoid coils of two stators, which are sandwiched between yokes. These yokes have the same number of teeth as the poles of the rotor magnet. The stators are positioned so that their electric phase angles are 90 degrees apart.

Structure of FDK stepper motors



■ Code names

SM15-20 XX-X

①: SM15, ②: 20, ③: XX, ④: X

① Code for motor type
② Number of steps
③ Serial number
④ Modification code

■ Rotor magnets

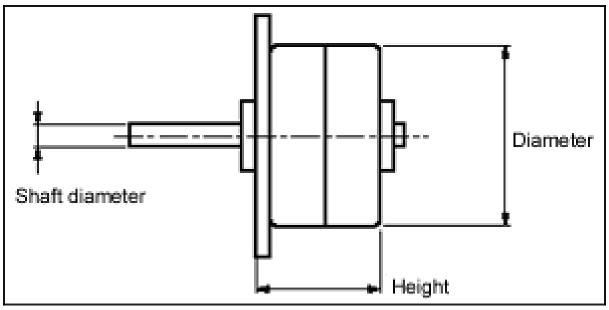
Rotors are the most important component of stepper motors, and FDK uses its original magnets in rotors.

The following types of FDK magnets are used in rotors to match each of the diverse stepper motor applications.

Rotor magnets		B29 Ferrite plastic magnet Pole-oriented anisotropic	B51 Ferrite anisotropic	N51 Rare earth
Residual induction	Br(mT)	-	-	650~690
Coercive force	bHc(KA/m)	-	-	348~395
	iHc(KA/m)	-	-	616~672
Max. energy product	(BH)max.(KJ/m^3)	-	-	6.5~7.1
Density	ρ(g/cm^3)	3.7	4.7~5.0	5.7~5.9

■ Types and specifications

Type	No. of steps (step angle)					Applicable rotor grade			Weight (g)	Motor dimensions (mm)			Pin terminal
	20 (18°)	24 (15°)	48 (7.5°)	96 (3.75°)	100 (3.6°)	B29	B51	N51		Out diameter	Height	Shaft diameter	
SM6	●							●	1.14	φ6	7.4	φ1	●
SMS6	●							●	1	φ6	4.9	φ1	●
SM8	●							●	3	φ8	8.8	φ1	●
SMS8	●							●	1.8	φ8	6.6	φ1	●
SM10	●							●	4	φ10	9.7	φ1.5	●
SM15	●							●	12	φ15	10	φ1.5	●
SME20	●							●	28	φ20	14.2	φ1.5	
SMP20	●					●		●	28	φ20	18.2	φ1.5	
SME25		●						●	35	φ25	15	φ2	
SMF25				●				●	20	φ25	8.5	φ2	
SMJ35			●			●		●	80	φ35	14.7	φ2	
SMB40			●	●	●			●	110	φ42	14.4	φ3	
SMJ40			●			●		●	150	φ42	21.8	φ3	
SMW42			●	●				●	100	φ42	18.3	φ3	

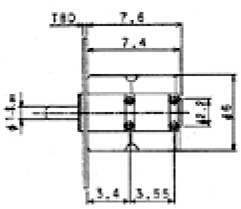


Note: * "External dimensions" refer to the three measurements shown in the lefthand drawing.
* White circles indicate models under development.

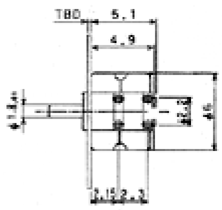
Shapes and dimensions

These drawings are full-scale. Please see page 8 for shaft length.

