M-S Motor X15.xxx

Description

The Miniature Stepper Motor M-S X15.xxx series was developed primarily as an indicator drive for dashboard instrumentation and other indicator equipment. The inherent properties of torque, current consumption, robust construction, etc. extend its use also to a number of other applications. The motor can operate directly from a numerical, i.e. digital, driving signal to move and position a pointer to visualise any parameter required. A fine analogue representation of its value and its changes is made without the need for a digital to analogue conversion.
The miniature stepper motor consists of a motor and gear train with a reduction ratio of 1/180. It is produced with the advanced wide range technologies of the SWATCH GROUP. These technologies assure a high quality product as proven by the success of the famous SWATCH watch. The motor is robust and simple in construction without concessions to versatility or longevity.
Each half revolution of the rotor, defined as a full step, is converted to a one degree rotation of the pointer shaft. The full step itself again is divided into three partial steps, i.e. a 360 degree rotation of the pointer shaft consists of 1080 partial steps. Full steps can be carried out up to 600 Hz resulting in a 600 ∞/s angular speed. Such characteristics allow a large dynamic range for indicator applications.

Features

- 1/3∞resolution per step
- low current consumption
- small dimensions: ÿ 30 x 9 mm
- can be directly driven by a μ-controller
- large temperature range: -40∞C ˜ 105∞C
- high speed: >600 ∞/s
- qualified for automotive applications

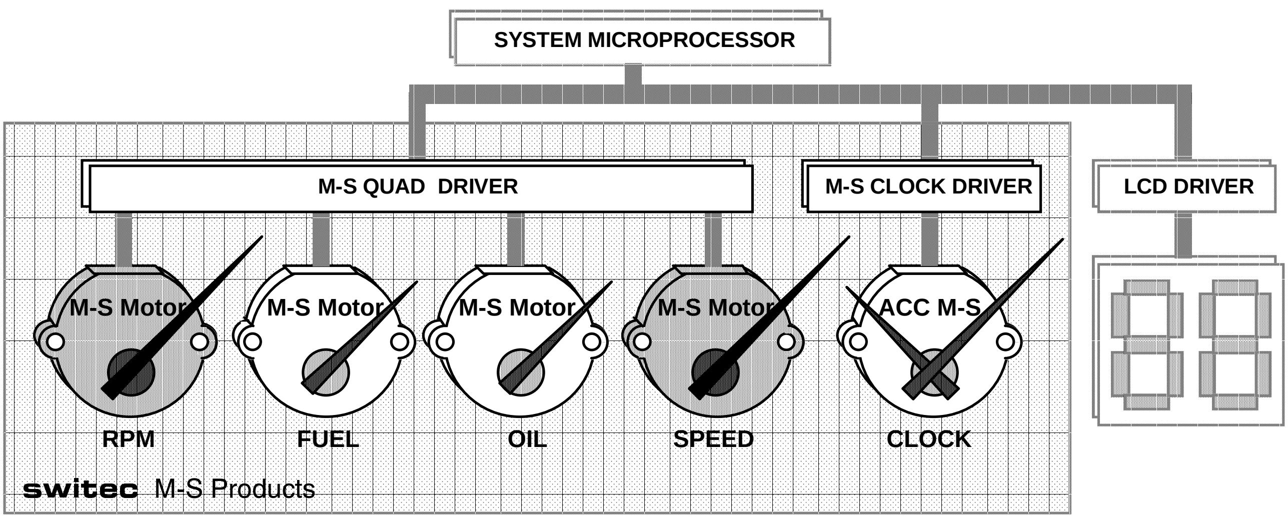
Motor versions

This specification applies only to the following motor versions.

Without stop : X15.156, X15.158, X15.559, X15.579
With stop : X15.166, X15.168, X15.569, X15.589

For more details on the differences between those motors, please refer to the buyer's guide.

Typical Application



Analogue/Digital Instrument Cluster Concept Fig. 1

Pin Connection

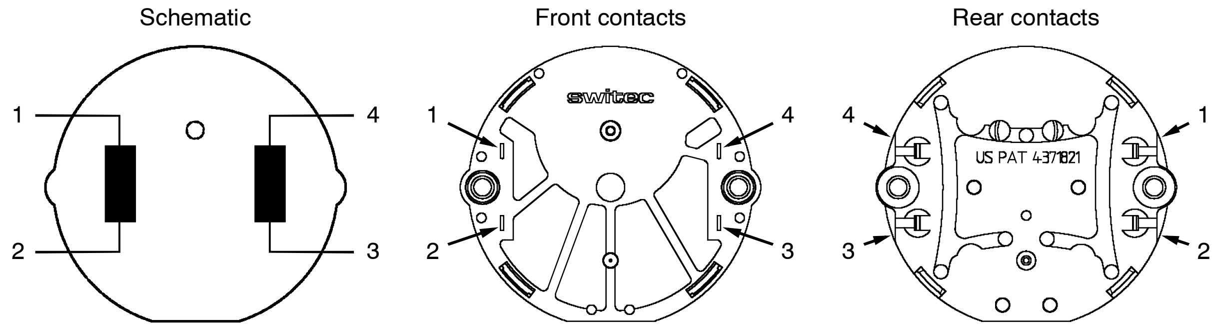


Fig. 2

Absolute Maximum Ratings

Parameter	Symbol	Conditions
Driving voltage	U_b	10 V
ESD tolerance (MIL 883)	U_{ESD}	10'000 V
EMI tolerance (1 kHz; AM 80%; 100 kHz - 2 GHz)	E	80 V/m
Storage temperature	T_{stg}	95 °C
Solder temperature (10 sec)	T_s	260 °C

Table 1

Stresses beyond these listed maximum ratings may cause permanent damage to the M-S X15.xxx. Exposure to conditions beyond specified operating conditions may affect the M-S X15.xxx reliability or cause malfunction.

Electrical and Mechanical Characteristics

T_{amb} = 25°C and U_b = 5 V; unless otherwise specified.

