RS Data Sheet

Size 1 and 2 Stepper Motors

7.5° stepper motors

Size 1 (RS stock no. 332-947)

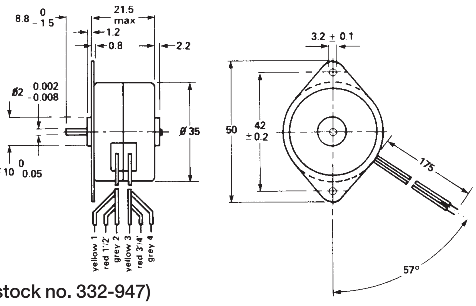
Size 2 (RS stock no. 332-953)

Two 7.5° stepper motors each with four 12Vdc windings (coils) and permanent magnet rotor construction. Designed for unipolar drive, these motors are easily interfaced to simple and relatively low power electronics thus providing economical means of motion and speed control. Due to their permanent magnet rotors these motors have a braking torque even when not energised. This is the detent (residual) torque which is a useful feature for positional integrity.

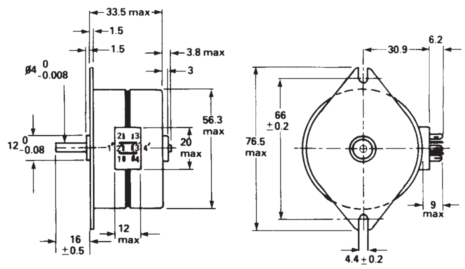
The size 1 motor is ideal for applications requiring low torque drive but it can also be used with the RS range of synchronous gearboxes (**RS** stock no. 336-400 etc.) to provide finer step angle and increased torque at lower speeds.

The size 2 motor is a more powerful general purpose motor ideally suited for direct drive applications.

7.5° Stepper motors



Size 1 (**RS** stock no. 332-947)



Size 2 (**RS** stock no. 332-953)

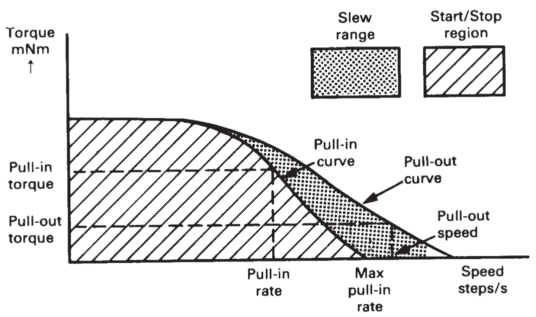
Technical specification

	Size 1	Size 2	Units
Power consumption of motor only	2	5.3	W
Maximum working torque	6	57	mNm
Holding torque	10	85	mNm
Torque derating	-0.4	-0.4	%/°C
Maximum pull-in rate	350	130	steps/s
Resistance per phase at +20°C	120	47	Ω
Inductance per phase	160	400	mH
Current per phase	100	240	mA
Permissible ambient temperature range	-20 to +70	-20 to +70	°C
Permissible storage temperature range	-40 to +100	-40 to +100	°C
Permissible motor temperature	120	120	°C
Insulation resistance at 500V (CEE 10)	>2	>2	MΩ
Step angle	7° 30′	7° 30′	
Step angle tolerance, not cumulative	±40′	±20′	
Number of steps per revolution	48	48	
Direction of rotation	reversible	reversible	
Rotor inertia	2.6	45	gcm^2
Mass	80	300	g
Maximum radial force	2.5	10	N
Maximum axial force	0.75	1.5	N
Bearings	slide (bronze) bronze)	slide (sintered	

Characteristics and terminology

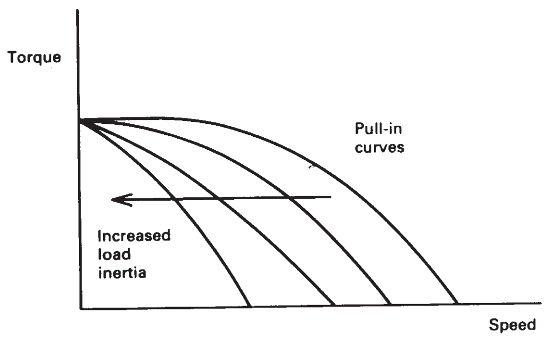
Torque-speed characteristic for a stepper motor may be represented as in Figure 1.