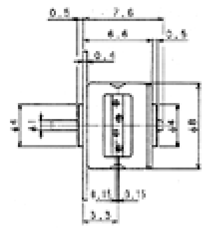
SM6



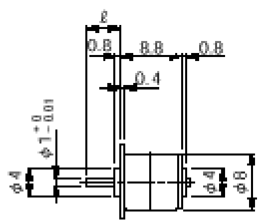
SMS6



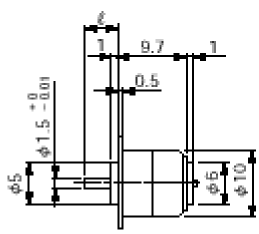
SMS8



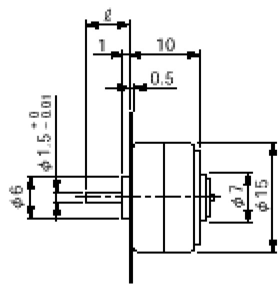
SM8



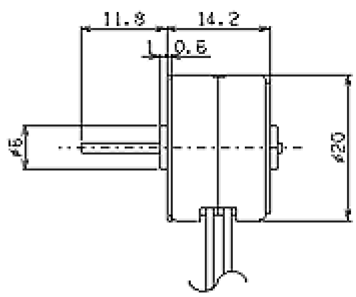
SM10



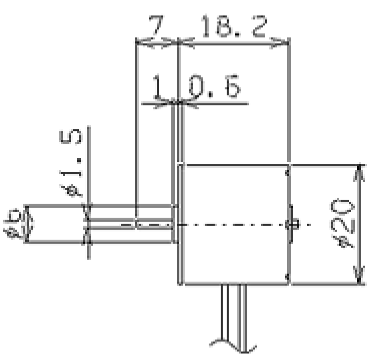
SM15



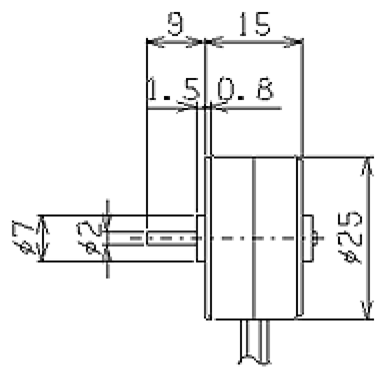
SME20



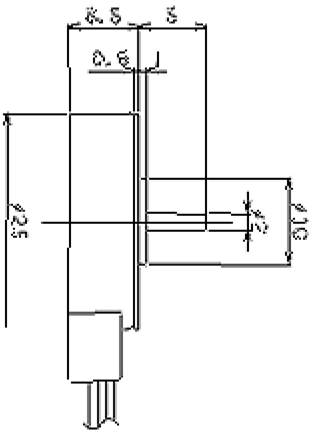
SMP20



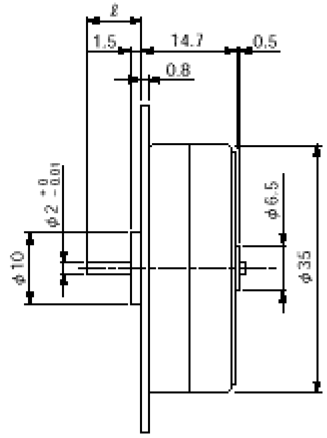
SME25



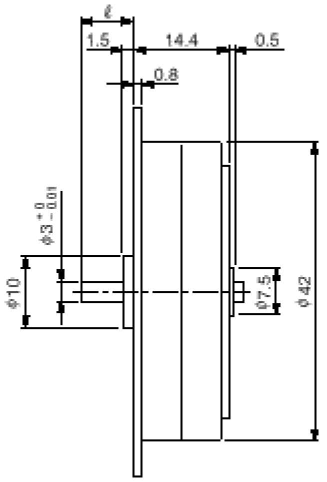
SMF25



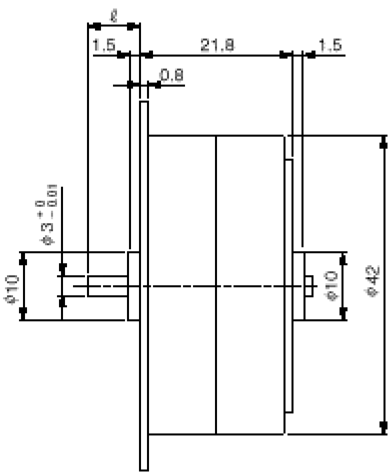
SMJ35



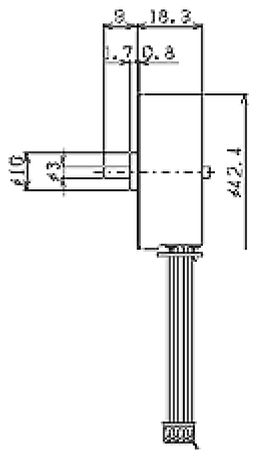
SMB40



SMJ40



SMW42

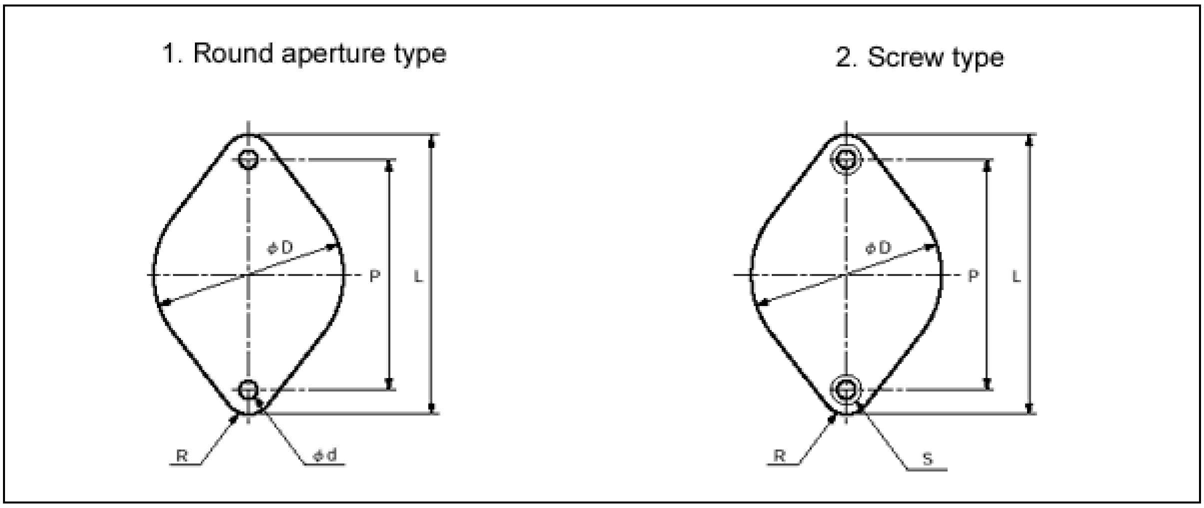


Unit : mm

■ Standard flanges

1. Flange shapes