Parameter	Symbol	Test Conditions	Min.	Type	Max.	Units
Operating temperature	T_a		-40		105	°C
Coil resistance	R_b		260	290	320	Ω
Operating current	i_m	@ f_z = 200 Hz		15	20	mA
Magnetic saturation voltage	U_{bs}			9		V
Start-Stop Frequency	f_{ss}	@ $J_L = 0{,}2x10^{-6}kgm^2$	200			Hz
Maximum driving frequency	fm	@ $J_L = 0{,}2x10^{-6}kgm^2$	600			Hz
Dynamic torque	M_{200}	@ f_z = 200 Hz	1.0	1.3		mNm
	M_{600}	@ f_z = 600 Hz		0.35		mNm
Static torque	M_s	@ U_b = 5V	3.5	4.0		mNm
Gear play				0.5	1	Degree
Forces allowed on the pointer shaft :						
Axial force	F_A				150	N
Perpendicular force	F_Q				12	N
Imposed acceleration	α_p	see p. 5			1'000	rad/s^2
Noise level	SPL	(conditions : see p. 11)		45	50	dBA
Angle of rotation	fl	motors with internal stop			315	Degree

Table 2

Typical Performance Characteristics

Dynamic Torque Md = f(ω)

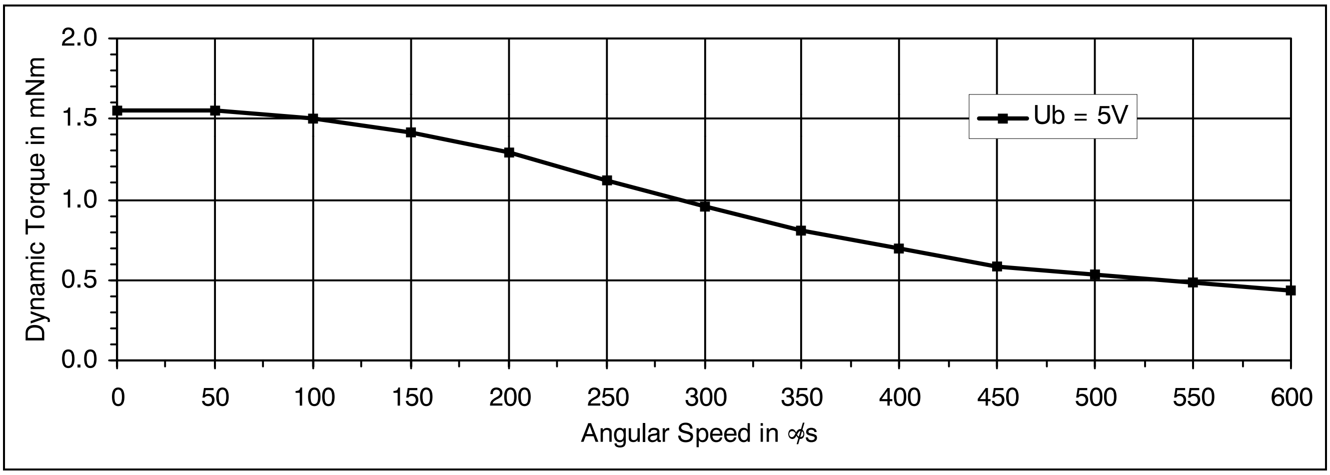


Fig. 3a

Dynamic Torque Md = f(Ub)

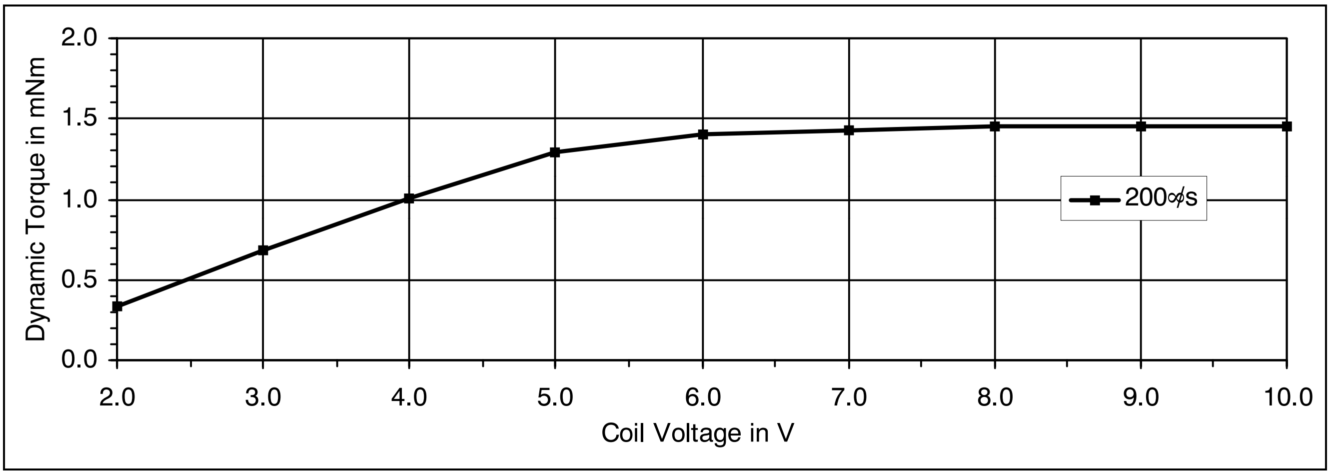


Fig. 3b

Dynamic Torque Md = f(Ta)

