●Features of stepping motor

In stepping motors, angle of rotation is proportional to the number of input pulses.

In stepping motors, the angle of rotation per step (step angle) is determined depending on their construction, and, for a given number of pulse signals, the angle of rotation is proportional to the step angle. For example, in order to make a stepping motor of 1.8 degree step angle rotate by 90 degrees, the number of pulse signals required is obtained as N = 50 from the equation of
$1.8 \times N = \theta$.
In general, it is put as:
$\theta o \times N = \theta$.
where θo: Step angle (deg./step)
N: Number of input pulses
θ: Angle of rotation

Angular error per one step is small, and errors are not accumulated.

Angular error per step (static angular error) is so small as plus/minus 5%. Because this error is not accumulated, even if rotors are rotated continuously, the error is still plus/minus 5% of step angle.

Characteristics of response to starting/stopping is excellent.

Thanks to the excellent response characteristics of starting/stopping signals in self-starting area (region), stepping motors can reverse their rotation instantaneously.
Starting and stopping can be done simply by sending pulse signals into drive circuit or not, and, further, rotation reverse can be made only by changing the input port of pulse signals to CW or CCW. However, acceleration and deceleration time must be taken into account because slow-up and down control is needed in the slew region.

Very low synchronous speed is obtainable under direct coupling of motor shaft.

Stepping motors can be driven as a very low synchronous speed by widening the pulse intervals from pulse generator without using a reduction mechanism such as gear train. It not only simplifies the system but also eliminates errors such as gear back-lash.

Stopping position can be maintained by holding torque.

Stepping motors have a large holding torque when windings are excited. In the PM type and HB motors which have permanent magnet, rotors have a holding torque (detent torque) even in the nonexcited condition.

Excellent controllability is obtained in open-loop control.

In DC servo motors, speed and/or positioning is controlled by sensing the motor operation with an encoder or tachogenerator, but in stepping motors, control relies only on pulse signals from pulse generator. Therefore, no sensor and operating circuit are needed.

●Glossary

VR type stepping motors
This type of stepping motor has a construction consisting of a rotor of magnetic material in the shape of gear and an excited stator. Attraction between these parts gives the motor rotation. Step angle accuracy is high, but output torque is rather poor.

PM type stepping motors
This type of stepping motor has a permanent magnet rotor, and step angle is comparatively large. This type of motor is poorer in step angle accuracy and output torque compared with other types, but featured by low cost.

HB type stepping motors
This is a hybrid type of VR and PM type motors. Rotor has teeth on its periphery and stator has also many teeth in its inner periphery. Further, the rotor has a built-in permanent magnet. Small step angle, high torque and high accurate performance feature this type of motor.

Rated voltage
Rated voltage in the motor specifications is set to that temperature rise meets standard value.

Rated current
This is the current that flows in motor when the rated voltage is applied. In case of stepping motors, this current flows when motors are excited and stopped.

Step angle
This is the angular displacement of rotor when one pulse is applied.

Holding torque
This is the maximum torque which a stepping motor generates when it is excited at the rated voltage and an angular displacement is given from outside. This is a very important factor, because it makes the foundation of the torque generated by stepping motors.

Detent torque
This is the torque generated in the motor with a permanent magnet rotor such as PM type and HB type when an angular displacement is given to the output shaft without excitation.

Self-starting region

This is the region in which motors can be started and stopped instantaneously.

Pulse rate

This is the number of pulse in a unit time, and is shown in the unit "pps" which means "pulses per second". The relation between pulse rate, speed (rpm) and angular velocity (rad/s) is given as below.

$$\omega = \frac{\pi}{180} \theta s \cdot P \rightarrow P = \frac{180}{\pi} \frac{\omega}{\theta s}$$

$$N = \frac{1}{6} \theta s \cdot P \rightarrow P = \frac{6N}{\theta s}$$

where ω : Angular velocity (rad/s)
π : Circular constant
θs : Step angle (deg.)
N : Speed (rpm)
P : Driving pulse rate (pps)

Maximum self-starting frequency (pps)

This is the maximum pulse rate in the self-starting region. Care must be taken, because it varies depending on the load inerita.

Slew region

In this region, driving is possible only by slow-up/slow-down control.

Maximum response frequency (pps)

This is the maximum pulse rate in the slew region.

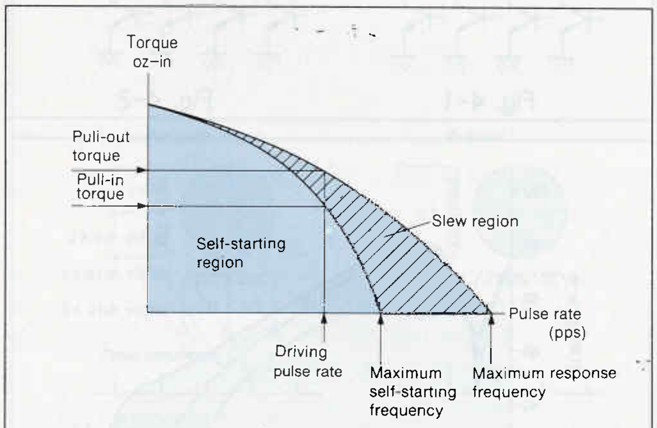

Fig. 1 Torque/speed characteristics curve

Pull-in torque

This is the torque generated when started in the selfstarting region, and it is called "synchronization torque" also.

Pull-out torque

This is the torque generated when driven in the slew region.

Pull-out

This means coming out of synchronized operation by being not able to follow the pulse signal from pulse generator. Over-loading is the general cause, but noise (Electric/Electro-magnetic) makes a cause in some cases.

Slow-up/slow-down

It is a kind of control to rise up pulse rate to drive stepping motors in the slew region to make them exhibit their capability to the full. Among various methods, an example of trapezoidal driving is shown in Fig. 2.

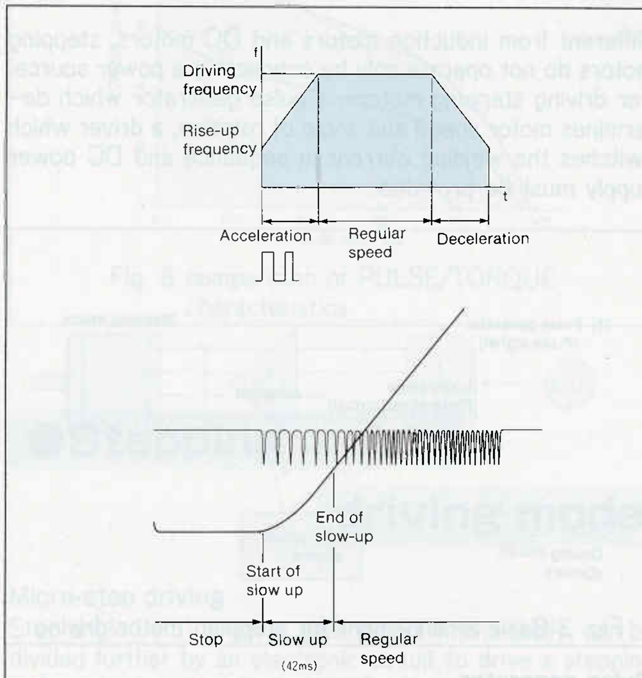

Fig. 2 Trapezoidal drive of slow-up/slow down control

Resonance phenomenon

When stepping motors are driven, torque decrease, missteps, vibration and other unfavorable phenomena may occur at some specific frequencies. It is called "Resonance phenomenon", and caused by the coincidence of intrinsic vibration frequency and input pulse frequency of motor. It is experienced generally in the range of 100 to 200 pps. It is impossible to eliminate this resonance fully, but the defect can be reduced by changing excitation mode or providing a damper.

●How to drive stepping motors

Different from induction motors and DC motors, stepping motors do not operate only by connecting a power source. For driving stepping motors, a pulse generator which determines motor speed and angle of rotation, a driver which switches the winding current in sequence and DC power supply must be provided.

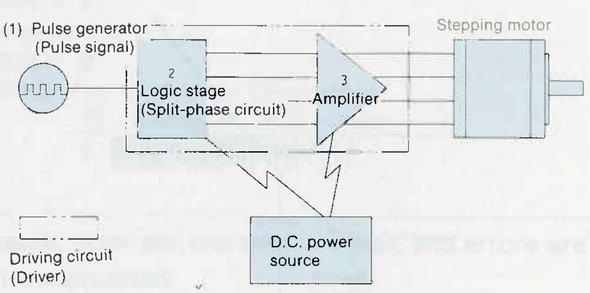

Fig. 3 Basic arrangement for stepping motor driving

Pulse generator

This is the circuit which generates pulse signals to determine the angle of rotation and speed of stepping motors. Motor speed is determined by the pulse rate (pps) and the angle of rotation relies on the number of pulse signals, because stepping motors operate in synchronization with the pulse signals generated in this generator.

Driving circuit (driver)

A stepping motor driving circuit consists of a logic stage, which generates signals for every phase of motor by receiving single-phase pulse signals indicating speed and position, and a power stage for supplying motor windings with current.
In other words, it is a circuit which has a function of switching the motor windings in a sequence every time it receives a pulse signal from pulse generator.