The standard flange shapes of FDK stepper motors are divided into round aperture types and screw types. These standard shapes are intended to shorten the delivery period and reduce the initial costs. Special-shape flanges are available on a customized-design basis.

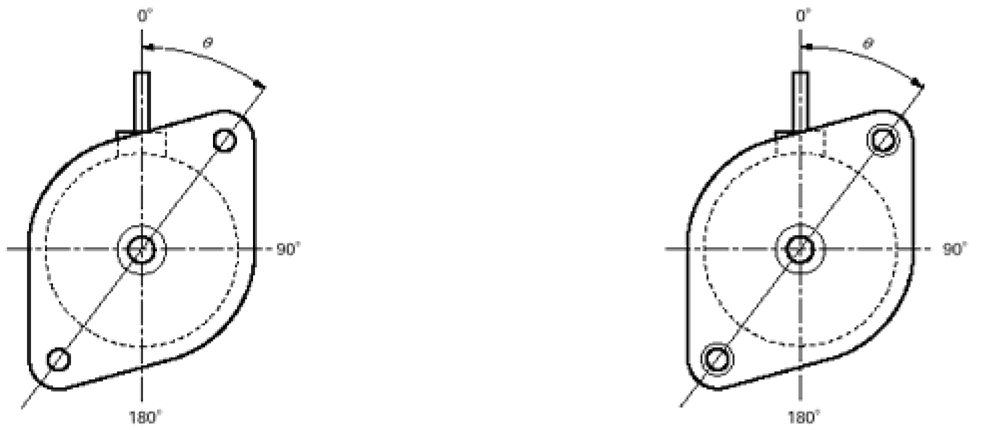


Unit:mm

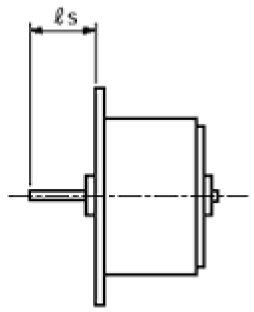
Type name	Flange type	Fixing screw	d	S	P	L	D	R
SM15	1	M2	2.2	-	$20^{\pm 0.1}$	24.5	15	2.25
SME20	1	M2	2.2	-	$25^{\pm 0.15}$	29.5	20	2
SMP20	1	M2	2.2	-	$25^{\pm 0.15}$	29.5	20	2
SME25	1	M2	3.2	-	$25^{\pm 0.15}$	38	20	3
SMF25	2	M3	3.2	-	$32^{\pm 0.15}$	38	20	3
SMJ35	1	M3	3.2	-	$42^{\pm 0.2}$	50	35	4
	2	M3	-	M3	$42^{\pm 0.2}$	50	35	4
SMB40 SMJ40 SMW42	1	M3	3.5	-	$49.5^{\pm 0.2}$	57.7	42	2
	2	M3	-	M3	$49.5^{\pm 0.2}$	57.7	42	2

2. Flange angle

Flange angles are measured from the lead wires as seen from the shaft side.