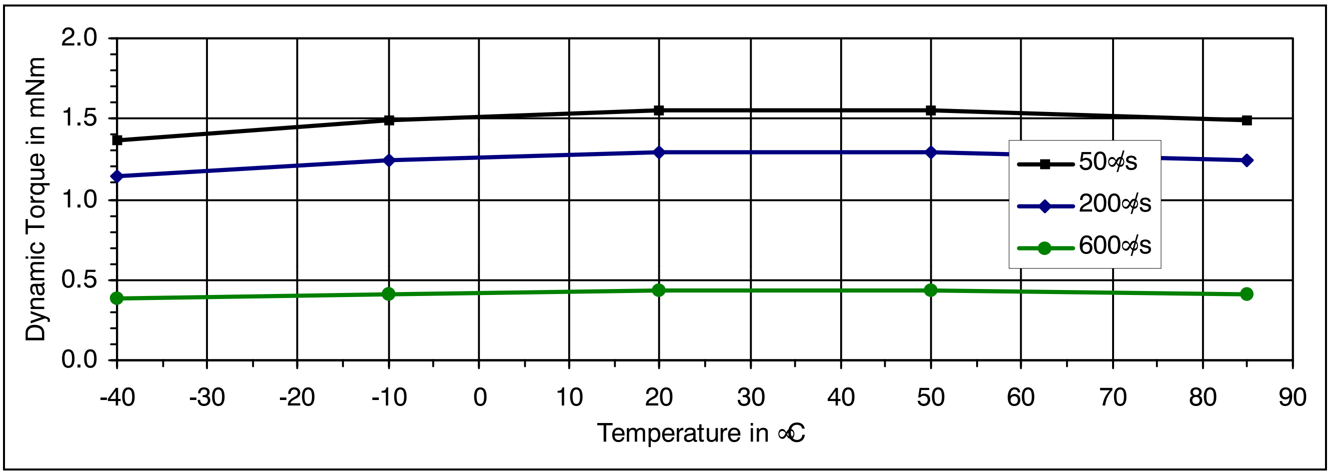


Fig. 3c

Typical Performance Characteristics (continued)

Noise Emission SPL = f(ω)

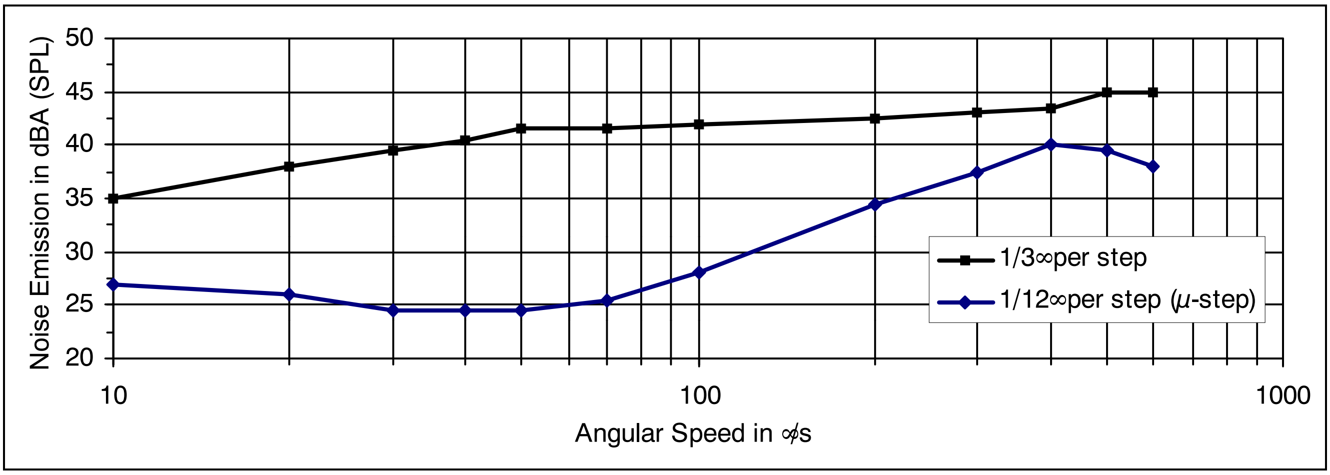


Fig. 3d

Product Identification

Coding for production date

Each motor is marked with the product number and its manufacturing date.

Hour	Day	Manufact. place	Week	.	Year
00	1	Line 1 - Zhuhai	01		0
|	|	> = Normal prod.	|		|
23	7	\ = Special trace.	52		9
		< = Special trace.			
		Line 2 - Zhuhai			
		} = Normal prod.			
		# = Special trace.			
		{ = Special trace.			

Example:

145>26.9 — 14th hour (14:00 - 14:59), Friday, Line 1 Zhuhai, normal production, week 26, 1999

Coding for prototypes

The coding for prototypes and special motor types is printed above or below the production date.

Sample	Variant
|	|
A	1
|	|
Z	9

Example:

A1
145>26.9 — A-sample, variant 1
14th hour (14:00 - 14:59), Friday, Line 1 Zhuhai, normal production, week 26, 1999

Patents

US PAT 4371821
OTHER PATENTS IN:
DE, GB, FR, JP, CH, HK

Installation and Dimensions

Motor Mounting

The Miniature Stepper Motors can be secured in place by a variety of methods. For all automotive applications even when the motor is exposed to very strong vibrations, the soldering of the contact pins is sufficient provided the versions with mounting pegs are used. The mounting pegs have been developed to allow screw-free fixing in ALL applications.

As a general rule, screws are unnecessary and should be avoided as much as possible, both for cost and process capability reasons. The motor has a robust design but normal care should be taken that excessive forces do not deform the housing.
For further details, refer to the application note ìMounting the M-S/ACC Motorî X15.002.02.AN.E.

