M-S Motor XC5.xxx

Description

The Miniature Stepper Motor M-S XC5.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: Ø 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

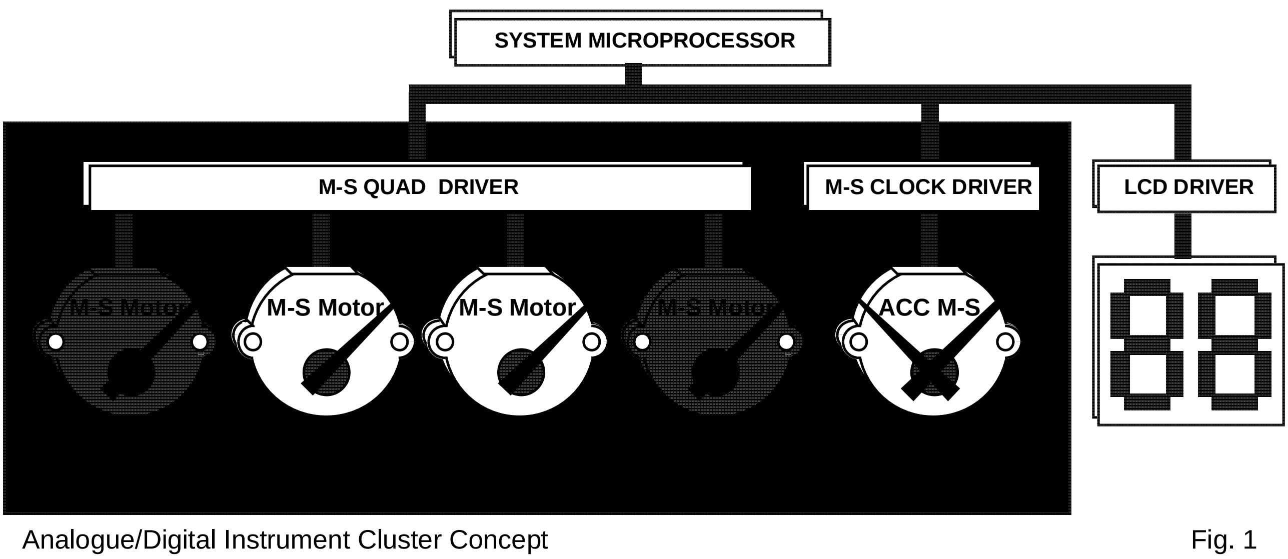
Motor versions

This specification applies only to the following motor versions.

Without stop : XC5.156,XC5.158,XC5.15B, XC5.579
With stop : XC5.166,XC5.168, XC5.569, XC5.589

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

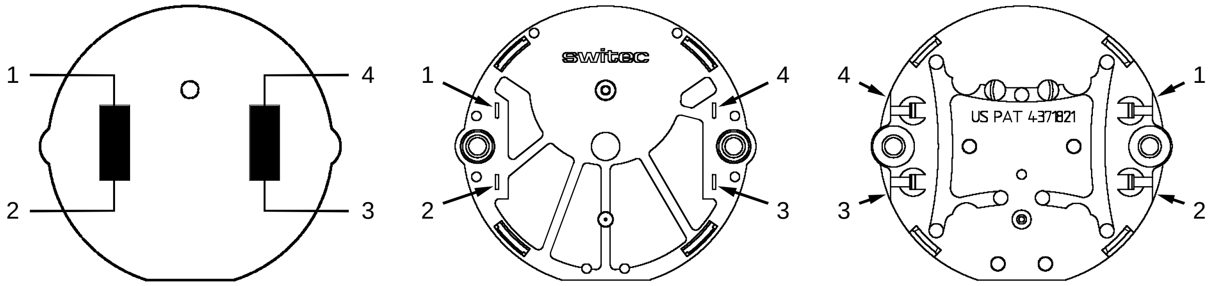


Fig. 2

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 XC5.xxx. Exposure to conditions beyond specified operating conditions may affect the M-S XC5.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}	@ $J_L = 0{,}2 \times 10^{-6} kgm^2$			200	Hz
Maximum driving frequency	fm	@ $J_L = 0{,}2 \times 10^{-6} kgm^2$			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 push on force	F_A				150	N
Axial pull off force (refer to part drawing)						
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 of motors with internal stop	ß	MS w/o stop: Unlimited rotation			315	Degree

Table 2

Typical Performance Characteristics

Dynamic Torque Md = f(ω)