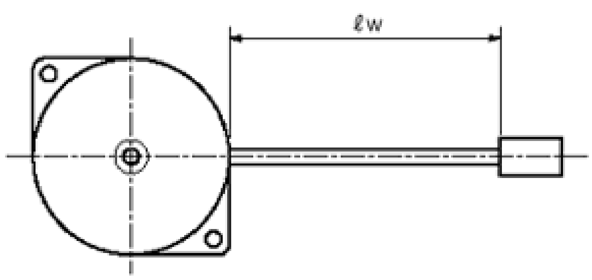


■ Shaft length



The shaft length is measured from the outer flange surface, and is determined through consultation between the customer and our engineers.

■ Lead wire length



The lead wire length is measured from the outer circumference of the stepper motor to the near-end of the connector (or to the end of the core wire of the lead wire when there is no connector). The normal tolerance is ±10 mm.

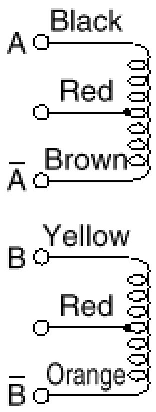
■ Lead wires

FDK also provides standard lead wires with regard to wire color, thickness, stepper motor rotational directions, and other aspects. Examples are shown below.

1. Standard colors and rotational directions (in two-phase excitation)

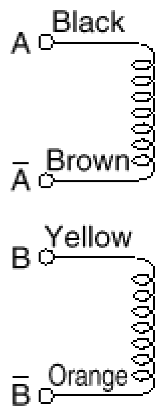
①Standard Type 1 ("Clockwise" or "counterclockwise" rotation is as seen from the shaft side.)

Unipolar Mode



	CW → / ← CCW			
Red	+	+	+	+
Red	+	+	+	+
Black	−	−		
Brown			−	−
Yellow	−			−
Orange		−	−	

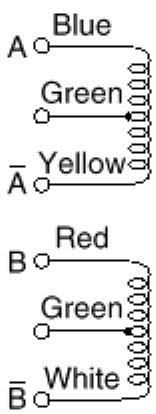
Bipolar Mode



	CW → / ← CCW			
Black	−	−	+	+
Brown	+	+	−	−
Yellow	−	+	+	−
Orange	+	−	−	+

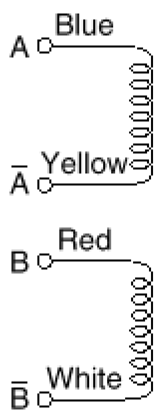
②Standard Type 2 ("Clockwise" or "counterclockwise" rotation is as seen from the shaft side.)

Unipolar Mode



	CW → / ← CCW			
Green	+	+	+	+
Green	+	+	+	+
Blue	−	−		
Yellow			−	−
Red	−			−
White		−	−	

Bipolar Mode



	CW → / ← CCW			
Blue	−	−	+	+
Yellow	+	+	−	−
Red	−	+	+	−
White	+	−	−	+

●: standard
○: semi-standard

2. Standard lead wires

Type	UL standard wires							
	Style number						Wire diameter	
	UL 1007	UL 1061	UL 1685	UL 3265	UL 1430	UL 1571	AWG 28 equivalent	AWG 26 equivalent
SME20		○	○			●	●	
SMP20		○	○			●	●	
SME25		○	○			●	●	
SMF25	●	○	○	○	○	○	●	
SMJ35	●	○	○	○	○	○	●	
SMB40	●			○	○	○	●	○
SMJ40	●			○	○	○	●	○
SMW42	●			○	○	○	●	○

3. UL electric wire standards

Style number	Rated		Insulation		Remarks
	Temperature	Voltage	Materials	Min. thickness (mm)	
UL1571	80°C	30V	PVC, cross-linked PVC	0.05～2.54	
UL1061	80°C	300V	Semi-hard PVC	0.229	CSA AWM
UL1685	105°C	30V	Cross-linked PVC	0.05～2.54	
UL1007	80°C	300V	Thermo-resistant PVC	0.381	CSA TR･64(90°C)
UL1430	105°C	300V	Cross-linked PVC	0.4	CSA REW
UL3265	125°C	150V	Cross-linked PE	0.254	CSA AWM

■When ordering stepper motors

How to place orders

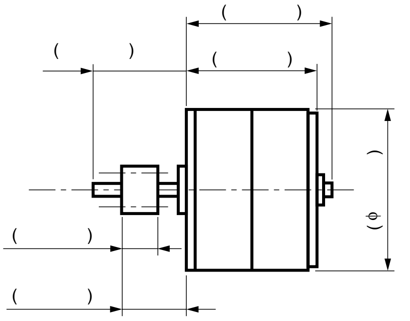
When ordering our stepper motors, please provide the following information so we can recommend the most suitable models.