Figure 1 **Torque-speed characteristics**



The pull-in curve describes the maximum constant start/stop rate that a frictionally loaded motor can achieve without loss of step. This curve is dependent on the method of driving the motor and the load inertia. The effect of the latter is shown in Figure 2.

Figure 2 **Effect of load inertia on pull-in curve**



The pull-out curve describes the maximum stepping rate which a frictionally loaded motor can follow without losing steps, assuming sufficient time is allowed to accelerate the motor by ramping the frequency of the command drive circuit. Within the start/stop region the motor can be started, stopped or forced to change direction of rotation following a sudden command change from the drive circuit. However, within the slew range the motor can only be accelerated or decelerated to the required speed and it cannot suddenly change direction.

Detent torque: The maximum torque that can be applied to the spindle of an unexcited motor without causing continuous rotation.

Holding torque: The maximum steady torque that can be externally applied to the spindle of an excited motor without causing continuous rotation.

Maximum working torque: The maximum torque that can be obtained from the motor.

Pull-in torque: The maximum torque that can be applied to a motor spindle when starting at the pull-in rate.

Pull-in rate (speed): The maximum switching rate (speed) at which a frictionally loaded motor can start without losing steps.

Maximum pull-in rate (speed): The maximum switching rate (speed) at which an unloaded motor can start without losing steps.

Pull-out rate (speed): The maximum switching rate (speed) which a frictionally loaded motor can follow without losing steps.

Pull-out torque: The maximum torque that can be applied to a motor spindle when running at the pull-out rate.

Step angle: The nominal angle that the motor spindle must turn through between adjacent step positions.

Stepping rate: The number of step positions passed by a fixed point on the rotor per second.

Positional accuracy

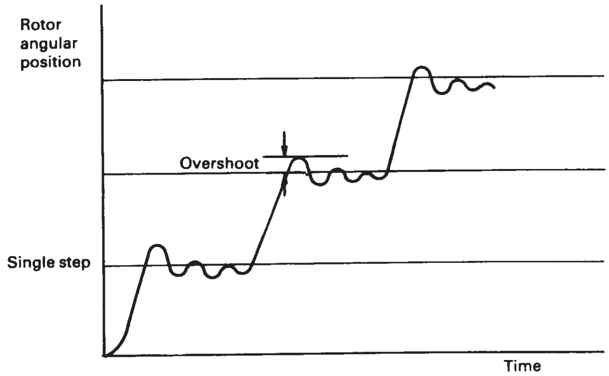
This represents the tolerance of each angular step movement. Typically within 5-10% of one step angle this error is non-cumulative ie. remains constant regardless of the number of steps advanced.

For a 4-phase motor this error averages to zero in 4 steps (corresponding to a full drive cycle). For this reason when accurate positioning is desired it is recommended, whenever possible, that the movement is divided into multiples of 4 steps.

Overshoot

When making a single step the rotor tends to overshoot and oscillate about its new position. The response depends on the drive method and load inertia. The greater the torque to inertia ratio, the less is the overshoot. In addition friction damping reduces the amount of overshoot.