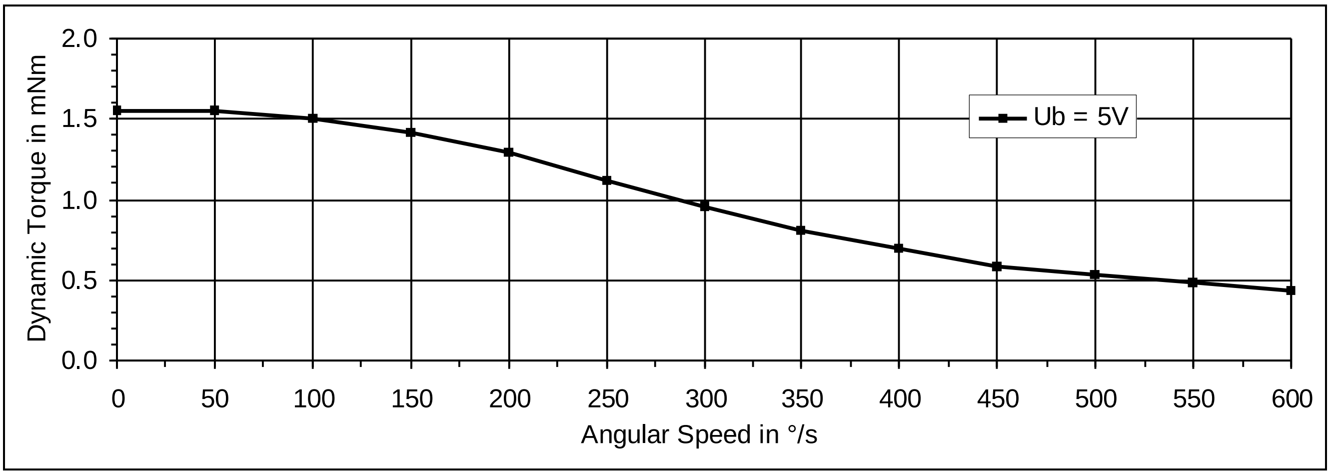


Fig. 3a

Dynamic Torque Md = f(Ub)

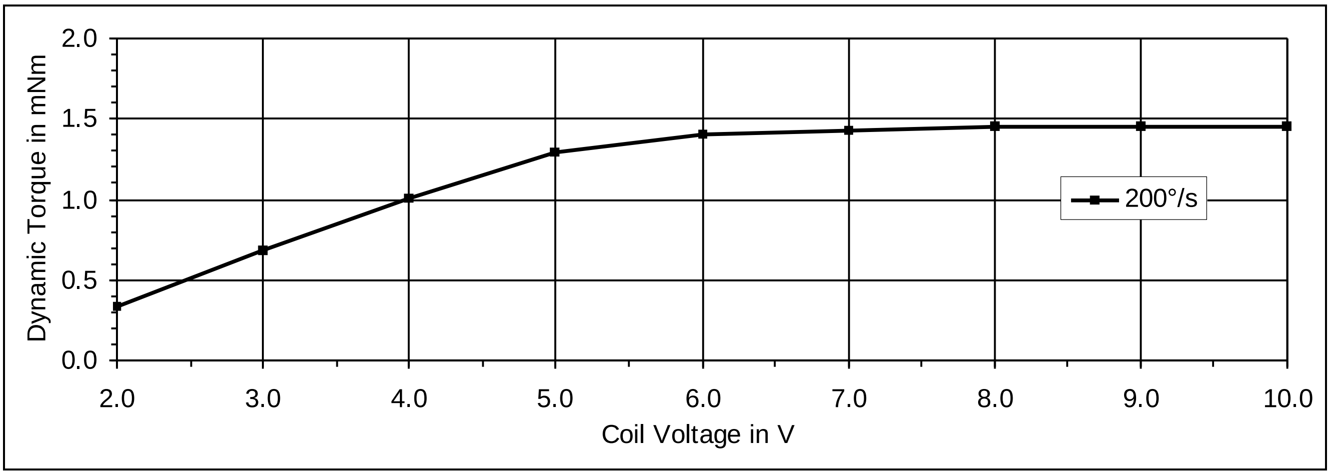


Fig. 3b

Dynamic Torque Md = f(Ta)