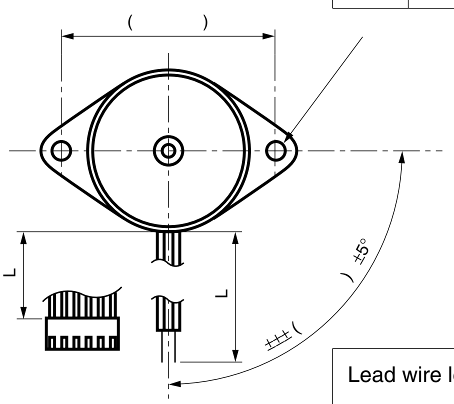
1) Model	SM	Rotor material	Specify If any: [ ]
2) Voltage	DC [ ] V	3) Number of steps	[ ]steps / rev.
4) Excitation mode	2-phase • 1-phase • 1/2 step	5) Drive mode	Unipolar • Bipolar
6) Winding resistance	[ ] Ω/phase (at 25˚C)		
7) Current	[ ] mA/phase MAX. (at pps)		
8) Holding torque	[ ] mN·m MIN. (2-phase • 1-phase)		
9) Dynamic torque	PULL— (OUT • IN)	[ ] mN·m MIN. (at pps)	
	PULL— (OUT • IN)	[ ] mN·m MIN. (at pps)	
	PULL— (OUT • IN)	[ ] mN·m MIN. (at pps)	
10) Drive circuit	Constant voltage/Chopper (Please attach additional information material on chopper current, electronic chips, etc.)		

11) External dimensions

Round hole	φ
Tapped hole	M

Pinion gear	
Needed/Not needed/ Not needed for samples	
Modules	[ ]
No. teeth	[ ]
Additional information on gear specification	
Accuracy	JGMA 6





Pin location				
	1		4	
	2		5	
	3		6	

Lead wire length: L
mm

* Please provide specific values in [ ]. If these values are not given, we will apply our standard values. Note that, for design reasons, it may become necessary to change your specified values.

12) Connector	Needed/Not needed/Not needed for samples Model [ ]
13) Lead wire	Specify If any: [ ]

14) Select from ① through ④ to indicate the most important factor in deciding specifications.

① Resistance (priority over torque and current) ② Torque (priority over resistance and current)

③ Current (priority over torque and resistance) ④ Other factors [ ]

* Information items 1)~5), or 6)~9), provide us with the minimum data needed to know your requirements. Please be sure to fill in these items.

* In case you have not selected a specific stepper motor model, indicate the acceptable ranges of the motor's external dimensions. (For example, φ 42 max.)

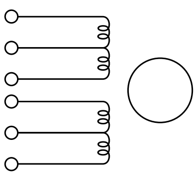
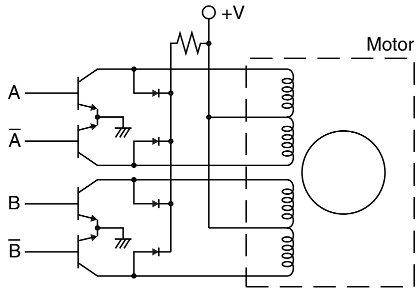
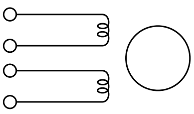
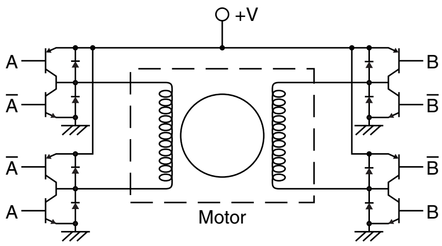
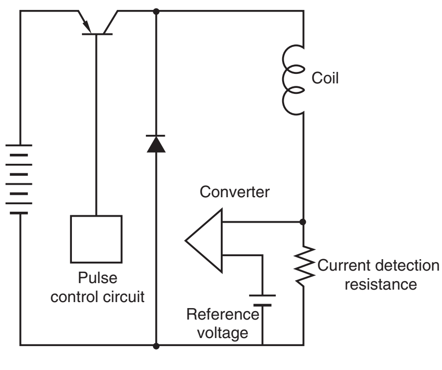
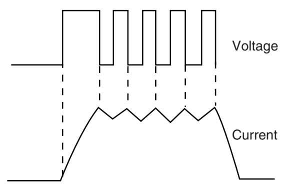
* To speed up the delivery of samples, we would prefer to apply our standard specifications to the samples insofar as possible, and omit the gears and connectors from them.