DC Power source

Regarding the motor power source, it is preferable to use a DC stabilized power source as far as possible.
However, in some driving circuits, a switching power source or rectifier power source can be used. Power sources for circuit must be constant voltage sources which fit the circuit elements.

There are a variety of stepping motor driving modes depending on the type of motor windings and the type of driving circuits. Because every driving mode has its merit, a driving mode which is most suitable to the application must be selected.

Constant voltage driving mode and constand current driving mode

Constant voltage driving mode

Constant voltage driving mode is that in which a constant voltage is applied to the windings of stepping motor. In this mode, the circuit arrangement is rather simple as shown in Fig. 4-1, but, in high speed operation, the winding impedance increases to cause decreased current resulting in lower torque.
A method of improving torque characteristics at high speed in the constant voltage driving mode is to connect an external resistance as shown in Fig. 4-2. In this method, current decrease at high speed can be prevented by a smaller electrical time constant brought by applying higher voltage and connecting a noninductive resistance (with small inductance L) in the motor windings in series. Large power loss will be caused by the resistance, but it is a simple method at low cost. The resistance value to be connected in this case is calculated as follows. An example of characteristics improvement by the use of external resistance is shown in Fig. 5.

$$Rx = \frac{Vcc - E}{I}$$

$$Vcc \geqq E$$

$$PR = I^2 Rx$$

where
Vcc : Power source voltage
E : Rated voltage of motor
I : Rated current of motor
P : Loss caused at external resist.

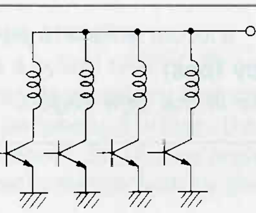

Fig. 4-1

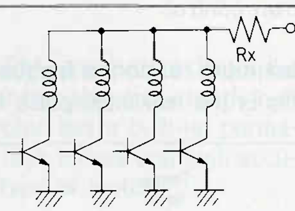

Fig. 4-2

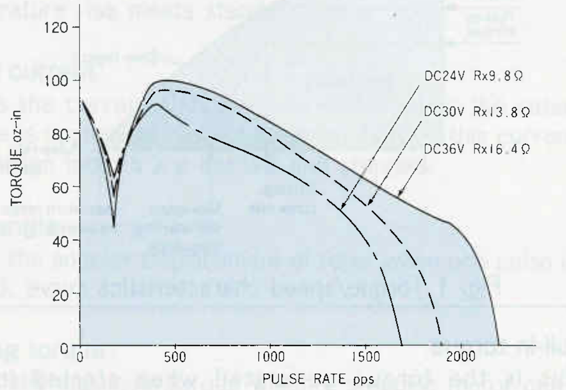

Fig. 5 An example of characteristics improvement

Constant current driving mode

Constant current driving mode is the method in which voltage fairly higher than the rated voltage of motor is chopped up in pieces and applied to motor windings to keep the current constant through the speed range from low to high. Circuits are complex and costly but output torque can be improved remarkably at the time of high speed rotation with a merit of low power consumption. When this mode is used, low winding resistance must be selected.

Uni-polar driving and bi-polar driving

Uni-polar driving

In uni-polar driving, current flows always in one direction in a winding, and is used conveniently in the stepping motors which have a connection with center taps as shown in Fig. 7-1. The driving circuit is simple as seen in the figure, but, due to the poor efficiency of shunt windings (1/2 compared with bi-polar driving), output torque is small at low speed.

Bi-polar driving

In bi-polar driving, current flows in both directions in a winding. It is suitable for the stepping motors which have the connections shown in Fig. 7-2. Contrary to uni-polar driving, the driving circuit is complex, but windings are used efficiently and high torque is obtained at low speed.

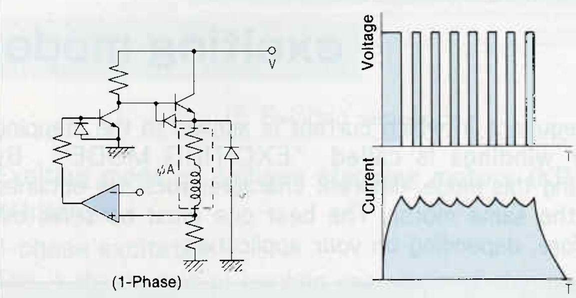

Fig. 6 Constant current chopper circuit

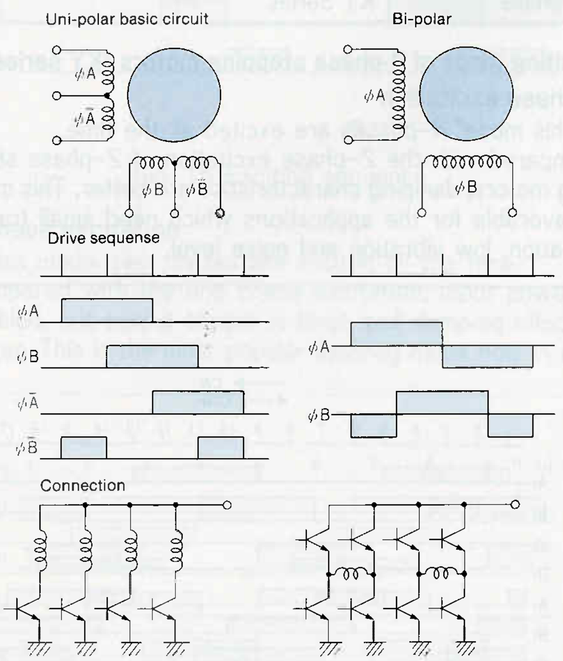

Fig. 7-1 Unipolar Fig. 7-2 Bi-polar
Fig. 7 Exciting sequence and basic circuit

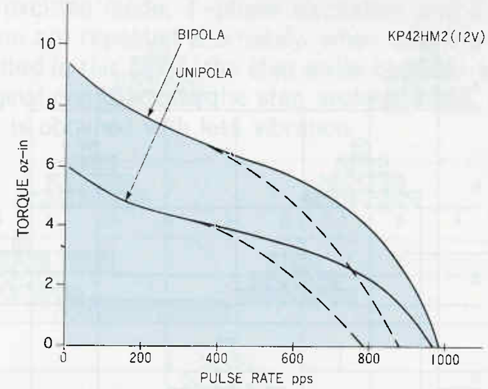

Fig. 8 comparision of PULSE/TORQUE characteristics

●Stepping motor driving mode

Micro-step driving

Step angle (θo) which is determined mechanically, can be divided further by an electronic circuit to drive a stepping motor slowly with minute angular increments. This drive mode is called "MICRO-STEP DRIVING". In the conventional exciting mode, exciting phase is turned ON and OFF in response to the input pulses to rotate the rotor by a fixed angle step by step, but in the micro-step driving, the specific step angle (θo) is divided further by increasing the current in one of the exciting phases gradually and decreasing the current in the other phase gradually. This driving mode gives smooth rotation.

Movement of rotor, exciting sequence and an example of circuit are shown in fig. 9, 10 and 11 respectively.

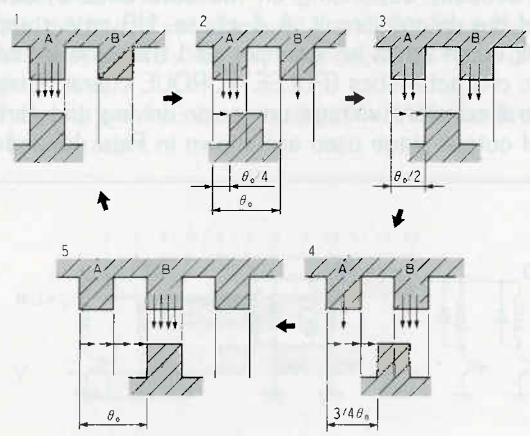

Fig. 9 Rotor movement during the angle θo

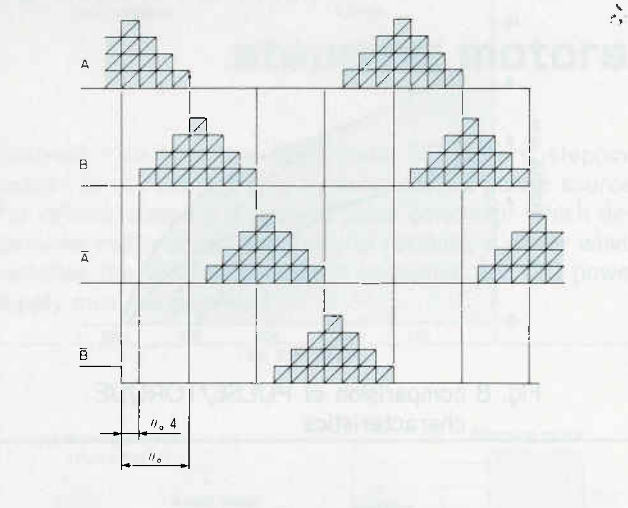

Fig. 10 Exciting sequence

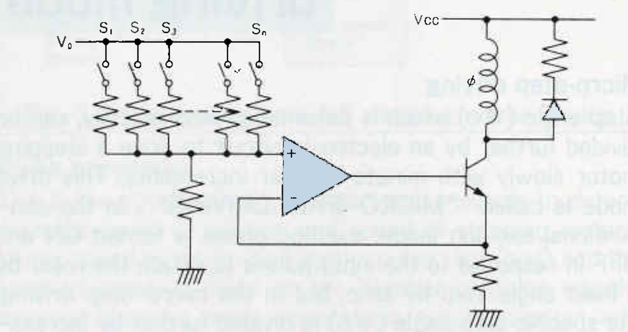

Fig. 11 Example of step-wave generating circuit (for 1-phase)

Output circuit and dynamic characteristics

In driving a stepping motor, its dynamic characteristics vary drastically depending on the difference of output stage of the driving circuit. A 4-phase, HB type stepping motor is taken up as an example, and the variation of its dynamic characteristics (PULSE-TORQUE characteristics) in general constant voltage uni-polar driving and various kinds of output stage used are shown in Figs. 12 and 13.