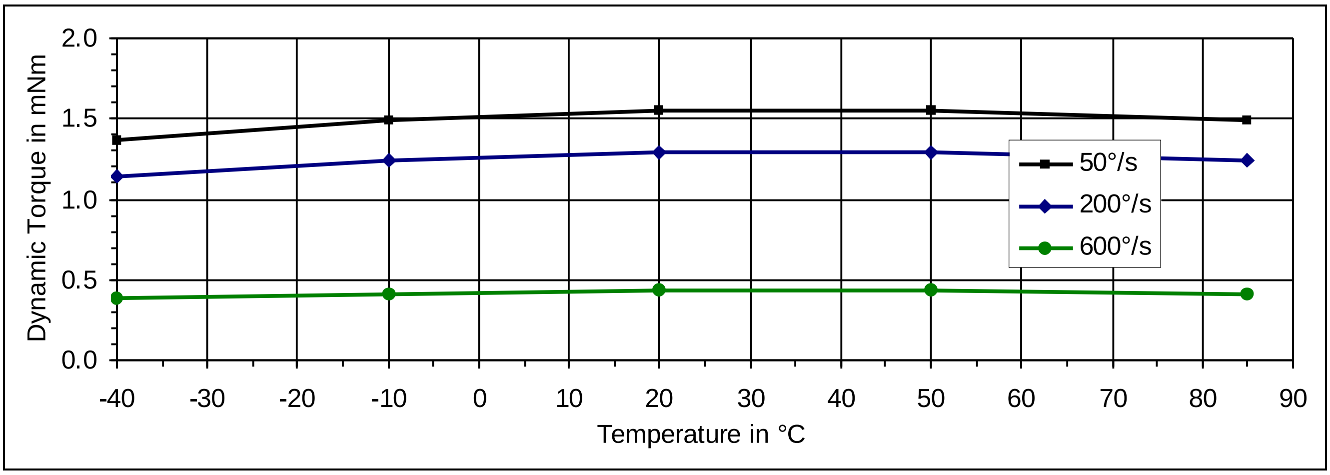


Fig. 3c

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.			
		Line 3 - 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	A-sample, variant 1
145>26.9	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 “Mounting the M-S/ACC Motor” X15.002.02.AN.E.

Examples for Motor Mounting

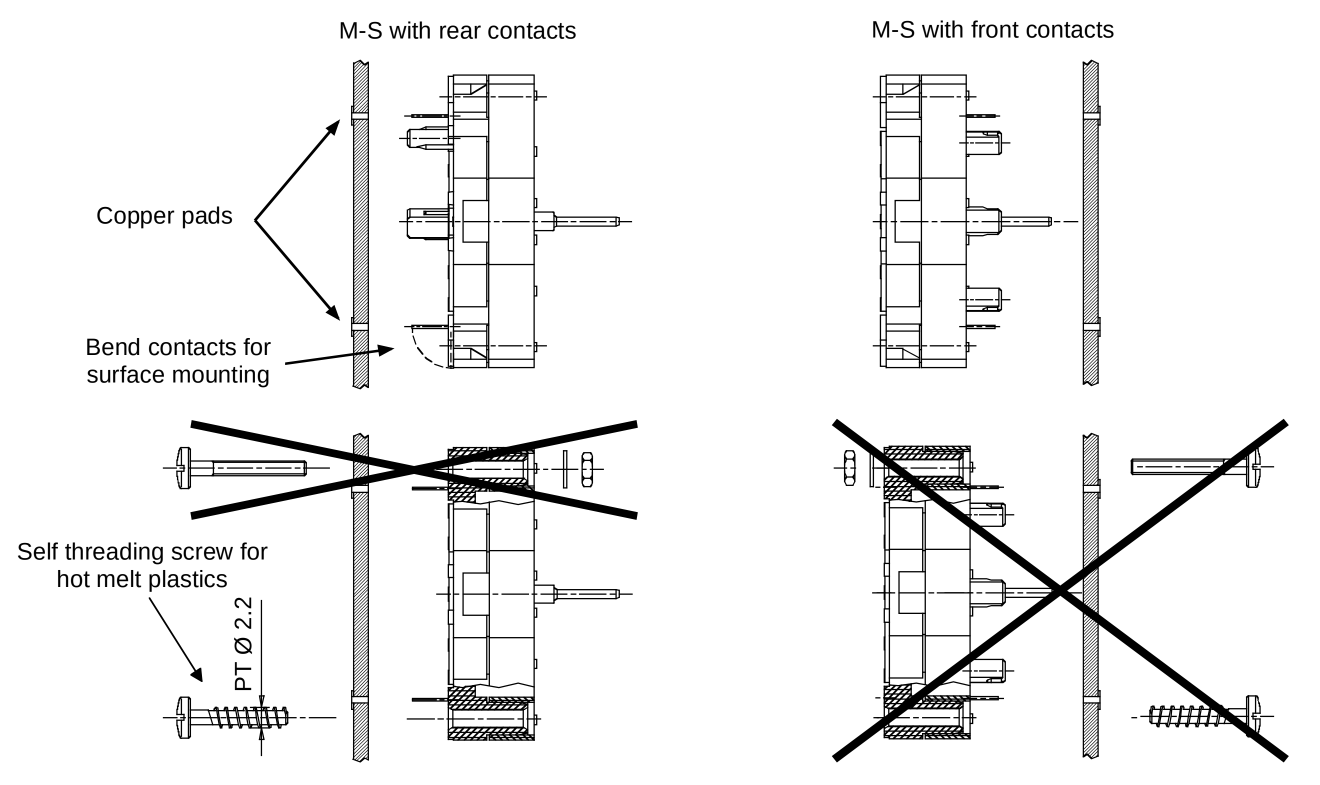


Fig. 4

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

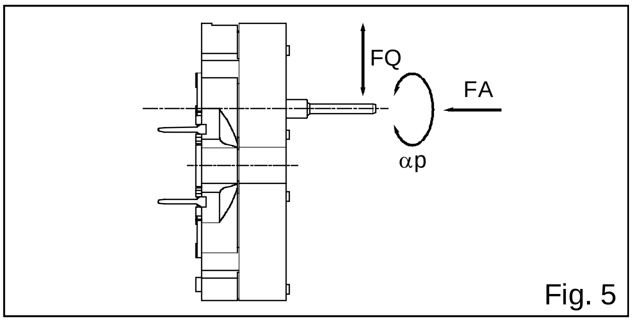


Fig. 5

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 current less 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