Figure 3 **Overshoot**



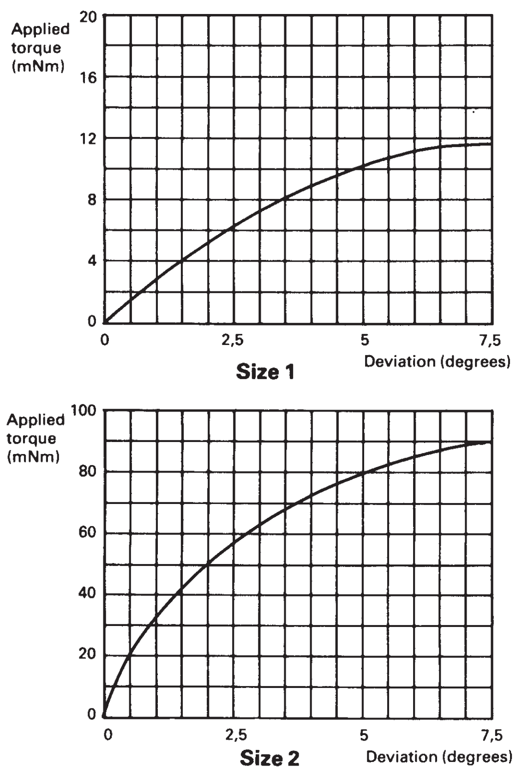
Resonance

Certain operating frequencies cause resonance and the motor loses track of the drive input. Audible vibration may accompany resonance conditions. These frequencies should be avoided if possible. Driving the motor on the half step mode (see motor drive methods) greatly reduces the effect of resonance. Alternatively extra load inertia and external damping may be added to shift resonance regions away from the operating frequency.

Deviation

The change in spindle position from the unloaded holding position due to external torque application to the spindle of an excited motor. Torque-deviation curves for size 1 and size 2 motors are shown in Figure 4.

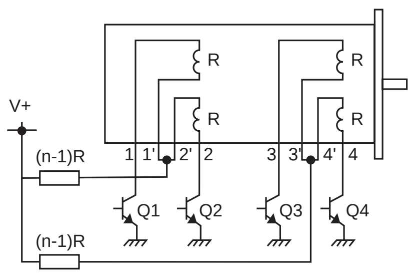
Figure 4 **Deviation as a function of applied torque**



Motor drive methods

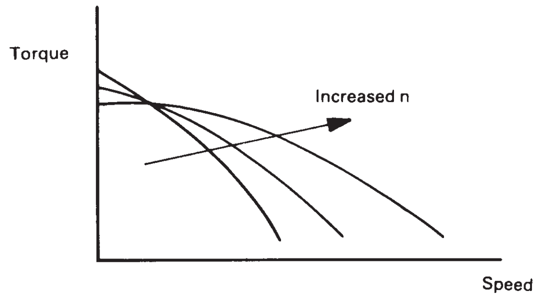
The normal way of driving a 4-phase stepper motor is shown in Figure 5.

Figure 5 **Unipolar drive**



This is commonly known as the 'Unipolar L/nR drive'. Here the current in each winding, when energised, flows in one direction only. 'n', value is ≥1 (but not necessarily an integer) and nR is the sum of the external resistance plus the winding resistance (R). By selecting a higher value for n (ie. larger external resistance) and using a higher dc supply to maintain the rated voltage and current for each winding, improved torque speed characteristics can be obtained (Figure 6). Thus a 6V, 6Ω motor (1A per phase) can be driven from a 6Vdc supply without any series resistor, in the L/R mode. Alternatively it can be driven from a 24Vdc supply using 18Ω series resistance in the L/4R mode with much improved performance.

Figure 6 **Effect on motor performance of higher supply voltages and larger series limiting resistance**



To step a motor in a particular direction a specific switching sequence for the drive transistors Q1-Q4 needs to be followed. If this sequence is as in Table 1 (known as the unipolar full step mode) it results in the rotor advancing through one complete step at a time.

Table 1 **Full step mode**

	Step No.	Q1	Q2	Q3	Q4
Start position (arbitrary)		ON	OFF	OFF	ON
	1	ON	OFF	ON	OFF
(arbitrary)	2	OFF	ON	ON	OFF
	3	OFF	ON	OFF	ON
	4	ON	OFF	OFF	ON
Above sequence repeating	5	ON	OFF	ON	OFF

↑ Anti-clockwise ↓ Clockwise

Alternatively the motor can be driven in the half step mode by a mixed single/dual phase switching as shown in Table 2. This results in the rotor advancing through half the step angle at a time. This mode stabilises the motor operation and allows faster stepping rates (refer to stepper motor drives).