Examples for Motor Mounting

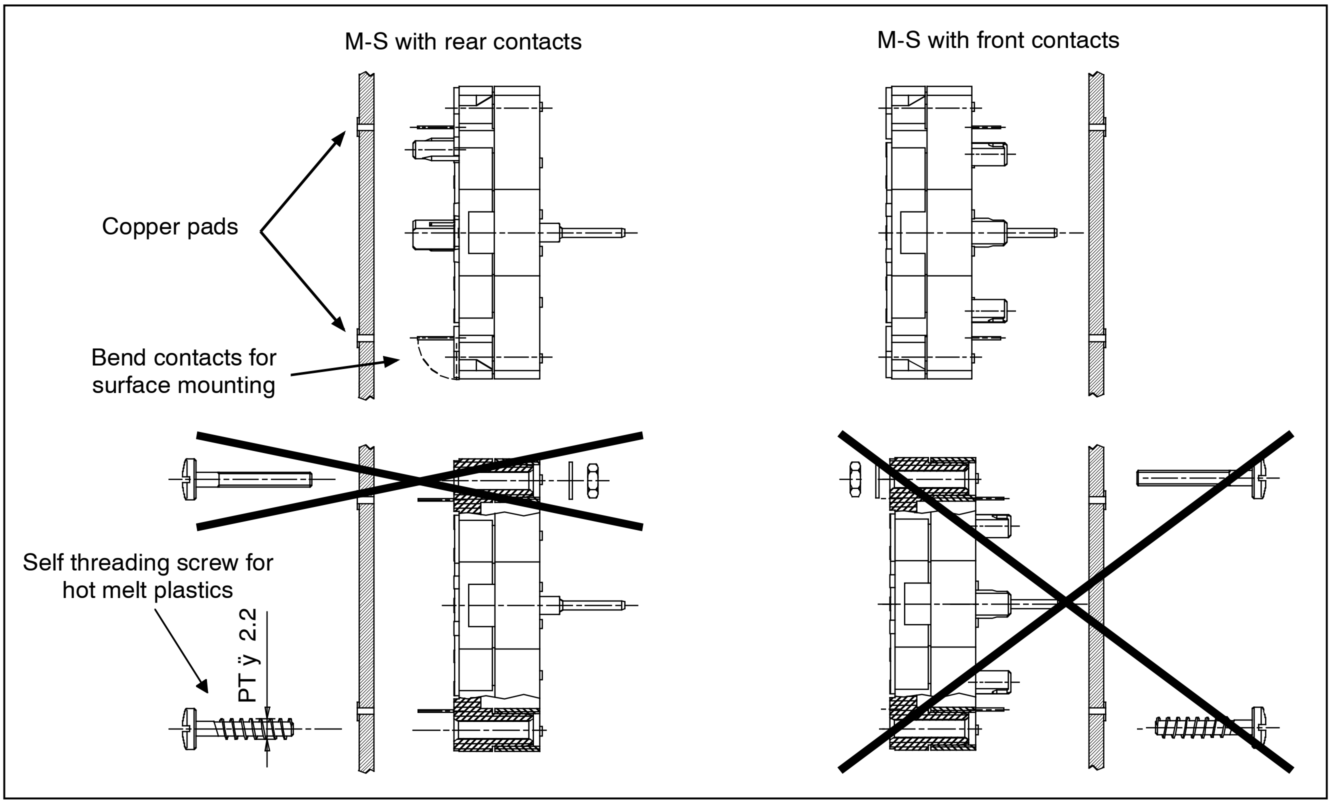


Fig. 4

Mounting Load on Pointer Shaft

The load mounting on the pointer shaft, such as a pointer, gear, etc. is usually done in a pressing operation. When using this technique, care should be taken that the forces (F_A and F_Q) do not exceed those given in the specifications (table 2).

Caution

Care should be taken not to impose excessive acceleration onto the pointer shaft. A kick on the mounted pointer might damage the gear and cause permanent damage to the M-S motor!

Forces on the Pointer Shaft

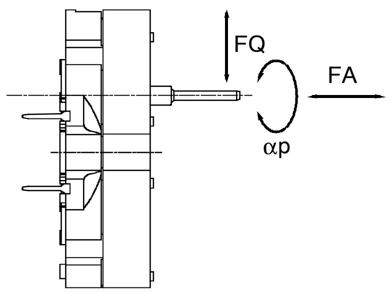


Fig. 5

Functional Description

General

The M-S series consist of a "Lavet" type stepper motor and a gear train. The integrated two step gear train reduces the rotation by a factor of 180 whereby a full step driving pulse results in a one degree rotation of the pointer shaft.
As mentioned earlier, the motor rotor makes one half revolution for each full step with each full step again divided into three partial steps. The steps are carried out according to the applied pulse sequence and driving diagram shown in fig. 8 and 9 respectively. The bit map (fig. 8) shows the logic levels at the contacts 1˜4 (fig. 7) and the corresponding coil voltage pulses.
The direction of rotation is determined by the bit map sequence chosen. The rotation can immediately and at any point be reversed up to the maximum start-stop frequency f_{ss} without loosing a step. The frequency f_{ss} is dependent on the mechanical load applied and can be calculated using the formulae given below.
The driving diagram (fig. 9) shows how the M-S can be driven using standard logic components capable of supplying 20 mA output current at V_{dd} of 5 volts.
For applications where very little current is available, such as for battery powered devices, the motors can be supplied with an optional currentless static torque (see p.4). Here the full step positions 1 and 4 provide a static torque even in the absence of the coil current I_b.