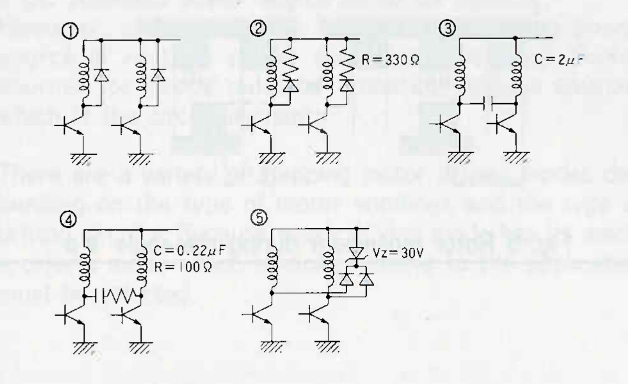

Fig. 12 Example of output circuit in constant voltage

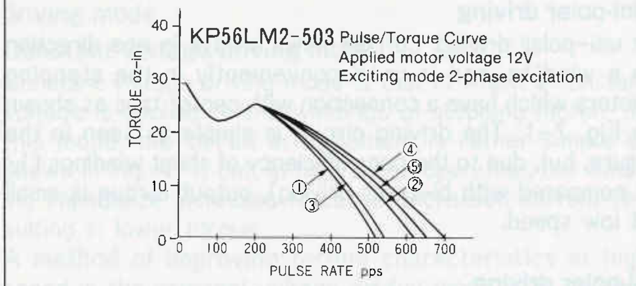

Fig. 13 PULSE/TORQUE characteristics in constant voltage uni-polar drive

●Stepping motor exciting mode

The sequence in which current is applied to the stepping motor windings is called "EXCITING MODE". By changing this mode, different characteristics are obtained from the same motor. The best one must be selected, therefore, depending on your application.

Number of phase of motor	Motor series	Exciting mode
4-phase	KY Series	4-phase excitation 3-4 phase excitation
2-phase	KP Series KH Series	1-phase excitation 2-phase excitation 1-2 phase excitation
3-phase	KT Series	

Exciting mode of 4-phase stepping motors (KY series)

4-phase excitation

In this mode, 4-phases are excited all the time. Compared with the 2-phase excitation of 2-phase stepping motors, damping characteristics are better. This mode is favorable for the applications which need small torque variation, low vibration and noise level.

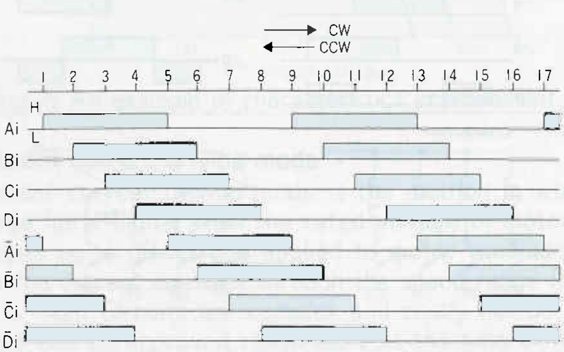

Fig. 14 Exciting sequence

3 – 4 phase excitation

In this excitation mode, 3-phase excitation and 4-phase excitation are repeated alternately. When stepping motors are excited in this mode, the step angle becomes a half of the original one. It is same with 1 – 2 phase excitation of 2-phase stepping motors in theory, but the stability of running is far better.

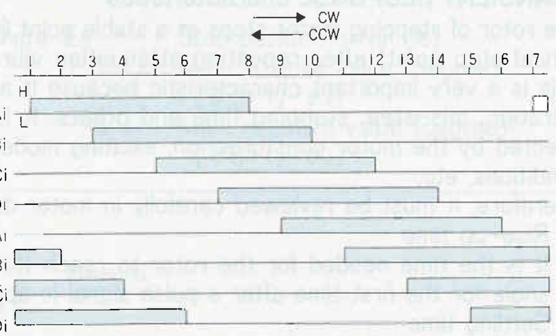

Fig. 15 Exciting sequence

Exciting mode of 2-phase stepping motors (KP and KH Series)

1-phase excitation

This is the method of exciting one phase all the time. Although the power consumption is small, it tends to cause vibration due to the poor damping effects.

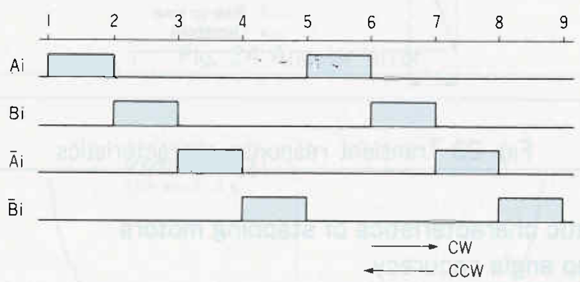

Fig. 16 Exciting sequence

2-phase excitation

In this mode, two phases are excited all the time. Compared with the one phase excitation, input power is doubled, but output torque is large and damping effect is better. This is the most popular exciting mode now in use.

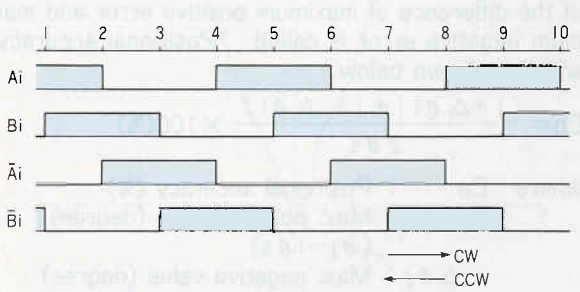

Fig. 17 Exciting sequence

1 – 2 phase excitation

In this exciting mode, 1-phase excitation and 2-phase excitation are repeated alternately. when stepping motors are excited in this mode, the step angle becomes a half of the original one. Because the step angle is a half, smooth running is obtained with less vibration.

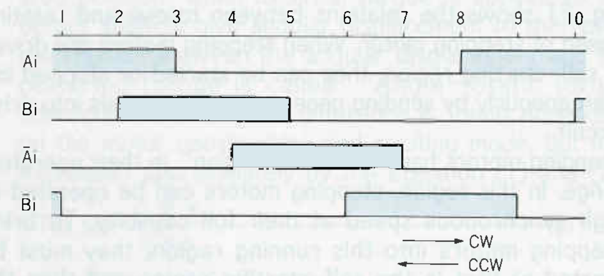

Fig. 18 Exciting sequence

Excitation method for 3-phase stepping motors (KT-Series)

2-phase excitation:

In this method, 2-phases are excited all the time. And employed rather commonly because of larger output torque than other method.

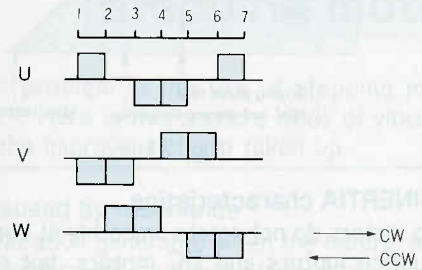

Fig. 19 Excitation sequence

2 – 3phase excitation:

In this method, 2-phase excite and 3-phase excite are repeated alternately. By this method, a half-step drive can be performed.

And the drive makes smoother rotation and creates smaller vibration.

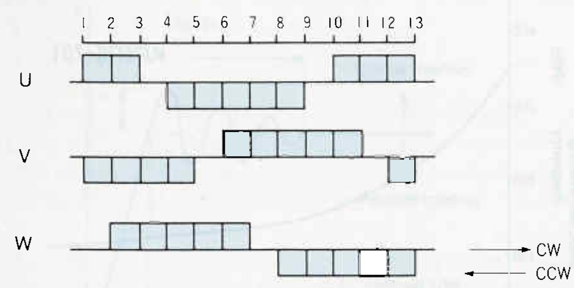

Fig. 20 Excitation sequence

●Basic characteristics of stepping motor

Dynamic characteristics of stepping motor

TORQUE–SPEED characteristics

Fig. 21 shows the relations between torque and rotating speed of stepping motor. When stepping motors are driven in self–starting region, they can be started or stopped instantaneously by sending necessary pulse signals into drive circuit.

Stepping motors have a "Slew Region" in their operating range. In this region, stepping motors can be operated at high synchronous speed at their full capacity. To bring stepping motors into this running region, they must be started at first in the self–starting region and then the pulse rate is increased gradually in a short time by slow–up/slow–down control.