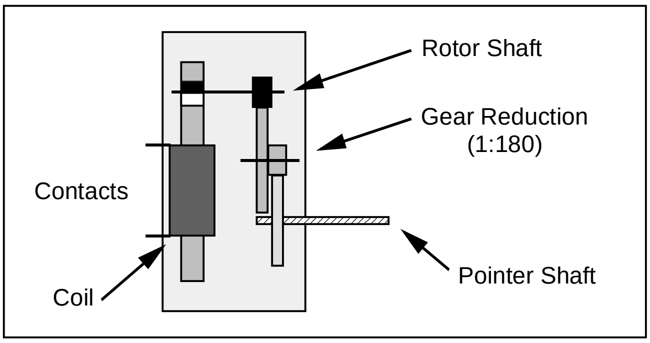


Fig. 6

Pin Configuration

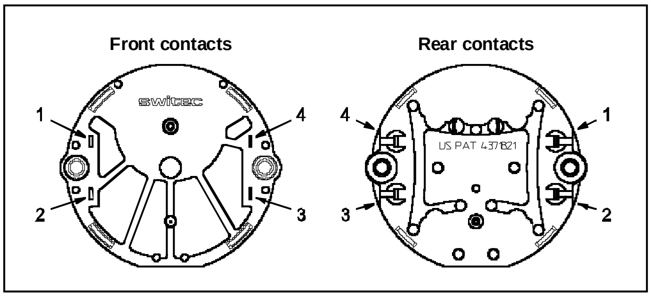


Fig. 7

Rotor Positions

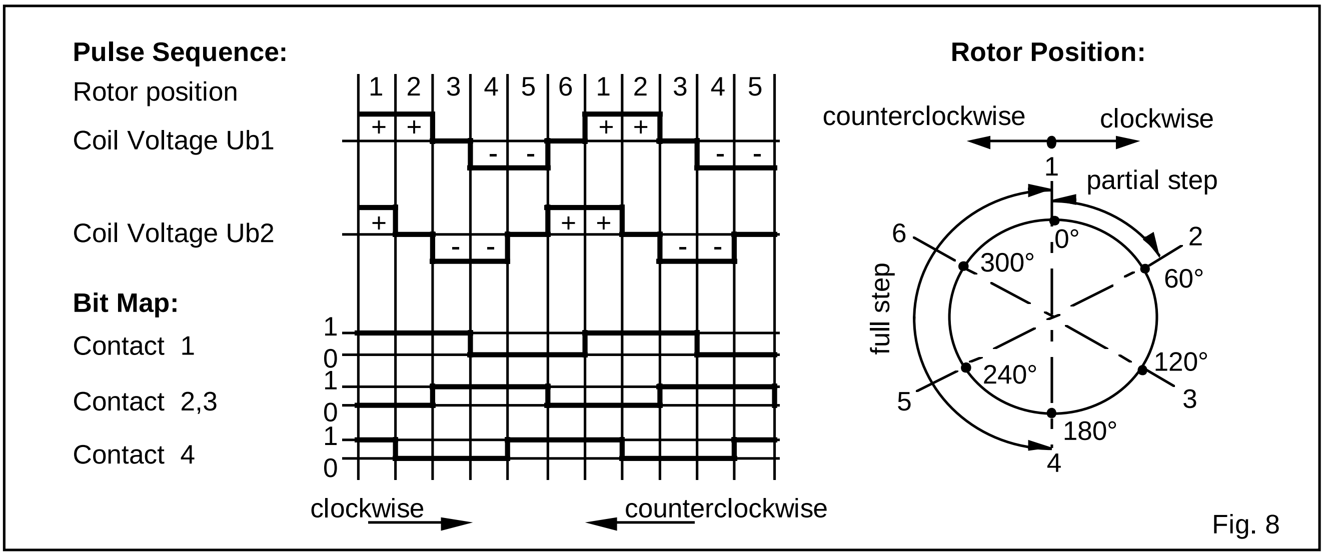


Fig. 8

Driving Diagram

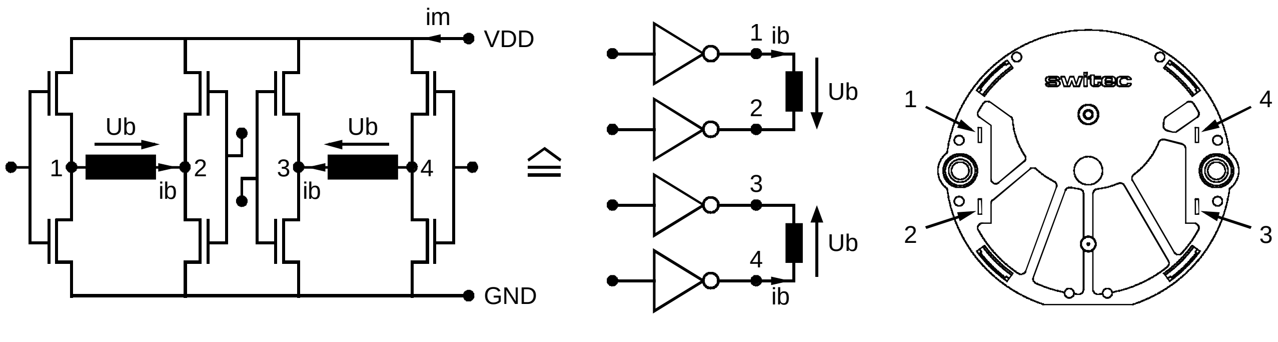


Fig. 9

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 XC5.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-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 $J_{M-S} + J_L = J$ 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°) $M_\alpha = J \cdot f_Z{}^2 \cdot \frac{\pi}{180}$ $(J = J_{M-S} + J_L)$