* We cannot produce an approved specification paper, unless we reach an agreement with our customers on major specifications.

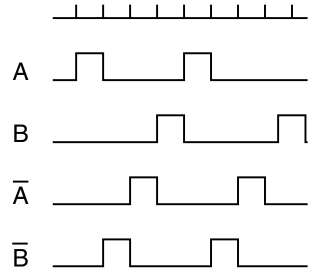
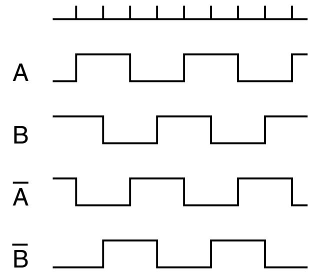
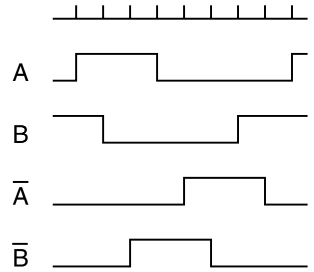
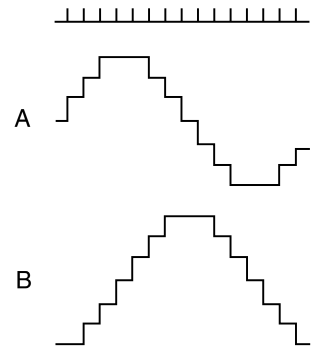
■Drive

FDK's stepper motors also offer selections in excitation modes, drive modes, and circuit formats. Below are examples of popular options.

1. Drive modes

Mode	Stepper motor	Basic circuit	Remarks
Unipolar drive	 Lead wires: 6		• Widely used because of simple drive circuit design.
Bipolar drive	 Lead wires: 4 Bidirectional current		• Motor windings are used efficiently. • Large torque is obtained relative to motor size. • Increasingly used due to availability of monolithic IC drive circuits.
Chopper drive			• Chopper control enables application of a high voltage to the coil. • A quick current start is realized. • A low power loss is ensured. • The switching period of current is determined by the following excitation modes: ①Self excitation The ON-OFF frequency is dependent on the time constant of the coil. ②Separate excitation Also called "PWM mode", this separate excitation mode can vary the ON time within the switching period of a high-frequency reference oscillator. Example of voltage/ current waveforms 

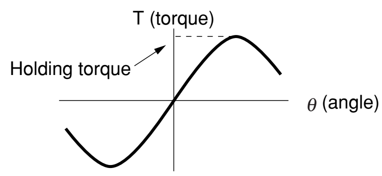
2. Excitation modes

Mode	Explanation	Excitation sequence (H: on, L: off)
Single-phase excitation	• Only one phase excited at a time. • Low power consumption.	
Two-phase excitation	• Two phases excited at a time. • Large torque output, although consuming 2 times more power than single phase. • Small damping oscillation, and wide-range responses. • Most popularly used excitation mode.	
Half-step excitation	• Alternating single- and two-phase excitation modes. • Consumes 1.5 times more power than single phase. • Step angle equal to half of single- and two-phase step angles, thus called "half-step drive". • Two times wider response frequency range.	
W half-step excitation	• Also called "microstep" drive, this excitation features finer step angles through the control of current. • Its step angle is half of the half- step excitation, and quarter of the two-phase excitation. • This excitation mode is used to obtain finer step motions or smoother rotations.	

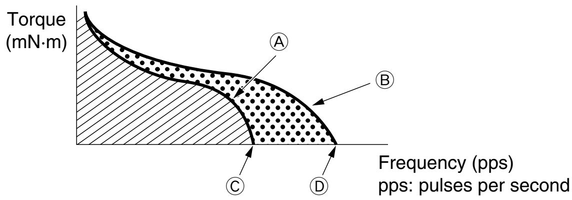
■When using stepper motors

1. The characteristics of stepper motors are affected by their drive circuits. Please disign the circuit carefully.
2. Temperature is also an influential factor. Be sure to operate the stepper motors within the permissible temperature range.
3. When test-driving stepper motors, check their service life, vibration, noise, etc.