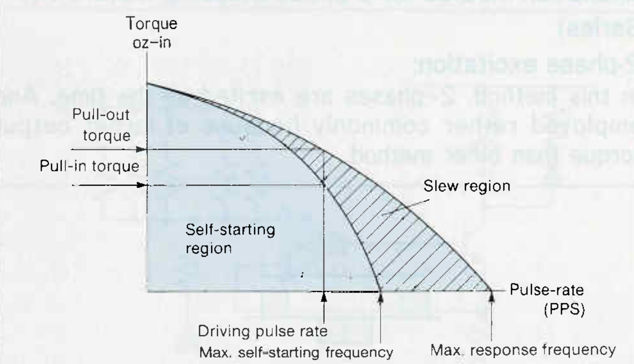

Fig. 21

PULSE-INERTIA characteristics

Stepping motors do not rotate smoothly at constant speed like induction motors and DC motors, but repeat start, acceleration, deceleration and stop. Such characteristics of motion are heavily affected by the moment of inertia of load.

As the load inertia increases, the self–starting region is narrowed. The maximum self–starting frequency of stepping motor with load inertia is expressed apporximately by following equation.

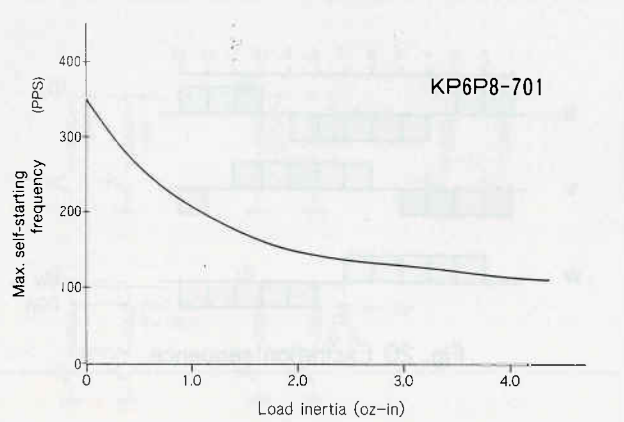

Fig. 22

$$PL=\frac{Ps}{\sqrt{1+\frac{JL}{JR}}}$$

where PL : Max. self–starting frequency with load inertia (pps)
Ps : Max. self–starting frequency of motor only (pps)
JP : Moment of inertia of rotor (oz–in^2)
JL : Moment of inertia of load (oz–in^2)

TRANSIENT RESPONSE characteristics

The rotor of stepping motor stops at a stable point (theoretical stop point) after repeating attenuation vibration. This is a very important characteristic because it affects vibration, mis–step, stopping time and others. It is also affected by the motor consturuction, exciting mode, load conditions, etc.

Therefore, it must be reviewed carefully in motor design.

1) Rise–up time
It is the time needed for the rotor to reach the step angle for the first time after a pulse signal is applied.
2) Settling time
This is the time from application of a pulse signal to the stop of rotor after attenuation of rotor vibration.

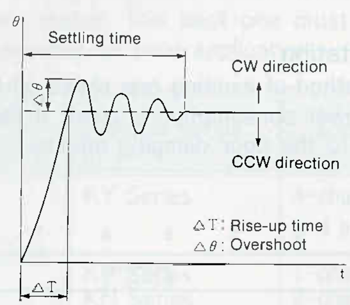

Fig. 23 Transient response characteristics

Static characteristics of stepping motors

Step angle accuracy

This is the error for the theoretical rotaing angle determined by the exciting mode adopted or mechanically. This error may be caused by the dispersion of mechanical accuracy and winding resistance. It includes (1) Positional accuracy, (2) Stop position error and (3) Hysteresis error.

1) Position accuracy
Starting from any one point, rotor is rotated one step by one step through 360 degrees. An angular error between the theoretical position and actual position for every step is measured through 360 degrees. One half of the difference of maximum positive error and maximum negative error is called "Positional accuracy" which is shown below.

$$Ep=\frac{|+\Delta\theta i|+|-\Delta\theta j|}{2\theta s}\times 100(\%)$$

where Ep : Positional accuracy (%)
$+\Delta\theta i$: Max. positive value (degree) (θj−iθs)
$-\Delta\theta j$: Max. negative value (degree) (θj−jθs)
θs : Step angle (degree)

2) Stop position error
Starting from any one point, rotor is rotated one step by one step through 360 degrees. An angular error between the theoretical position and actual position for every step is measured through 360 degrees. The maximum angular error for one step among them is called "Stop position error" which is shown as below.

$$Es = \frac{+\Delta \alpha i \times 100}{\theta s} \quad \text{or} \quad Es = \frac{-\Delta \alpha j \times 100}{\theta s}$$

where Es : Stop position error (%)
$+\Delta \alpha i$: Max. positive value (degree) $[\theta(i+1) - \theta i]$
$-\Delta \alpha j$: Max. negative value (degree) $[\theta(j+1) - \theta j]$

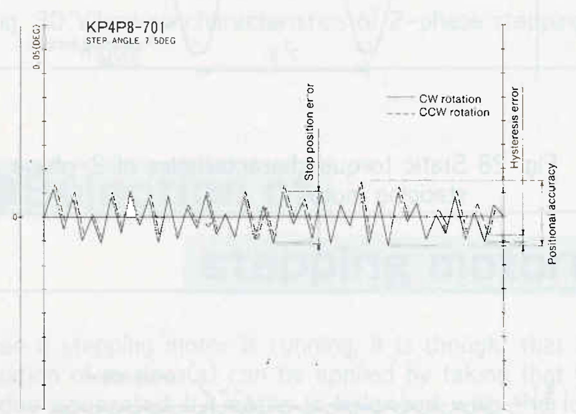

Fig. 24 Angular error

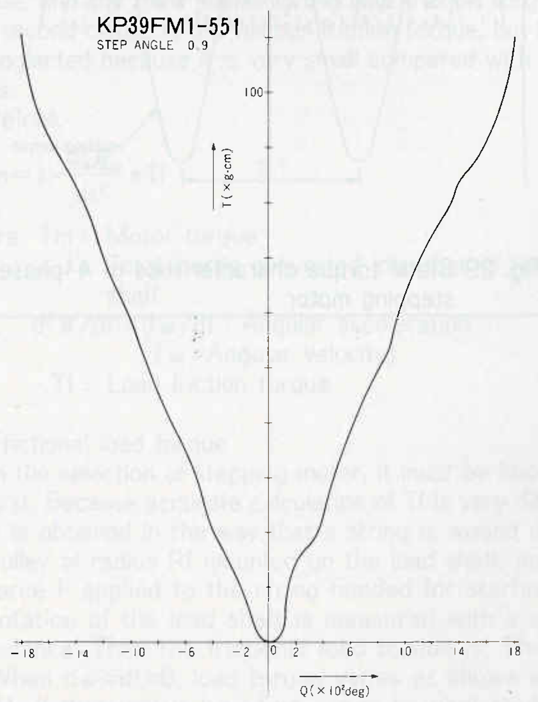

Fig. 25 Angle-static torque characteristics

3) Hysteresis error
Stepping motors have some discrepancies in the stop positions in CW and CCW rotation. This error is called "Hysteresis error", and the maximum discrepancy between both rotations is taken in general.

Angle−Static torque characteristics
In an excited stepping motor with its rotor held at a stop position, when external torque is applied to the output shaft to give angular displacement to the rotor, the relation between the angular displacement and the restoring torque is called "Angle−Static torque characteristics". Some difference is found depending on the motor construction and exciting mode, but it is expressed approximately by the Equation (1) and (2).

$$T = Tm \sin \frac{\Delta \theta \pi}{2 \theta s} \qquad (1)$$

$$\Delta \theta = \frac{2 \theta s}{\pi} \sin^{-1} \frac{T}{Tm} \qquad (2)$$

where θs : Step angle
Tm : Holding torque
$\Delta \theta$: Angular displacement

●Actions for vibration reduction of stepping motors

The biggest problem in the use of stepping motors is "Vibration". Here in this section, kinds of vibration and actions for the improvement are taken up.

Vibration caused by resonance

This is the vibration generated when the natural frequency of motor coincides with input pulse frequency. The range of 100 to 200 pps is that where it is generated, and, in some cases, motor will pull out of the synchronous speed.

Vibration at low speed operation

Stepping motors rotate by repeating start and stop in every step angle. Motor behavior is the repetition of attenuation vibration, which generates large vibration naturally at low speed.

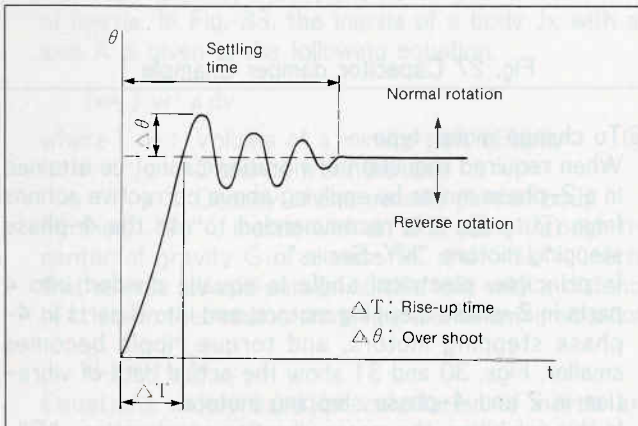

Fig. 26 Transient response characteristics

Vibration at medium and high speeds

The attenuation vibration of stepping motor is shown in Fig. 26. The over shoot in Fig. 26 affects the vibration at medium and high speed.