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-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}

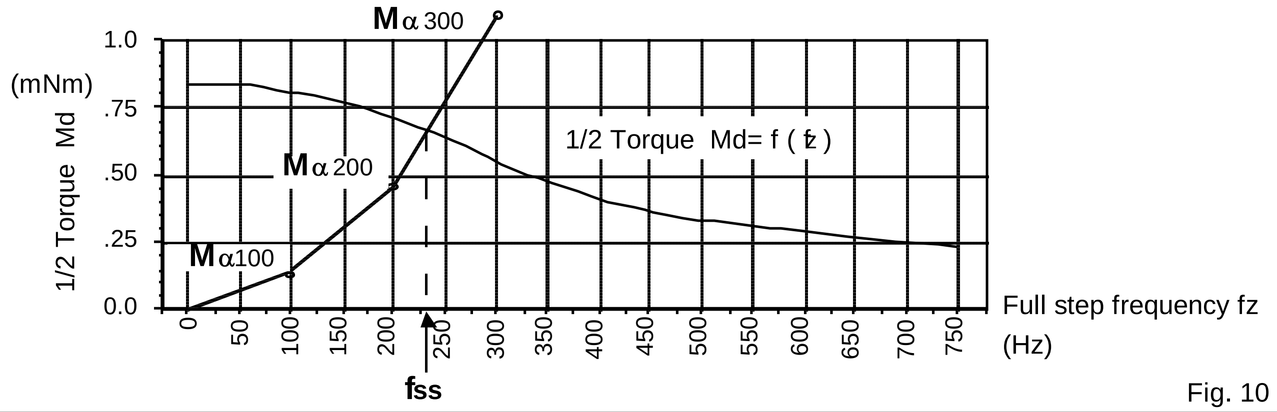


Fig. 10

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 $\Delta\omega$ 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

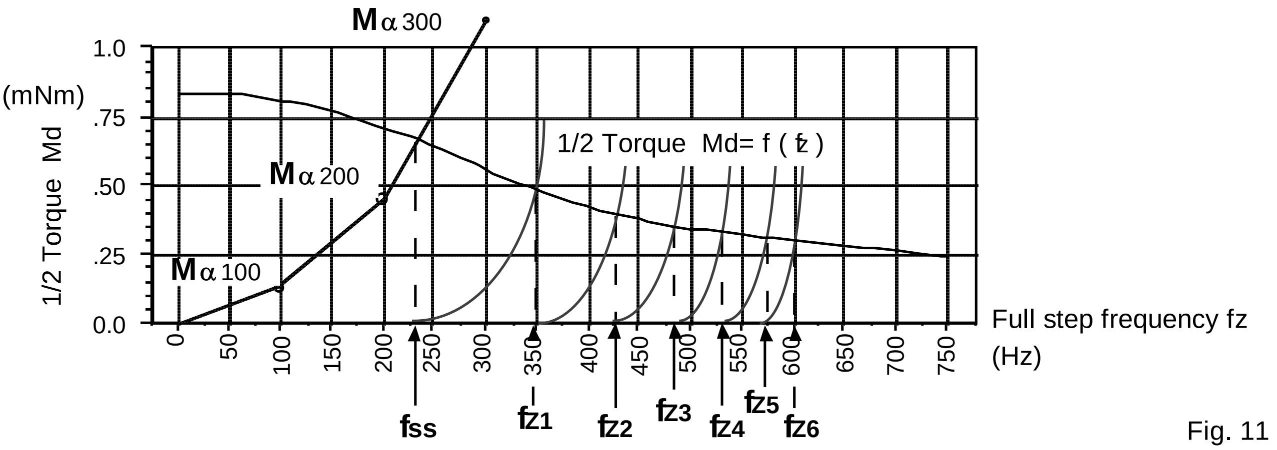


Fig. 11

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 XC5.xxx. The circuit allows the user to drive four motors as it contains four identical drivers on the same chip.