Table 2 **Half step mode**

	Step No.	Q1	Q2	Q3	Q4
		ON	OFF	ON	OFF
Start position	1	ON	OFF	OFF	OFF
	2	ON	OFF	OFF	ON
	3	OFF	OFF	OFF	ON
	4	OFF	ON	OFF	ON
	5	OFF	ON	OFF	OFF
	6	OFF	ON	ON	OFF
	7	OFF	OFF	ON	OFF
	8	ON	OFF	ON	OFF
Above sequence repeating	9				

↑ Anti-clockwise ↓ Clockwise

Use of size 1 motor with the RS range of synchronous gearboxes

The RS stepper motors (size 1) may be fitted to the RS range of synchronous gearboxes **RS** stock no. 336-400 etc. to provide improved resolution (finer step angle) and increased torque at lower speeds. Another important advantage is the greatly increased capability of the motor to drive higher inertial loads since load inertia seen by the motor is (I /hn2), I being the load inertia at the gearbox output, n is the gearbox ratio and h is the gearbox efficiency. Optimum power transfer is achieved when load inertia (seen by the motor) matches that of the motor's rotor. With loads of this magnitude the start/stop without error (pull-in) curve is slightly different from the no load condition. Maximum allowable load inertia (seen at the motor end) is five times the optimum load inertia. The table below gives the load inertia values at the gearbox output shaft for each gearbox used with size 1 motor.

Gearbox **RS** stock no.	Gearbox ratio	Recommended optimum load (kg cm^2)	Max. allowable load (kg cm^2)
336-450	25:2	0.27	1.36
336-444	25:1	1.1	5.5
336-438	50:1	4.44	22.2
336-422	125:1	24.85	124
336-416	250:1	100	380*
336-400	15000:1	6000*	6000*

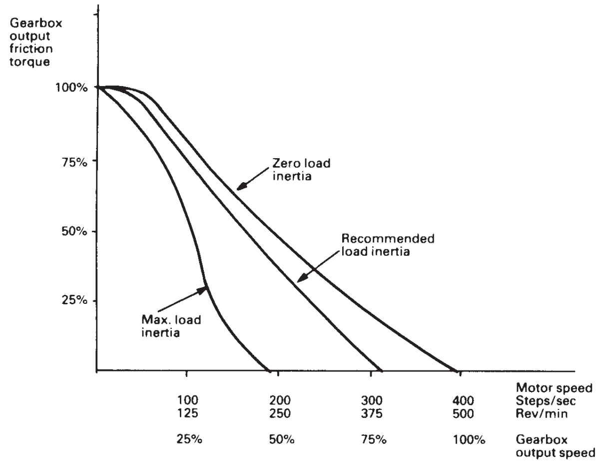
* limited by gearbox maximum ratings

In addition the following limiting values must not be exceeded at the gearbox output shaft:

Maximum radial force: 40 Newtons
Maximum axial force: 20 Newtons

When size 1 motor is fitted to any of the RS synchronous gearboxes and driven by the RS driver IC the torque-speed characteristic of the combined motor and gearbox under various load conditions is shown in Figure 28. However, if the motor is driven by the RS stepper motor drive board **RS** stock no. 217-3611 which gives improved performance, these results are correspondingly improved.

Figure 7 **Torque-speed characteristics for motor-gearbox combination**



Percentage values above are to be found, for any particular gearbox, in the table below.

Gearbox **RS** stock no.	100% output torque (Ncm)	100% output speed rpm	Output step angle
336-450	5.1	40	0.6°
336-444	10.3	20	0.3°
336-438	20.5	10	0.15°
336-422	46.6	4	0.06°
336-416	80*	2	0.03°
336-400	80*	0.033	0.03°

* output torque limited by gearbox.

Note: Typical backlash at gearbox output = 2° and should be considered if positional accuracy is critical.