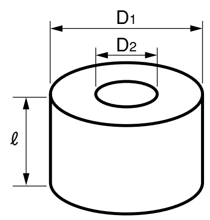
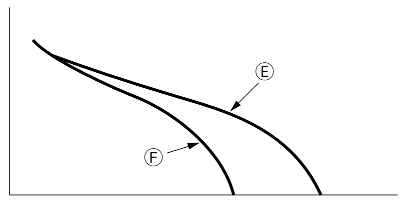
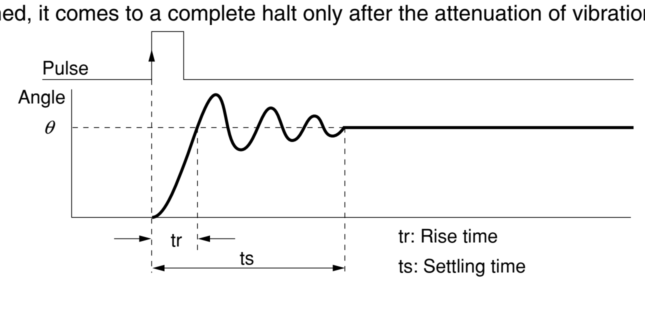
■Stepper motor terminology

<table>
<tr><th>Term</th><th>Meaning</th></tr>
<tr><td>Holding torque</td><td>The maximum torque generated to counter an external torque, which is applied to the shaft when the motor is in a stationary excited state.</td></tr>
<tr><td>Detent torque</td><td>Same as holding torque, except the motor is left in a stationary non-excited state.</td></tr>
<tr><td>θ – T (stiffness)
characteristics</td><td>Relation between the displacement angle and torque when an external torque is applied to the shaft of the motor in a stationary excited state.

</td></tr>
<tr><td>Dynamic characteristics
(torque vs. frequency)

Pull-in characteristics
Pull-in range
Pull-in torque

Pull-out characteristics
Pull-out range
Pull-out torque</td><td>Relation between the drive frequency and torque, as shown by lines Ⓐ and Ⓑ in the graph below.


Ⓐ Pull-in (starting) characteristics:
Relation between the input frequency and the maximum (pull-in) torque capable of starting the motor at this input frequency level.
Ⓑ Pull-out (slewing) characteristics:
Relation between the input frequency and the maximum torque obtainable by synchronizing the motor rotation with this input frequency, which has been gradually increased after the start of the motor in the pull-in range.
The area shaded by solid lines ▨ indicates the “pull-in range.” Stepper motors can be operated without problem as long as the operation characteristics are in this range. The area marked by dots ▩ indicates the “pull-out range.” If the operation characteristic is in the area, the motor speed must be properly adjusted.</td></tr>
<tr><td>Maximum starting rate</td><td>The highest frequency at which the motor can be started and halted in synch with the input signals under a no-load condition (indicated by point Ⓒ in the above graph).</td></tr>
<tr><td>Maximum slewing rate</td><td>The highest frequency at which the motor can be rotated in synch under a no-load condition, when the starting frequency is gradually increased (indicated by point Ⓓ in the above graph).</td></tr>
<tr><td>Step position error</td><td>The maximum positive or negative error caused when the motor has rotated one step from a holding position to the next position, and is expressed in angular measure or the ratio of the error angle to the step angle.
Step position error = l [Measured step angle] – [Theoretical step angle] l (Note: Max. value)</td></tr>
</table>

Position error	The motor is stepped N times (N = 360°/ step angle) from any initial position, and the angle from the initial position is measured. This routine is repeated for all the different initial positions. If the measured angle to the N-step position is θ_N and the error is $\Delta\theta_N$, then we have: $\Delta\theta_N=\theta_N-$ (step angle)$\times$N The position error is equal to the differential of the maximum and minimum $\Delta\theta_N$, and is normally expressed with a ± sign. That is: Position error$=\pm\frac{1}{2}\mid\Delta\theta(\max)-\Delta\theta(\min)\mid$
Hysteresis position error	The values obtained from the above position errors, when the measurement is taken in both clockwise and counterclockwise stepping directions.
Moment of inertia	The inertia of matter rotating around an axis is expressed as: $J=\int\rho r^2dv$ (ρ : density, r: distance from axis, dv: cubic factor) For example, the inertia of the righthand cylinder rotating around its own central axis obtained by: $J=\frac{\pi}{32}\rho\,\ell\,(D_1^4-D_2^4)$  D_1 : outer diameter (cm) D_2 : inner diameter (cm) ρ : density ℓ : height J : inertia ($g\cdot cm^2$) Although the motor has its own inertia, its pull-in characteristics are changed when the load is given a large inertia. The larger the load inertia, the smaller the pull-in area, as shown in the graph below.  ⒺPull-in characteristics when there is no load inertia. ⒻPull-in characteristics when linked to a large load inertia.
Single step response/ Indicial response	While the stepper motor performs its stepping operation whenever the excitation condition is switched, it comes to a complete halt only after the attenuation of vibration. 
Stepping rate/ revolving speed (rps, rpm)	The revolving speed of the stepper motor is usually expressed in pps (pulses per second), or sometimes in the number of steps per second. The relationship between the drive frequency and the rotational speed is as follows: ① Rotational speed (rps: revolutions per second) $=$frequency (pps) $\div\left(\frac{360°}{\text{single-step angle}}\right)$ ② Rotational speed (rpm: revolutions per minute) = rps $\times$ 60