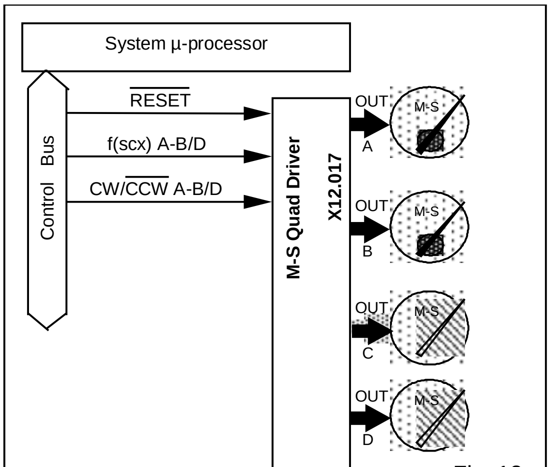


Fig. 13a

M-S Dual Driver X12.014

Manufactured with the same technologies and using the identical drivers as the M-S Quad Driver X12.017, the M-S Dual Driver X12.014 allows the user to drive two motors which require a smooth and appealing movement of the pointer (i.e major gauges such as speed and RPM). Minor gauges such as fuel or temperature which move only from time to time may be driven in the partial steps mode directly by the micro-processor (refer to example fig. 13b).

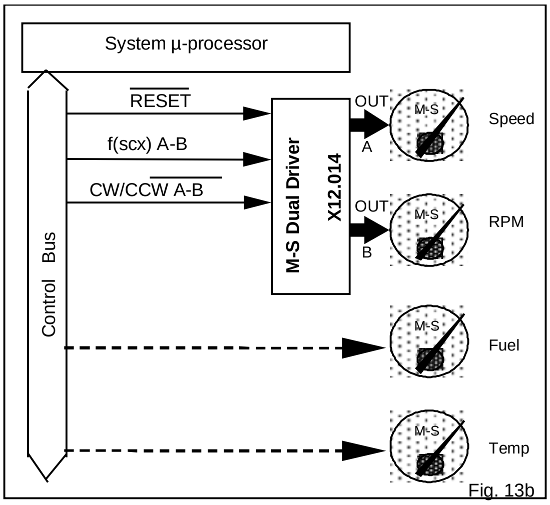
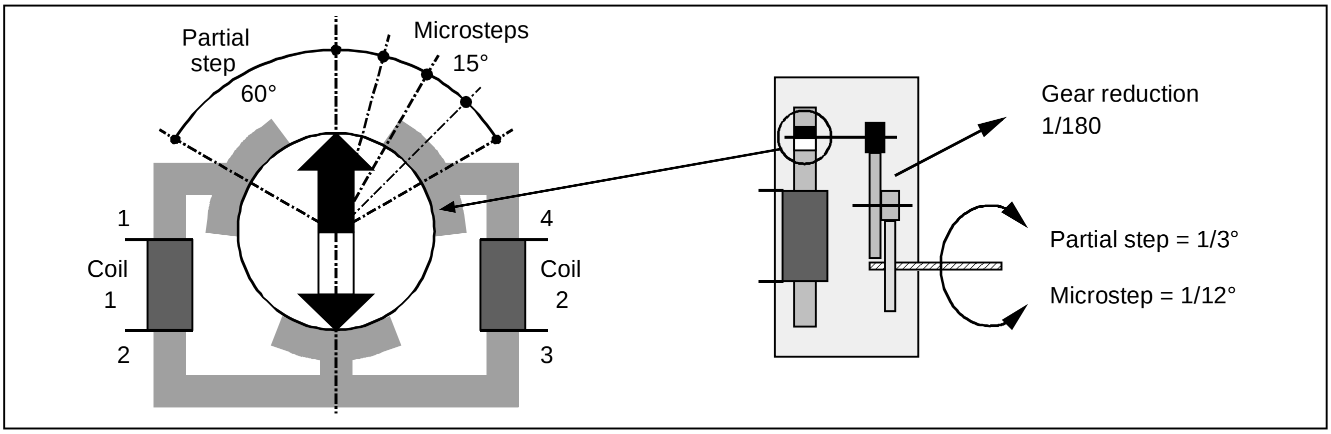


Fig. 13b

Microstepping Mode of Operation

The M-S Quad/Dual Driver converts 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.