Design considerations

The torque-speed characteristic must be consulted whenever a stepper motor is chosen for a particular application. The following equations generally apply.

Required torque = friction torque + acceleration torque where
friction torque = friction force × radius
acceleration torque = load inertia × acceleration
acceleration =

$$\frac{\text{change in speed (steps/sec)}}{\text{acceleration time (sec)}} \times \frac{2\pi}{\text{steps/rev}}$$

Thus for a 7.5° stepper motor

$$\text{acceleration} = \frac{\Delta\,\text{speed}}{\Delta t} \times 0.13$$

Units: Torque - mNm
Inertia - gm^2
Acceleration - radians/sec

Unit conversion

Unit	$\times 10^{-4}$	$\times 10^{-1}$	$\times 10$	$\times 10^3$
mNm			Ncm	Nm
gm^2	gcm^2	$kgcm^2$		kgm^2

Acceleration control is achieved by varying the input frequency to the motor drive circuit eg. using an RC time constant and a voltage controlled oscillator.

Note: The pull-out torque capability of the motor at the required speed must be higher than the required torque to ensure correct operation.

Use of gearbox

The following equations apply when the motor drives a load through a gearbox.

$$I_r = \frac{I_L}{n^2\eta} \quad \text{and} \quad T_r = \frac{T_L}{n\eta}$$

where

I_r = reflected load (including gearbox inertia at motor shaft)

I_L = load inertia at gearbox output

T_r = reflected load torque at motor side

T_L = load torque required at gearbox output

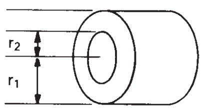
n = gearbox ratio

η = gearbox efficiency (typically 0.6 - 0.7 for the RS range of synchronous gearboxes).

Moment of inertia (load inertia)

1. Cylinder

$$I = \frac{M}{2}\, r_1^2 + r_2^2)$$



M = mass of cylinder

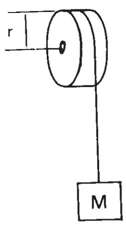
2. Disc or shaft

r_2 = 0 in above equation thus

$$I = \frac{M}{2}\, r_1^2$$

3. Pulley and weight (or rack and pinion)

$I = Mr^2$



In the above equations

M is in grams
r is in metres
I is in gram. (metres)^2

Examples

1. A frictional load of 20mNm must be moved 300° in 2 seconds. Thus using a 7.5° motor

$$\text{Stepping rate} = \frac{300}{7.5 \times 2} = 20 \text{ steps/sec}$$

Consulting the torque-speed curve for size 2 motor shows that at 20 steps/sec the torque capability is 60 mNm. Thus acceleration torque available = 60 - 20 = 40 mNm.

It is always useful in practice to apply a safety margin by devaluing the available motor torque to say 60% of theoretical value, ie. 40% safety margin.

2. A 0.2gm^2 load is to be accelerated to 200 steps/sec against a frictional torque of 60mNm using a size 1 motor and a 25:1 reduction gearbox (**RS** stock no. 336-444). Calculate acceleration time and number of steps required to reach terminal speed.

Using the formulae in this data sheet;

$$\text{Reflected load inertia} = \frac{0.2}{(25)^2 \times 0.7} = 45 \times 10^{-5}\ gm^2$$

Motor rotor inertia = 26 x 10^{-5} gm^2

$$\text{Reflected friction torque} = \frac{60}{25 \times 0.7} = 3.43\text{mNm}$$

From the pull-out curve for the size 1 motor the torque at 200 steps/sec is 4mNm

Acceleration torque = 4 - 3.43 = 0.57mNm

$$\text{Acceleration} = \frac{0.6 \times 0.57}{(26 + 45) \times 10^{-5}} = 482 \text{ rad/sec}^2$$

allowing 40% safety margin

$$\text{Acceleration time} = \frac{200}{482} \times 0.13 = 54\text{m sec}$$

Therefore number of steps required during acceleration = average speed × time = $\frac{200}{2} \times 0.054$ or 6 complete steps.