Actions for improving vibration

Following actions are taken for the improvement of vibration.

①To operate at a frequency out of resonance frequency.
In driving stepping motors, the frequency must be set basically out of resonance frequency range of 100 to 200 pps.

②To change excitation mode
By changing the excitation mode to 1−2 phase excitation, step angle is halved resulting in smaller vibration at low speed.

③To change load torque
By increasing load torque, especially frictional torque, vibration energy is absorbed to reduce vibration.

④To provide mechanical damper
This is a method of absorbing vibration by applying mechanical braking force from outside. Mechanical dampers include friction damper, flywheel damper, viscous damper and magnet damper.

⑤To provide electrical damper
This is a method to absorb vibration energy by changing the condition of serge absorbing circuit in output stage of driver. Typical example is capacitor damper.

●Capacitor damper

In this method, a capacitor is inserted between every phase. Using the electro-motive force at ON/OFF of transistors, certain amount of current is applied to the windings which were released from excitation, for braking. In this method, it must be noted that torque is decreased at high speed.

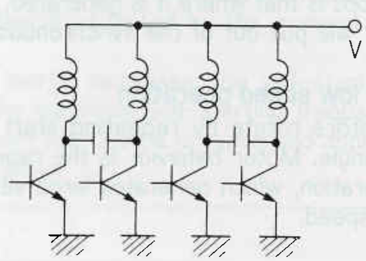

Fig. 27 Capacitor damper Example 1

⑥To change motor type
When required reduction of vibration cannot be attained in a 2-phase motor by applying above corrective actions from ① to ⑤, it is recommended to use the 4-phase stepping motors "KY-Series".
In principle, electrical angle is equally divided into 4 parts in 2-phase stepping motors, and into 8 parts in 4-phase stepping motors, and torque ripple becomes smaller. Figs. 30 and 31 show the actual data of vibration in 2 and 4-phase stepping motors.
In this exhibition, the motor vibration acceleration "G" against driving pulse is measured, and the output is analysed in a vibration frequency analyzer (FFT) to show the result 3-dimensionally. In comparison of these data, effective suppression of vibration through whole range of driving frequency can be seen.

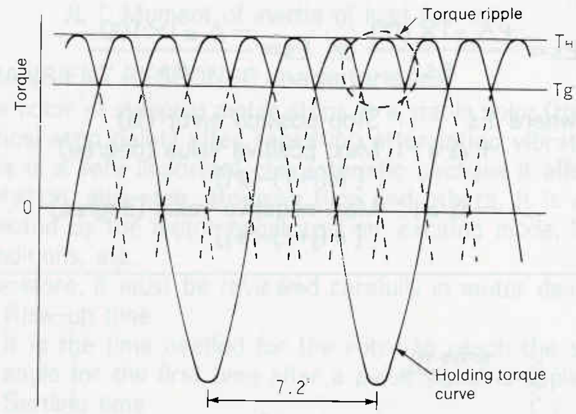

Fig. 28 Static torque characteristics of 2-phase stepping motor

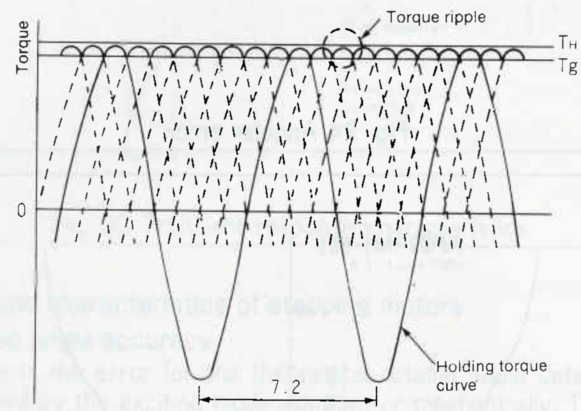

Fig. 29 Static torque characteristics of 4-phase stepping motor

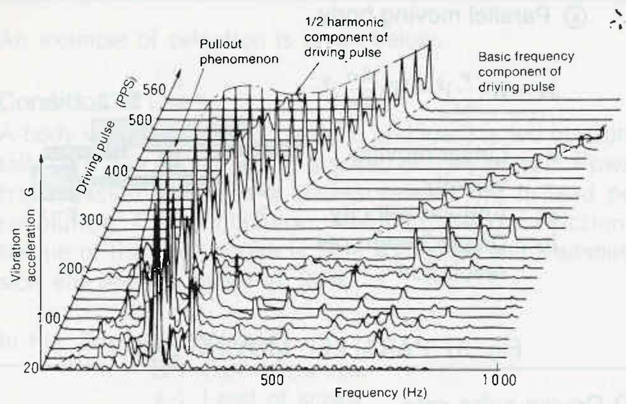

Fig. 30 Vibration characteristics of 2-phase stepping motor

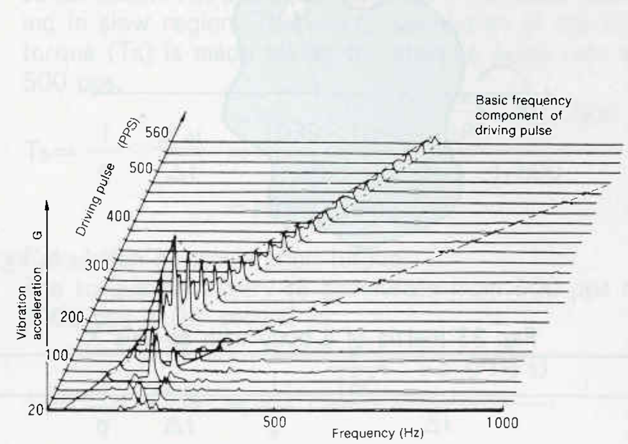

Fig. 31 Vibration characteristics of 4-phase stepping motor

●Selection of stepping motors

When a stepping motor is running, it is thought that the Equation of motion (a) can be applied by taking that the torque generated by motor is balanced with the load torque.

$$Tm = J\frac{d^2\theta}{dt^2} + D\frac{d\theta}{dt} \cdot Tf \quad \text{------(a)}$$

where, the first term in the right side shows acceleration torque, and the third clause is the load friction torque. The second clause is the viscous friction torque, but it can be neglected because it is very small compared with other items.

Therefore,

$$Tm = J\frac{d^2\theta}{dt^2} + Tf$$

where Tm : Motor torque

J : Total inertia converted into that of rotor shaft

$d^2\theta/dt^2 = d\omega/dt$: Angular acceleration

(ω = Angular velocity)

Tf : Load friction torque

1) Frictional load torque

In the selection of stepping motor, it must be known at first. Because accurate calculation of Tf is very difficult, it is obtained in the way that a string is wound on the pulley of radius Rf mounted on the load shaft, and the force F applied to the string needed for starting the rotation of the load shaft is measured with a spring balance. Then the frictional load torque is; Tf=Rf F. When $d\omega = dt = 0$, load torque varies as shown in Fig. 31. If the viscous load torque can be neglected, it is common to use starting frictional torque rather than static frictional torque.

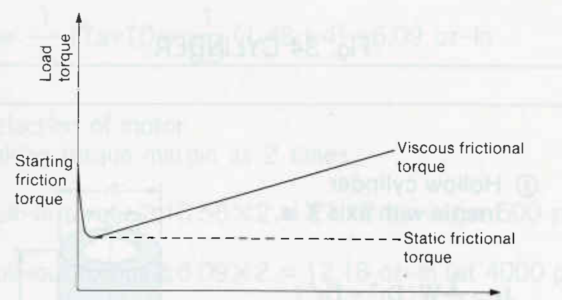

Fig. 32 Load torque variation

2) Inertia

Stepping motors tend to be affected more by inertia than other motors. In the model selection of stepping motors, therefore, it is very important to have the data of inertia. In Fig. 33, the inertia of a body Jx with an axis X is given in the following equation.

$$Jx = \int vr^2 \rho \, dv$$

where v : Volume of a minute part of body

r : Distance from the axis

ρ : Density of the mimute part of body

Further, "Jo", inertia with an axis going through the center of gravity G of a mass M, and "JL", inertia that relates an axis parallel to this axis with a distance of L, are in the relation shown by the following equation.

$$JL = Jo + L^2M$$

Equations widely used for calculation of inertia are shown next.