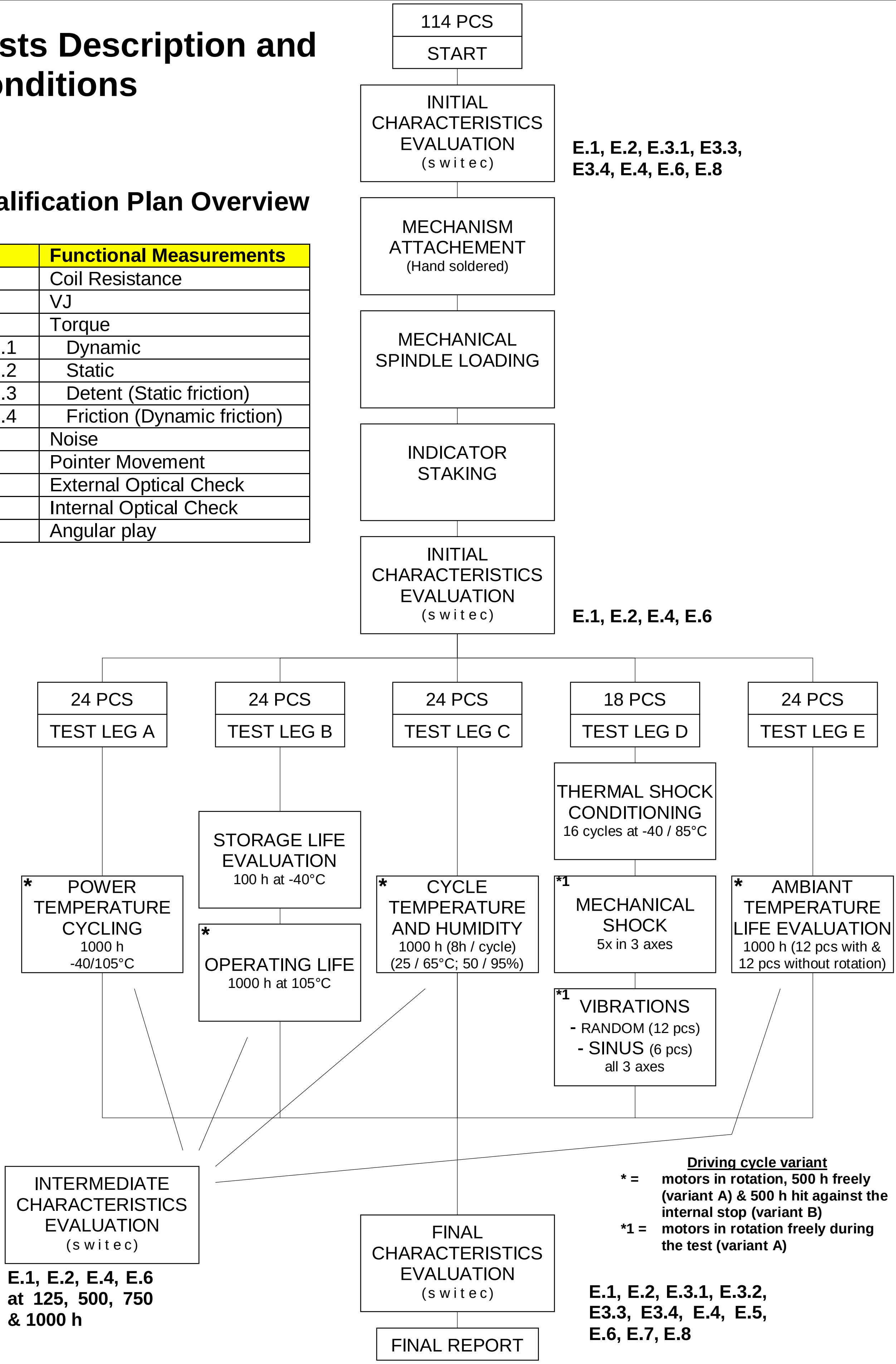
A partial step is an angular rotation of 1/3° of the M-S shaft or 60° on the rotor shaft.
The microstepping allows for a continuous smooth movement of a pointer if the M-S is used as pointer drive. It is not intended as a precise positioning. The precision of the angular position is given by the resolution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



Tests Description and Conditions

Qualification Plan Overview

E.	Functional Measurements
E.1	Coil Resistance
E.2	VJ
E.3	Torque
E.3.1	Dynamic
E.3.2	Static
E.3.3	Detent (Static friction)
E.3.4	Friction (Dynamic friction)
E.4	Noise
E.5	Pointer Movement
E.6	External Optical Check
E.7	Internal Optical Check
E.8	Angular play



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

The Driving Cycle consists of the following sequential movements in loop.
Before the first cycle, the motors with internal stop are driven continually in the same direction to hit the stop at 150°/s and then return 5°. The motor is zeroing at this position.

Type of driving speed used:

	ω_1	ω_2
Driving cycle at high speed:	200°/s	600°/s
Driving cycle at low speed:	100°/s	300°/s

1) Driving from 0° to 60° at ω_1 and wait 1 s.
2) Five cycles consisting each of a driving from 60° to 120° at ω_1 and back to 60° at ω_2 , Waiting during 2 s after each cycle.
3) Back to 0° at ω_1 .
4) A) Variant A: The motor is driven freely without hitting the stop. Driven at ω_2 to reach 300° (360° for motors w/o stop) and back again to 0° at ω_2.
   B) Variant B: The motor is driven against the stop on versions so fitted in order to increase the shocks and stresses. Driven at ω_2 to reach 360° and back again of 360° at ω_2.

The motor is driven about 25% of the time with driving cycle at high speed and 40% at low speed. During the waiting period, the recommended voltage is applied on the coils.