Schematic Layout

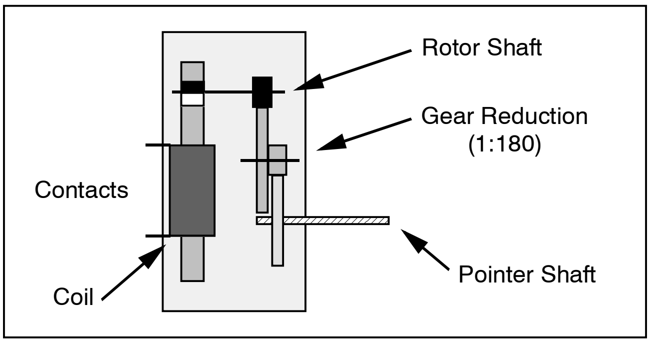


Fig. 6

Pin Configuration

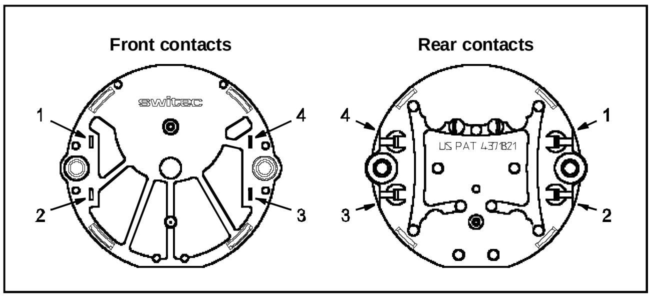


Fig. 7

Rotor Positions

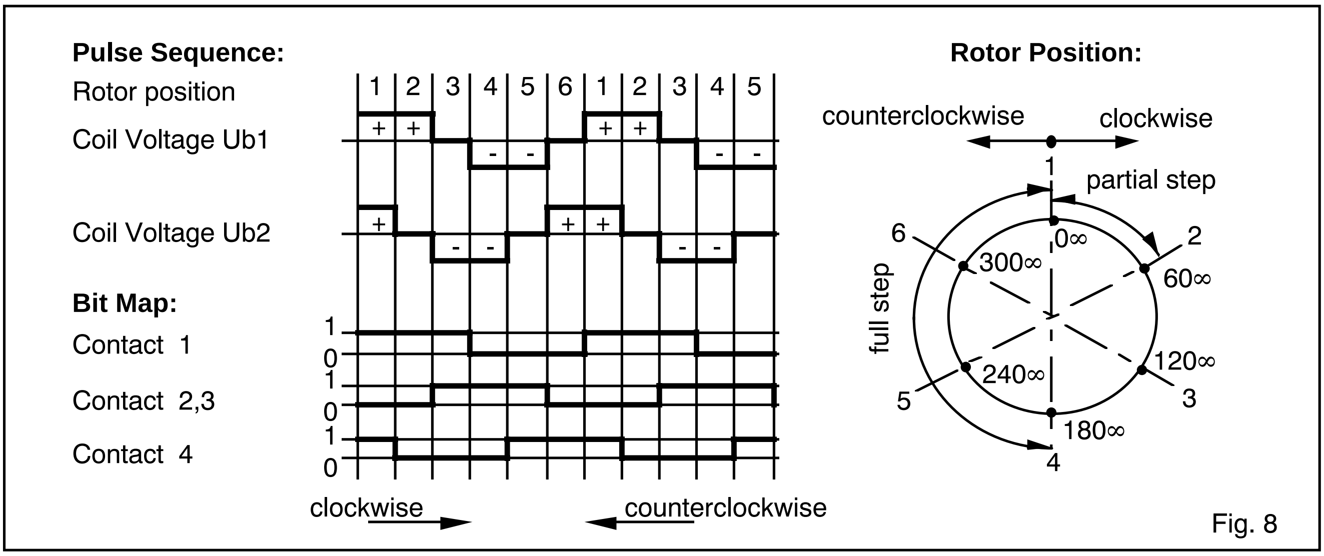


Fig. 8

Driving Diagram

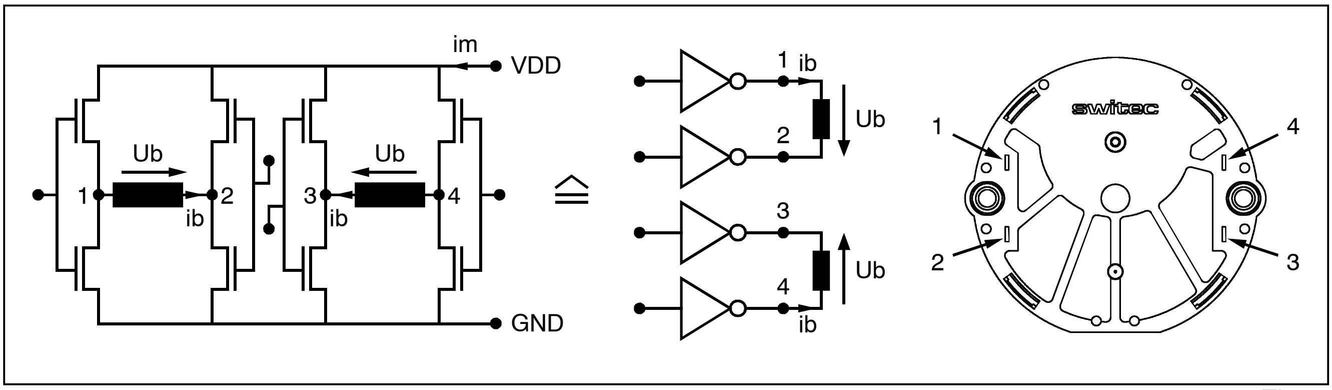


Fig. 9

Start-Stop-Frequency F_{SS}

As is normally the case for stepper motors, a shift register type driver supplies the clock frequency which determines the rotational speed of the motor. Up to the start-stop frequency f_{SS} a reverse rotation and a full stop is possible without missing, i.e. failing to carry out a driving step. The dynamic behaviour of the system (i.e. f_{SS}) is influenced by the inertia of the load. The f_{SS} of the M-S X15.xxx loaded with an inertial mass of 200 gmm^2 is approximately 200 Hz.

The following example shows how the f_{SS} of a motor can be calculated.

The parameters needed are:

- dependence of torque on the frequency (fig. 3)
- motor gear inertia $J_{M\text{-}S}$
- load inertia J_L
- number of steps z in 360 ∞
- full step frequency f_Z

The angular velocity is ω:

1) $$\omega = f_Z \cdot \frac{2\pi}{z} = f_Z \cdot \frac{\pi}{180}$$

The acceleration torque M_α needed to move the sum of the inertial masses $J_{M\text{-}S} + J_L = J$ with the angular acceleration α is:

2) $$M_\alpha = J \cdot \alpha$$

Also for an acceleration from zero to the applied velocity, i.e. the applied full step frequency f_Z, the acceleration torque M_α is equal to the effective dynamic torque M_d at this angular velocity :

3) $$M_\alpha = M_d$$

The value of M_d as a function of the full step frequency f_Z is determined by measurements directly on the motor. The acceleration torque M_α must also be determined as a function of f_Z. The angular acceleration α is:

4) $$\alpha = \frac{\omega}{t_\alpha} = \omega \cdot f_Z$$

5) $$M_\alpha = J \cdot f_Z{}^2 \cdot \frac{\pi}{180} \qquad (J = J_{M\text{-}S} + J_L)$$

The start-stop frequency f_{SS} is given by the intersection of the plot of these two curves as shown in fig. 10.
The calculation of f_{SS} using the indicator norm mass results:

$J_{M\text{-}S}$	=	$480\ 10^{-9}$	kgm^2
J_L	=	$200\ 10^{-9}$	kgm^2
J	=	$680\ 10^{-9}$	kgm^2
$M_{\alpha 100}$	=	0.118	mNm
$M_{\alpha 200}$	=	0.475	mNm
$M_{\alpha 300}$	=	1.068	mNm

Then, from fig. 10 => **f_{SS} = 235 Hz**

Graphic Determination of f_{SS}

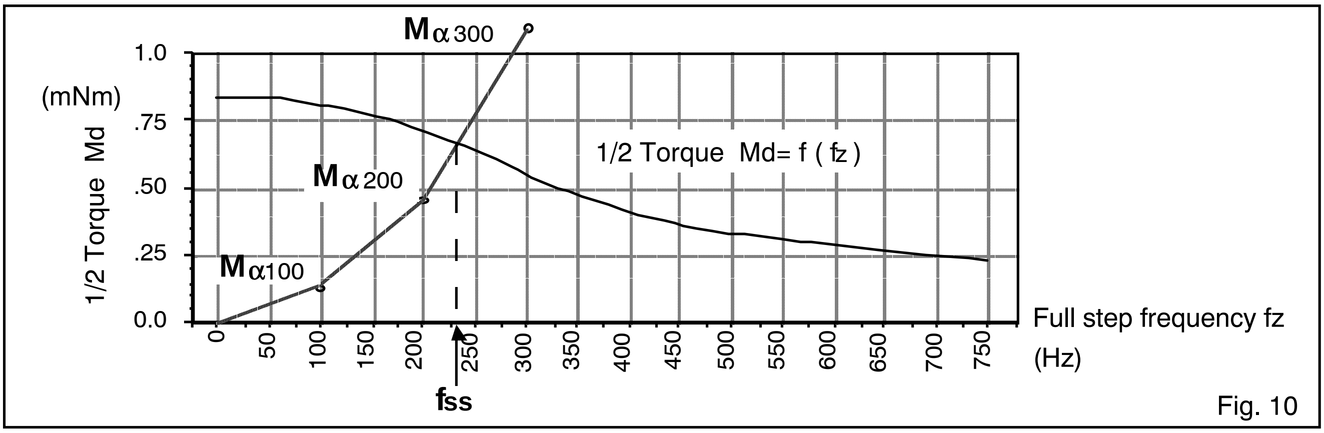


Fig. 10

Acceleration to Frequencies > F_{SS}

In order to determine the maximum acceleration step Δf, the same type of calculation can be made as for f_{SS}. The difference is that instead of the angular velocity ω, the change in the angular velocity Δω is used in the calculation. The intersection of the two curves is again used to determine the next higher step frequency f_i.

6) $$\Delta\omega = \omega_i - \omega_{i-1} = \frac{(f_i - f_{i-1}) \cdot \pi}{180} = \frac{\Delta f_i \cdot \pi}{180}$$

Using the acceleration time

7) $$t_\alpha = \frac{1}{f_i}$$

and the angular acceleration

8) $$\alpha = \frac{\Delta\omega}{t_\alpha} = \frac{(f_i - f_{i-1}) \cdot f_i \cdot \pi}{180}$$

the acceleration torque M_α needed to accelerate J to f_i can be calculated.

9) $$M_\alpha = J \cdot \alpha = \frac{J \cdot (f_i - f_{i-1}) \cdot f_i \cdot \pi}{180} = \frac{J \cdot f_i \cdot \Delta f_i \cdot \pi}{180}$$

The intersection of the curves gives the maximum driving frequency or the shortest period which is needed to drive the motor with a maximum acceleration.

Determination of the Acceleration Steps

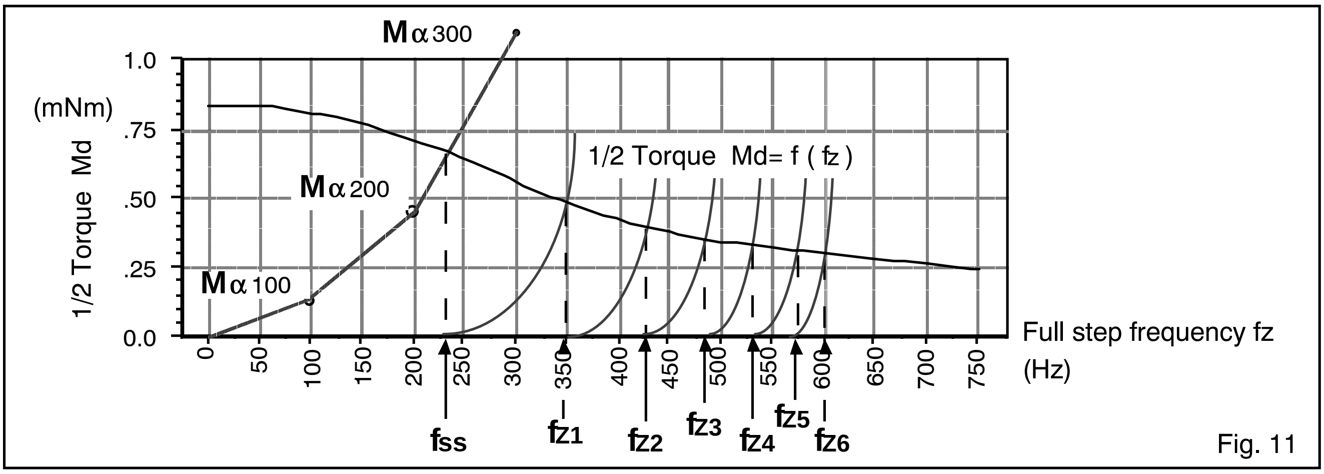


Fig. 11

Control Circuits

M-S Quad Driver X12.017

The M-S Quad Driver X12.017 is a monolithic CMOS device intended to be used as an interface circuit to ease the use of the Miniature Stepping Motors X15.xxx. The circuit allows the user to drive four motors as it contains four identical drivers on the same chip.