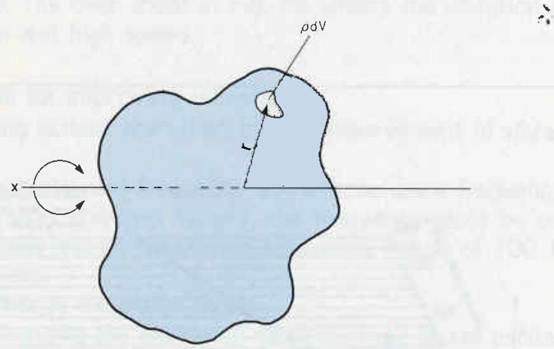

Fig. 33 Inertia of a body with an axis X

① Cylinder
Inertia with axis X is,

$$J_x = \frac{1}{8} W D^2$$
$$= \frac{\pi}{32} \rho \ell D^4$$

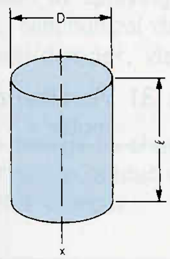

Fig. 34 CYLINDER

② Hollow cylinder
Inertia with axis X is,

$$J_x = \frac{1}{8} W (D_1^2 + D_2^2)$$
$$= \frac{\pi}{32} \rho \ell (D_1^4 - D_2^4)$$

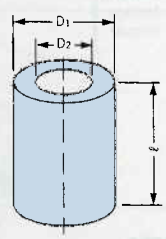

Fig. 35 HOLLOW CYLINDER

③ Square column
Inertia with axis X is,

$$J_x = \frac{1}{12} W (A^2 + B^2)$$
$$= \frac{1}{12} \rho ABC (A^2 + B^2)$$

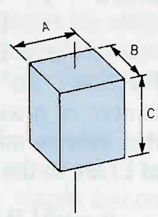

Fig. 36 SQUARE COLUMN

④ Parallel moving body

$$J_x = W\left(\frac{v}{\omega}\right)^2 = W\left(\frac{\ell o}{2\pi}\right)^2$$

v : Linear moving velocity
ω : Angular velocity
ℓo : Displacement per revolution

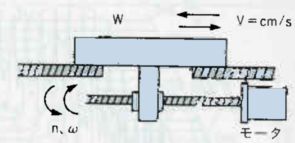

Fig. 37 PARALLEL MOVING BODY

4) Driving pulse rate
In stepping motors, torque varies depending on the pulse rate, and, the pulse rate is determined by the speed at which the system operates, transmission mechanism and volume to be controlled. The relations between driving pulse rate (pps), angular velocity (ω) (rad/sec.) and rotating speed (N) (rpm) are given as below respectively.

$$\omega = \frac{\pi}{180} \theta o P \rightarrow P = \frac{180}{\pi} \frac{\omega}{\theta o}$$

$$N = \frac{1}{6} \theta o P \rightarrow P = \frac{6N}{\theta o}$$

where ω : Angular velocity (rad/s)
π : Ratio of diameter to circumference 3.141592654…
θo : Step angle (deg)
P : Driving pulse rate (pps)
N : Speed (rpm)

After loading conditions and driving pulse rate are determined, check whether the motor can be started in the self-starting region or driving in the slew region using slow-up/slow-down control is needed on the pulse-torque characteristics curve of the stepping motor selected. An important point is the effect of inertia, which affects the self-starting region. The pulse-torque characteristics in the catalog are for motor only. Make a guess for the new self-starting region based on the maximum self-starting frequency under load. In the selection of a model of stepping motor, take sufficient allowance in performance, because stepping motors are very precise and delicately affected by the dispersion in assembly, change of ambient conditions and load variations.

●An example of how to select a stepping motor model

An example of selection is given below.

Condition of use

A body weighing 100 oz (a table and load) is fed horizontally on 0.5 in pitch basis at a speed of 2 in/second. Power transmission relies on a lead-screw of 0.2 in lead per revolution, 0.5 in diameter weighing 30 oz. Frictional torque of the lead-screw is Tf = 4.0 oz-in and transmission efficiency is taken as 90%

In Fig. 38, W : Weight
D : Ball screw dia.
ℓ : Lead of screw
v : Feed speed

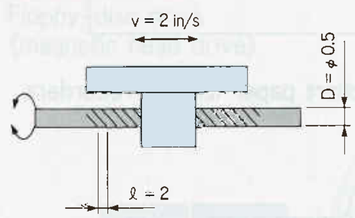

Fig. 38

①Moment of inertia of load

(a) Moment of inertia of body in linear motion J_1

$$J_1 = W\left(\frac{\ell}{2\pi}\right)^2 = 100\times\left(\frac{0.2}{2\pi}\right)^2 = 101\times10^{-3}\ \text{oz-in}$$

(b) Moment of inertia of ball screw, J_2

$$J_2 = \frac{1}{8}WD^2 = \frac{1}{8}\times30\times0.5^2 = 938\times10^{-3}\ \text{oz-in}$$

(c) Moment of inertia of load, J

$$J = J_1 + J_2 = 101\times10^{-3} + 938\times10^{-3}$$

$$= 1039\times10^{-3}\ \text{oz-in}$$

②Conversion of feed speed into pulse rate (f) pps

Supposing that a stepping motor of 0.9° step angle is used,

$$f = \frac{360}{\theta o}\cdot\frac{v}{\ell} = \frac{360}{0.9}\times\frac{2}{0.2} = 4000\ \text{pps}$$

As the value 4000 pps of (f) lies in the high speed range, study will be carried on under the condition of using a constant current chopper driver. (See Note below.)

Note: *Low speed — Nearly equal or less 500 pps, or within the self-starting region of the motor
*Medium speed — Approximately 500 to 2000 pps
*High speed — Approximately 2000 pps or higher

③Calculation of starting torque

Calculate the torque necessary for starting the load to select motor. The pulse rate obtained in ② needs starting in slew region. Therefore, calculation of starting torque (Ts) is made taking the starting pulse rate as 500 pps.

$$Ts = \frac{J}{g}\cdot\frac{\Delta\omega}{\Delta t} \fallingdotseq \frac{1039\times10^{-3}}{386}\cdot\frac{\frac{\pi}{180}\,0.9\times500}{1/500}$$

$$= 10.56\ \text{oz-in}$$

④Calculation of acceleration torque

The torque necessary to accelerate from 500 pps to 4000 pps in 0.1 second is,

$$Ta = \frac{J}{g}\cdot\frac{\Delta\omega}{\Delta t} \fallingdotseq \frac{J}{g}\cdot\frac{\frac{\pi}{180}\cdot\theta o\cdot(Ff-Fs)}{\Delta t}$$

$$= \frac{1039\times10^{-3}}{386}\times\frac{\frac{\pi}{180}\times0.9\times(4000-500)}{0.1}$$

$$= 1.48\ \text{oz-in}$$

⑤Total load torque

From the accelerating toruque calculated in ④ and the frictional torque given as an initial condition, total load is obtained as below

$$T = \frac{1}{\eta}(Ta+Tf) = \frac{1}{0.9}(1.48+4) = 6.09\ \text{oz-in}$$

⑥Selection of motor

Taking torque margin as 2 times,

Pull-in torque≧10.56×2 = 21.12 oz-in (at 500 pps)

Pull-out torque≧6.09×2 = 12.18 oz-in (at 4000 pps)

must be satisfied. From step angle of 0.9° , Model KY56HM1-551 is chosen.