Specific Test Conditions

Test Leg A: Power Temperature Cycling

Defect free functioning after passing 1000 h in Temperature Cycling Test.
The temperature cycle consists of ½ h at 105°C, ½ h to cool down to -40°C, ½ h at -40°C and ½ h to return to 105°C. The time of each cycle is 2 h.
During the first 500 h, the motors are driven freely (variant A) and during the last 500 h the motors hit against the internal stop (variant B).

Test Leg B: Storage and operating life evaluation

Defect free functioning after passing 100 h in Storage Life Evaluation and after 1000 h in Operating Life.
The storage life evaluation consists to place the motors without rotation at -40°C during 100 h. After this time all the motors must start correctly without step loss.
The operating life consists of a permanent temperature at 105°C during which the motors drive. During the first 500 h, the motors are driven freely (variant A) and during the last 500 h the motors hit against the internal stop (variant B).

Test Leg C: Cycle Temperature and Humidity

Defect free functioning after passing 1000 h in Cycle Temperature and Humidity Test.
The cycle temperature and humidity test consists of 2 h to ascend the temperature from 25°C to 65°C and the relative humidity from 50% to 95%. The temperature and the humidity are maintained during 4 h then they are descending to the start values 25°C and 50% of relative humidity. The time of each cycle is 8 h.
During the first 500 h, the motors are driven freely (variant A) and during the last 500 h the motors hit against the internal stop (variant B).

Test Leg D: Shocks and Vibrations Test

Defect free functioning after being subjected Shocks and Vibrations Tests.

- **Thermal shock conditioning**

  First, the motors are placed without rotation to be conditioned in a thermal shock test which consists of 16 thermal shocks between 85°C and -40°C in 10 s. The extreme temperatures are maintained ½ h. The time of each cycle is 1 h.

- **Mechanical shocks**

The motors are subjected to shocks 5 times in 3 axes on the vibration machine. Each shock consists of a half-sine waveform pulse with an acceleration peak of 50 g during 11 ms. The motors are driven freely (variant A) during this test.

- **Random vibrations**

Previously subjected to thermal/mechanical shocks, 2/3 of the motors are subjected to the random vibrations test in each 3 axes.
Vibrations are applied for 10 minutes at a level of 1.8 grms between 10 and 1000 Hz during which no step loss shall be evident. Then the motors are vibrated 20 h at a level of 4.5 grms without mechanical damage and then, they are again vibrated 10 minutes at the level of 1.8 grms. During this last step, no step loss shall be evident. The motors are driven freely (variant A) during this test.

- **Sinus vibrations**

Previously subjected to thermal/mechanical shocks, 1/3 of the motors are subjected to the sinus vibrations test in each 3 axes.
Vibrations are applied for 8 h with an acceleration of 6 gp-p, but maximum 10 mm of amplitude in the frequency range of 5 to 250 Hz with a sweep of 1 octave / minute. The motors are driven freely (variant A) during this test.

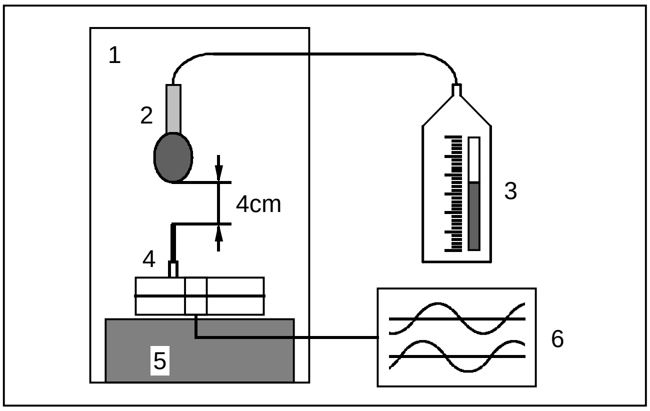
Test Leg E: Ambient Temperature Life Evaluation

Defect free functioning after passing 1000 h in Ambient Temperature Life Evaluation.
- 12 motors driven freely (variant A) at ambient temperature for 500 hours, followed by driving against the internal stop (variant B) where applicable for further 500 hours.
- 12 motors not driven at all.

Comparison is then made between motors subjected to this test, and those of the other legs in order to evaluate the evolution of the motors under different conditions.

Acoustic Measurements

Test Configuration



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. reflection free cube
6. M-S control unit in µ-stepping mode (1/12° / step)

Test Conditions

- temperature	T_{amb}	:	25	°C
- measurement distance	Lm	:	4	cm
- measurement range		:	20 ÷ 20k	Hz
- measurement time	tm	:	4	s
- angular speed max	ω	:	600	°/s
- ambient noise max		:	20	dBA
- motor 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 "

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_α/J)	rad/s^2
α_p	angular acceleration imposed to the pointer shaft	rad/s^2
ß	possible angle of rotation of the internal stop version	degrees
ω	angular speed	°/s (rad/s)
	random vibration unit	grms
	sinus vibration unit (g peak to peak)	gp-p

Table of Contents

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