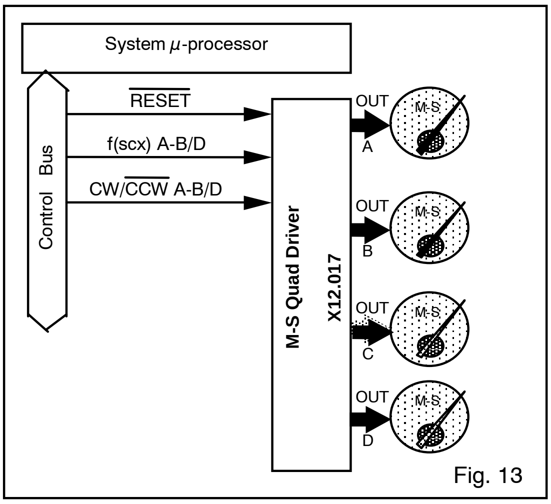


Fig. 13

Microstepping Mode of Operation

The M-S Quad Driver convert a pulse train into a current level sequence sent to the two motor coils of the M-S. This sequence of 24 current levels per rotor revolution is used to produce the microstepping movement of the rotor.
A microstep is an angular rotation of 1/12∞of the M-S shaft or 15∞on the rotor shaft.

A partial step is an angular rotation of 1/3∞of the M-S shaft or 60∞on the rotor shaft.
The microstepping allows for a continuous smooth movement of a pointer if the M-S is used as pointer drive. It is not intended as a precise positioning. The precision of the angular position is given by the resolution of the partial step.

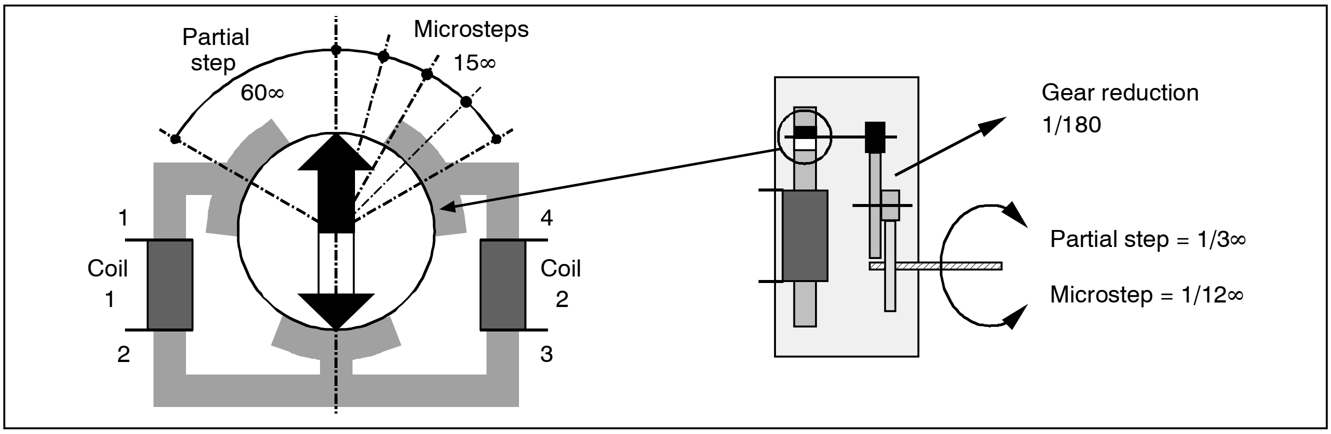


Fig. 14

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Tests and Test Conditions

General Conditions

Indicator Norm Load

- mass	m	:	2.5	g
- inertia	J_L	:	0.2×10^{-6}	kgm^2
- unbalance	M_u	:	0.01	mNm

Driving Cycle I

The driving cycle I consists of three sequential movements A, B and C:

A. A cycle of 1 second consisting of:
- 0∞to 60∞
  200 full steps/s

B. Five cycles of 2 seconds each consisting of:
- 60∞to 120∞
  200 full steps/s
- 120∞to 60∞
  Acceleration up to 600 full steps/s.
- After the last cycle back to 0∞

C. A cycle of 2 seconds consisting of:
- 0∞ to 360∞(300∞for motors with internal stop)
  Acceleration to 600 full steps/s
- 360∞(300∞for motors with internal stop) to 0∞
  Acceleration to 600 full steps/s
- Hold at 0∞until end of the 2 s cycle.

Driving Cycle II

Cycle II also consists of three sequential movements but which are carried out at one half the frequency used for Cycle I:

A. A cycle of 2 seconds consisting of:
- 0∞to 60∞
  100 full steps/s

B. Five cycles of 4 seconds each consisting of:
- 60∞to 120∞
  100 full steps/s
- 120∞to 60∞
  Acceleration up to 300 full steps/s
- After the last cycle back to 0∞

C. A cycle of 4 seconds consisting of:
- 0∞ to 360∞(300∞for motors with internal stop)
  Acceleration to 300 full steps/s
- 360∞(300∞for motors with internal stop) to 0∞
  Acceleration to 300 full steps/s
- Hold at 0∞until end of the 4 s cycle.

Specific Test Conditions

Temperature Cycling Test (400 h)

- defect free functioning after passing 50 times the eight hour cycle shown in fig. 15.
- two functional tests per cycle are carried out.
  1. driving cycle II for 20 minutes at -40∞C after one hour at -40 ∞C.
  2. driving cycle I from 20∞ C to 105∞ C is continued at 105∞C for one hour.
- U_b voltage is applied during the entire test period.