●Examples of stepping motor application

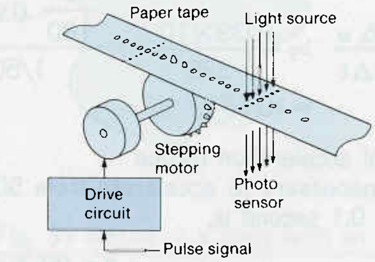

Fig. 39 Paper tape reader

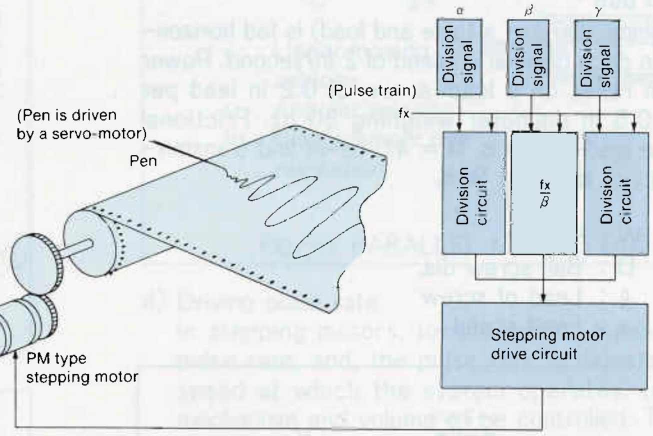

Fig. 40 Multi-speed chart paper feed of recorders

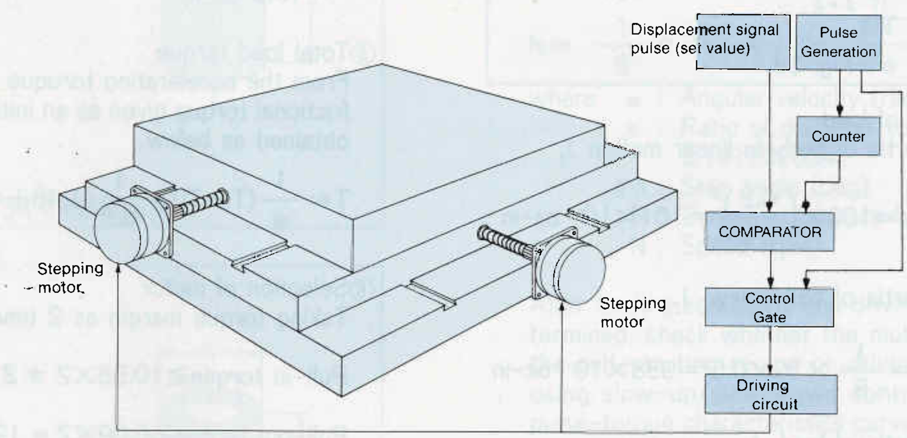

Fig. 41 X-Y tape control

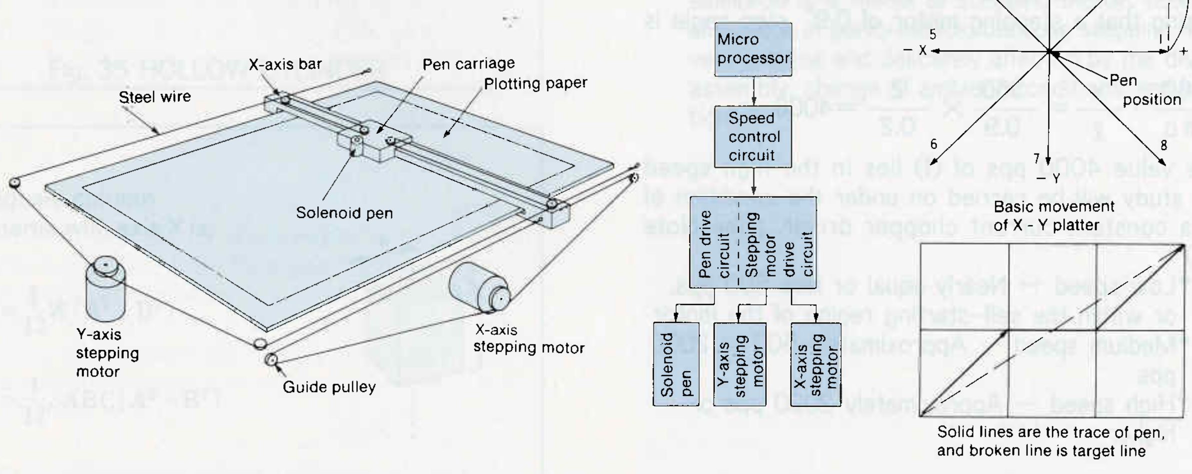

Fig. 42 Pen plotter

●Examples of stepping motor application

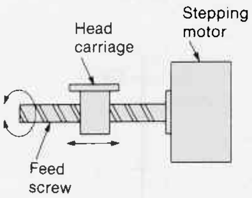

Fig. 43-1 Lead screw type

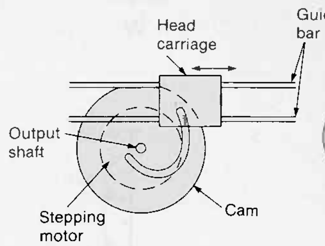

Fig. 43-2 Cam type

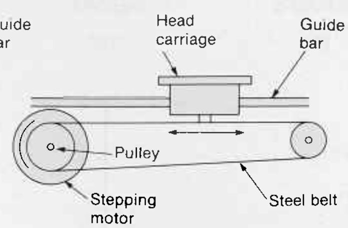

Fig. 43-3 Belt type

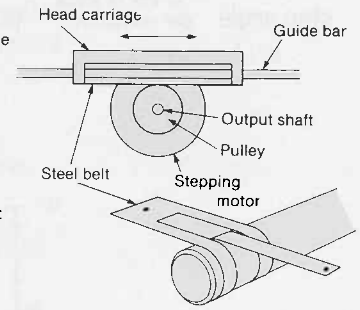

Fig. 43-4 Belt type

Fig. 43 Floppy-disc drive
(magnetic head drive)

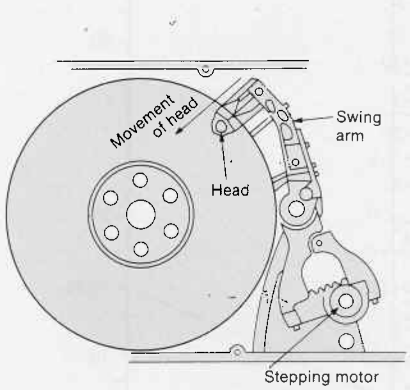

Fig. 44-1 Swing arm type

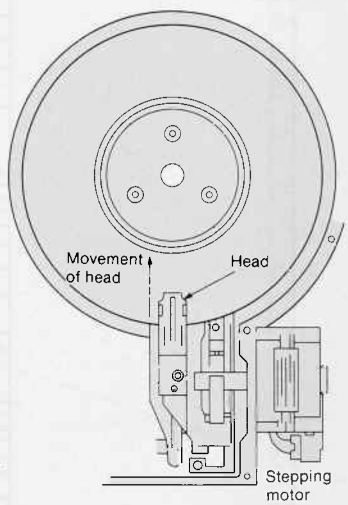

Fig. 44-2 Linear type

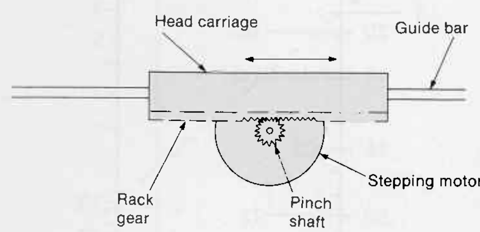

Fig. 44-3 Rack/pinion type

Fig. 44 Hard disc drive
(magnetic head drive)

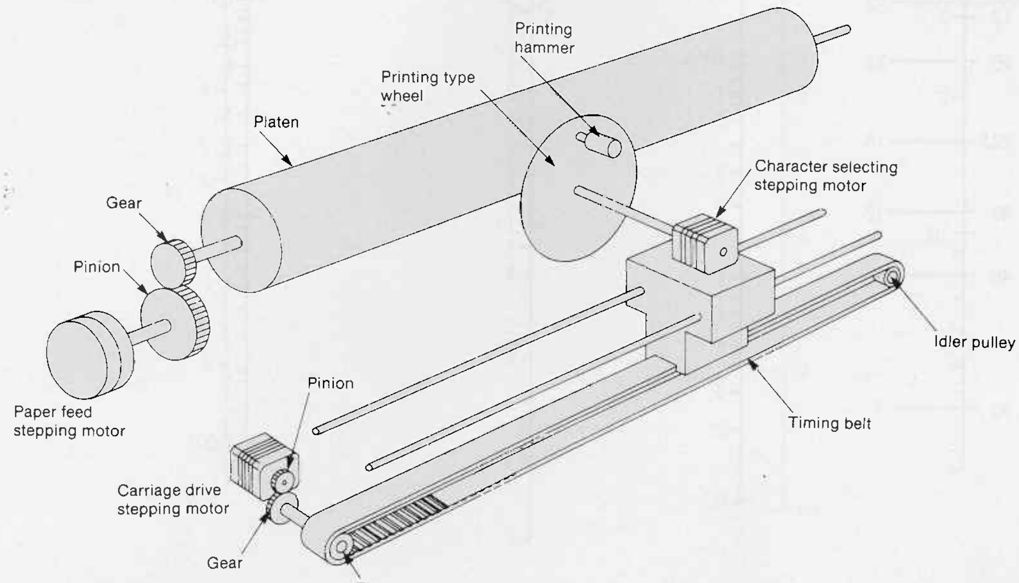

Fig. 45 Daisy-wheel type printer

■**The relationship among step angle, speed and output.**

Motor output can be calculated from speed and torque. Fig. 46 is the monograph for calculation of output.