■Appendix

1. Inertia conversion table

A \ B	kg·cm^2	kg·cm·s^2	g·cm^2	g·cm·s^2	lb·in^2	lb·in·s^2	oz·in^2	oz·in·s^2	lb·ft^2	lb·ft·s^2
kg·cm^2	1	1.01972×10^{-3}	10^3	1.01972	0.341716	8.85073×10^{-4}	5.46745	1.41612×10^{-2}	2.37303×10^{-3}	7.37561×10^{-5}
kg·cm·s^2	980.665	1	980.665 10^3	10^3	335.109	0.867960	5.36174×10^3	13.8874	2.32714	7.23300×10^{-2}
g·cm^2	10^{-3}	1.01972×10^{-6}	1	1.01972×10^{-3}	3.41716×10^{-4}	8.85073×10^{-7}	5.46745×10^{-3}	1.41612×10^{-5}	2.37303×10^{-6}	7.37561×10^{-8}
g·cm·s^2	0.980665	10^{-3}	980.665	1	0.335109	8.67960×10^{-4}	5.36174	1.38874×10^{-2}	2.32714×10^{-3}	7.23300×10^{-5}
lb·in^2	2.92641	2.98411×10^{-3}	2.92641×10^3	2.98411	1	2.59009×10^{-3}	16	4.14414×10^{-2}	6.94444×10^{-3}	2.15840×10^{-4}
lb·in·s^2	1.12985×10^3	1.15213	1.12985×10^6	1.15213×10^3	386.088	1	6.17740×10^3	16	2.68117	8.33333×10^{-2}
oz·in^2	0.182901	1.86507×10^{-4}	182.901	0.186507	0.0625	1.61880×10^{-4}	1	2.59009×10^{-3}	4.34028×10^{-4}	1.34900×10^{-5}
oz·in·s^2	70.6157	72.0079×10^{-3}	70.6157×10^3	72.0079	24.1305	6.25×10^{-2}	386.088	1	0.107573	5.20833×10^{-3}
lb·ft^2	421.403	0.429711	421.403×10^3	429.711	144	0.372972	2304	5.96756	1	3.10810×10^{-2}
lb·ft·s^2	1.35582×10^4	13.8255	1.35582×10^7	1.38255×10^4	4.63305×10^3	12	7.41289×10^4	192	32.1740	1

To convert an A unit into a B unit, multiply the A-unit value with the corresponding number listed in the above table.
Example: 5g·cm^2=5×5.46745×10^{-3}oz·in^2

2. Torque conversion table

A \ B	N·m	dyn·cm	kg·m	kg·cm	g·cm	oz·in	lb·in	lb·ft
N·m	1	10^7	0.101972	10.1972	1.01972×10^4	141.612	8.85074	0.737562
dyn·cm	$\times 10^{-7}$	1	1.01972×10^{-8}	1.01972×10^{-6}	1.01972×10^{-3}	1.41612×10^{-5}	8.85074×10^{-7}	7.37562×10^{-8}
kg·m	9.80665	9.80665×10^7	1	10^2	10^5	1.38874×10^3	86.7962	7.23301
kg·cm	9.80665×10^{-2}	9.80665×10^5	10^{-2}	1	10^3	13.8874	0.867962	7.23301×10^{-2}
g·cm	9.80665×10^{-5}	9.80665×10^2	10^{-5}	10^{-3}	1	1.38874×10^{-2}	8.67962×10^{-4}	7.23301×10^{-5}
oz·in	7.06155×10^{-3}	7.06155×10^4	72.0077×10^{-5}	72.0077×10^{-3}	72.0077	1	6.25×10^{-2}	5.20833×10^{-3}
lb·in	0.112985	1.12985×10^6	1.15212×10^{-2}	1.15212	1.15212×10^3	16	1	8.33333×10^{-2}
lb·ft	1.35582	1.35582×10^7	0.138255	1.38255×10	1.38255×10^4	192	12	1

To convert an A unit into a Bunit, multiply the A-unit value with the corresponding number listed in the above table.
Example: 100g·cm=100×9.80665×10^{-5}N·m
=100×9.80665×10^{-2}mN·m