Temperature Cycle

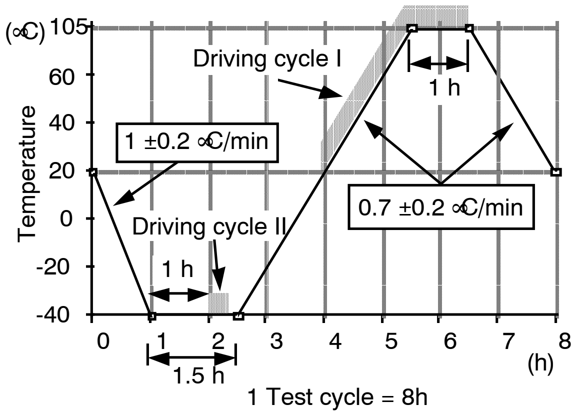

Fig. 15

5000 Hour Test

- 5000 hours standard functions with no step loss
- T_{amb}= 20 ˜ 25 ∞C
- motors equipped with indicator norm load
- continuous driving test cycle I carried out

1000 Hour Test

- 1000 hours standard functions with no step loss
- T_a= 105 ∞C
- motors equipped with indicator norm load
- alternatively 8 hours continuously driving test cycle I and 8 hours resting

Specific Test Conditions (continued)

Humidity Test

- 144 h storage at 50 ∝C and 93±3 % rel. humidity
- after one hour at ambient conditions the motor must function with no defects. No corrosion which could hamper operation must be present.

Temperature Shock Test

- operation with no defects after 10 shock tests
- motors were subjected alternately to a hot (80 ∝C) and a cold (-40 ∝C) environment. The temperature change occurred within one minute. The motors remained at the test temperatures for two hours.

Shock Test

- The motors withstand the shocks which occur during normal handling.
- Motors with no visible damage after a fall of one meter onto hard wood, still comply with the specifications.
- The test was carried out according to ISO 1413.

Vibration Test

- operation with no step loss during the test
- motors equipped with indicator norm load
- amplitude 10 mm (5˜ 12 Hz)
- acceleration up to 6 g. (12˜ 250 Hz fig. 16)
- 8 hours test per orientation
  (axis parallel; axis perpendicular)
- one octave/minute
- driving cycle I

Vibration Test Cycle

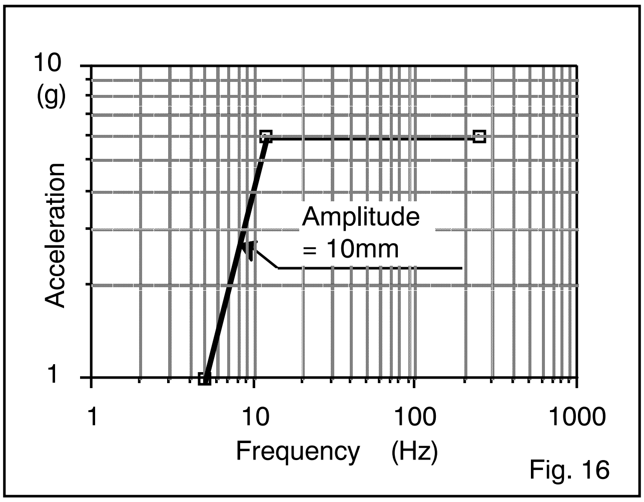

Fig. 16

Acoustic Measurements

Test Configuration

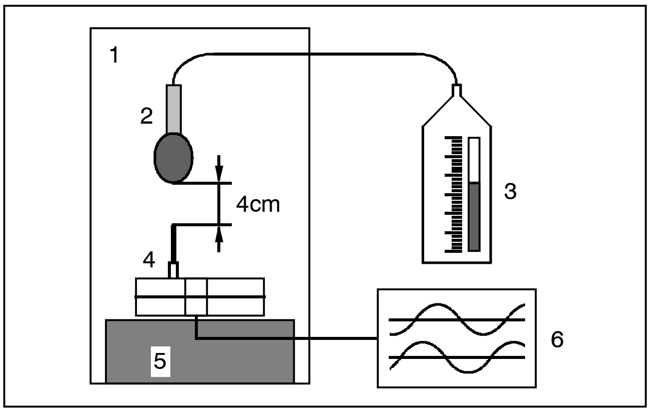

Fig. 17

1. reflection free room
2. microphone 1/2" omni-directional Larson-Davis, Typ. 2541
3. sonometer Larson-Davis Typ. 800B
4. motor under test
5. Foam cube
6. M-S control unit in μ-stepping mode (1/12∞/ step)

Test Conditions

- temperature	T_{amb}	:	25	∝C
- measurement distance	L_m	:	4	cm
- measurement range		:	20 ¨ 20k	Hz
- measurement time	t_m	:	4	s
- angular speed	ω	:	600	∝/s

- motor not mounted and without load.

Instrument Parameters

The noise level SPL was determined using the instrument settings (Larson-Davis Typ. 800B) :

- weighting :	" A "
- integration time :	" Slow "
- detection :	" RMS "

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Parameter Definitions

Parameter	Description	Unit
E	EMI tolerance	V/m
F_A	axial force on the pointer shaft	N
F_Q	perpendicular force on the pointer shaft	N
f_{AM}	amplitude modulated carrier frequency	Hz
f_m	maximum driving frequency	Hz
f_{ss}	start-stop frequency	Hz
f_z	full step frequency	Hz
Gnd	ground	-
I_b	coil current	A
i_m	M-S ac-current	A
J	total inertia $= J_{M-S} + J_L$	kgm^2
J_L	inertia of the load	kgm^2
J_{M-S}	inertia of the M-S	kgm^2
L_m	noise measurement distance	cm
m	mass of the driven load	g
M_α	acceleration torque	mNm
M_{200}	dynamic torque at 200 Hz full step frequency	mNm
M_d	dynamic torque	mNm
M_0	static torque at $U_b = 0$ V	mNm
M_s	static torque at $U_b > 0$ V	mNm
M_u	unbalance of the load	mNm
R_b	coil resistance	Ω
SPL	noise level of the motor (sound pressure level)	dB
T_a	temperature	°C
T_{amb}	ambient temperature	°C
T_s	solder temperature	°C
Tstg	storage temperature	°C
t_α	acceleration time	s
t_m	noise measurement time	s
U_b	coil voltage	V
U_{bs}	magnetic saturation voltage	V
U_{ESD}	Electro Static Discharge tolerance	V
V_{dd}	operating voltage	V
z	number of full steps per revolution (=360)	-
α	angular acceleration $(= M_\alpha/J)$	rad/s^2
α_p	angular acceleration imposed to the pointer shaft	rad/s^2
fl	possible angle of rotation of the internal stop version	degrees
ω	angular speed	°/s (rad/s)

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