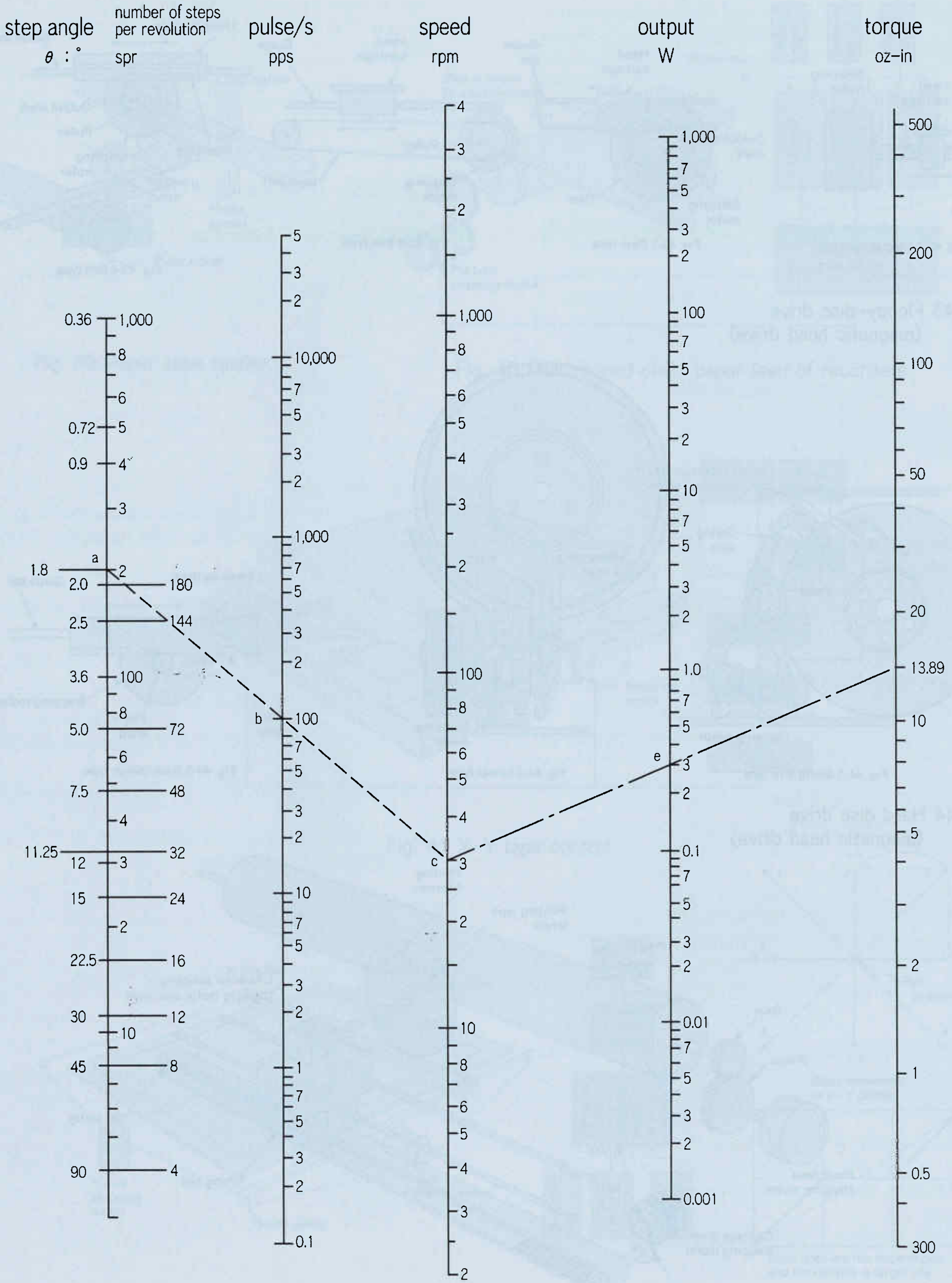

Fig. 46 The relationship among step angle, speed and output

■**Electrical time constant**

Electrical time constant can be calculated from winding inductance and resistance. Fig. 47 is the monograph for calculation of Electrical time constant.

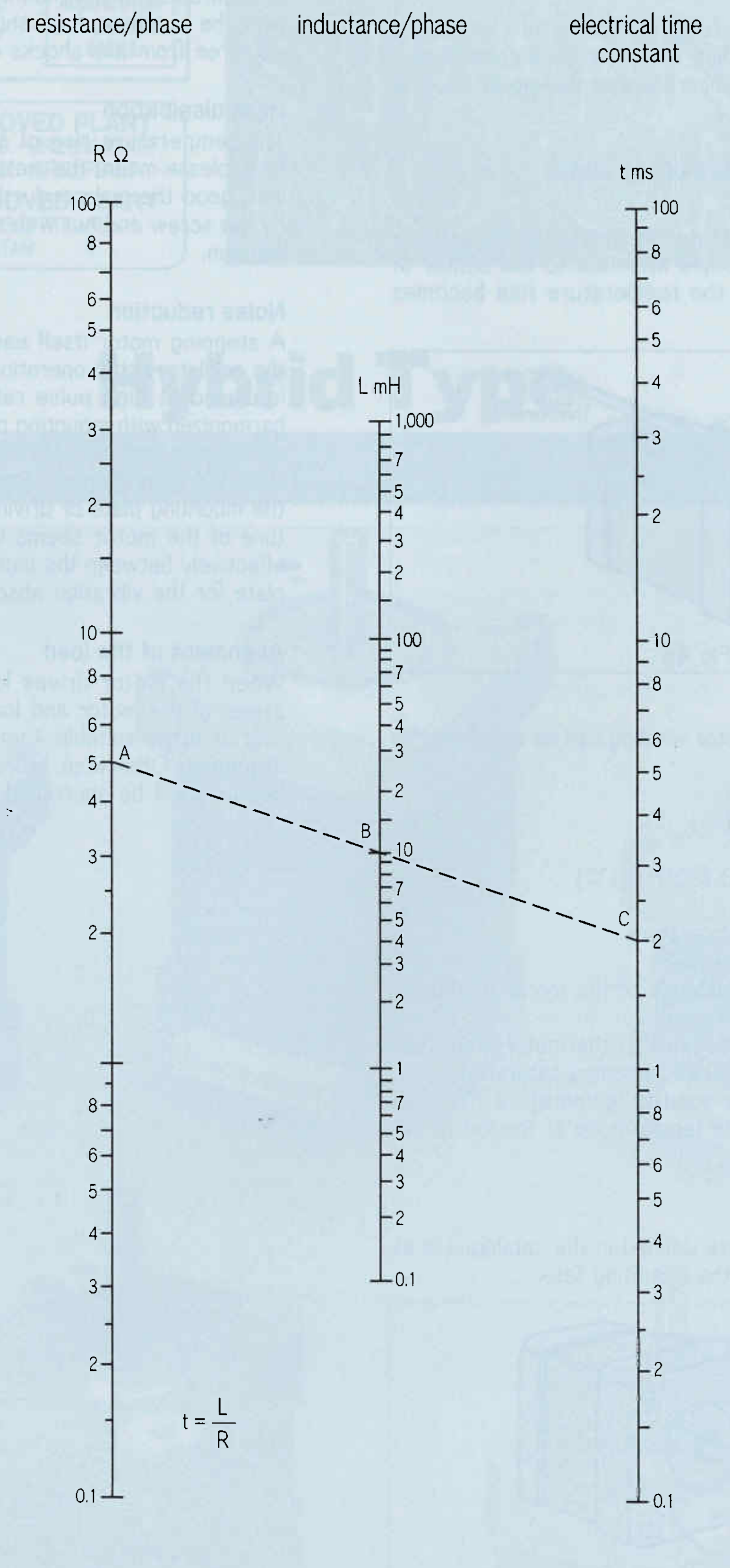

Fig. 47 Electrical time constant

●Application notices

Temperature rise

Heat radiation of the motor must be considred when the motors are driven.
Heat generation of the stepping motors are generally higher than others depending on the various conditions.
Please keep always the temperature of the motor housing not exceed 212 ° F(100℃).

Measuring the temperature of the motor.

Thermometer method.

The temperature of the motor is measured by using a thermometer or thermocouple attached to the center of the motor housing, after the temperature rise becomes saturated.

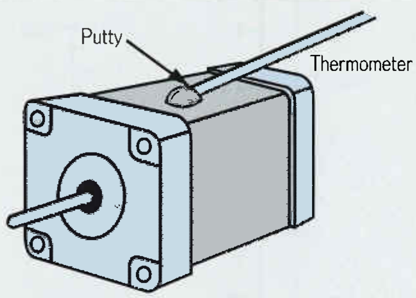

Fig 48

Calculation method.

The temperature of the motor winding can be calculated by the following formula.

Temperature $T = t + \Delta t$ [℃]

$$\Delta t = \left(\frac{R_2}{R_1} - 1\right)(235 + t) \ [℃]$$

t [℃] : Ambient temperature
Δt [℃] : Temperature rise
R_1 [℃] : Winding resistance of the motor at the am bient temperature.
R_2 [℃] : Winding resistance of the motor after the temperature rise becomes saturated.

In case of this method, the winding temperature T℃ must not exceeded the allowable temperature of the motor in-sulation class.

Direction of rotation

The direction of rotation are defined in the catalogue is as viewed from the front of the mounting fase.

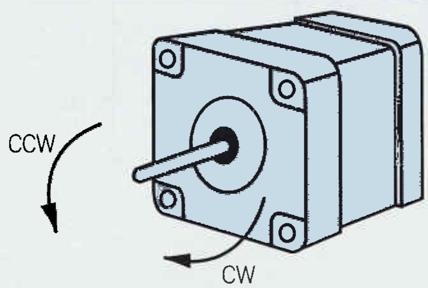

Fig. 49

Installation of the motors

Mounting direction

Any direction is not restricted in the installation of the motor, but usually mounting motors sideways is recom-mended.
In regardless of the mounting direction, please take care with the overhung load and thrust load on the shaft, and also free from any shocks on the shaft.

Heat dissipation

The temperature rise of stepping motors are relatively high, please mount the motors tightly on the metal surface with good thermal conductivity such as steel or aluminum by the screw and nut with spring washer for the heat dis-sipation.

Noise reduction

A stepping motor itself easily generates vibration due to the oscilatory step operation of rotor even when the motor is drived at high pulse rate, and when this vibration is harmonized with mounting plate, vibration noise is amplified and causes high acoustic noise. In this case, please recon-sider the drive frequency and/or thickness and material of the mounting plate or driving method. When the tempera-ture of the motor seems low, rubber plate can be used effectively between the motor mounting face and mounting plate for the vibration absorption.

Alignment of the load

When the motor drives load by coupling directly both axises of the motor and load, please use flexible coupling ring or other suitable items to make sure getting proper alignment. Otherwise, vibration will be caused and life of bearings will be shortened.