MICROINFORMATIQUE
SUPPLEMENT A LA NOTE D'APPLICATION 2

COMMANDE D'UN MOTEUR PAS-A-PAS PAR LE MODULE EZ430

1. *Documents et matériel de référence*

Le document de référence pour cette note d'application est :

1. ***Extrait de la spécification du moteur M-S Motor X25***
2. ***Slides : GPIO, Interruptions, Timers***
3. ***Matériel : moteur, petite roue, 4 câbles (à couper soi-même), barrette (voir figure ici-bas).***

2. *Objectifs de cette note d'application*

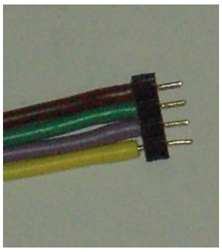
Le moteur M-S Motor X25 a plusieurs particularités :

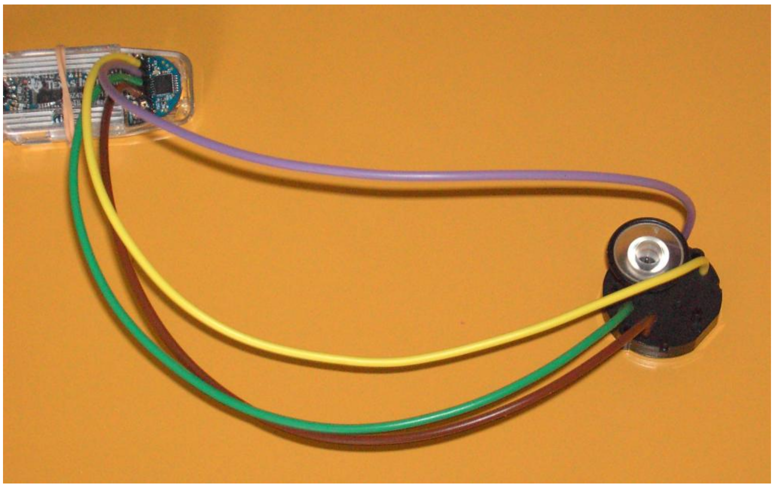
- Il s'agit fonctionnellement d'un petit moteur pas-à-pas, mais qui ne compte que deux pas par tour de rotor (360°).
- Il a ensuite un réducteur avec facteur de réduction 180.
- Avec ces caractéristiques, si les exigences de couple sont limitées, il peut être commandé directement par un microcontrôleur sans demander un étage de puissance intermédiaire.

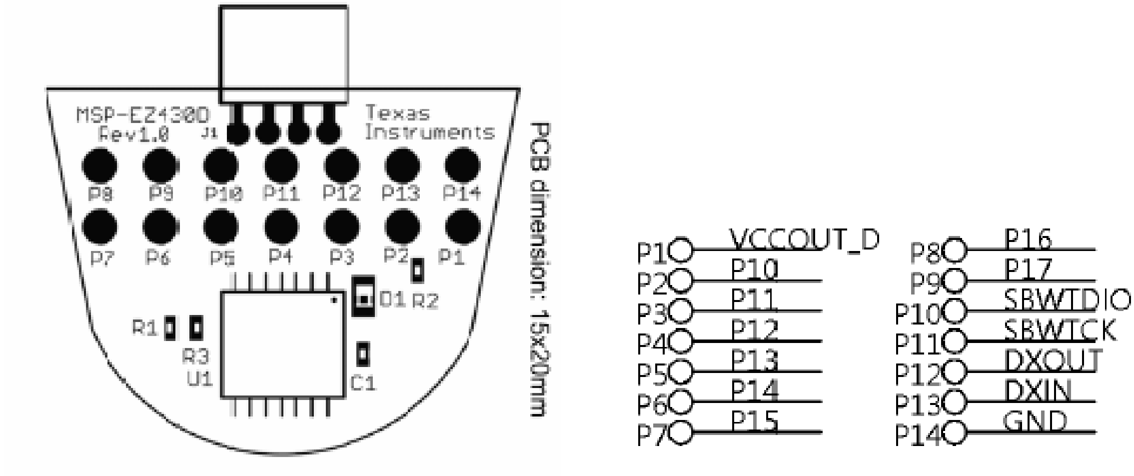
L'objectif de cet exercice est donc de l'actionner avec le module eZ430.

3. *Exercices*

1. Etudier la spécification technique du moteur.
2. Réaliser des connections électriques entre les quatre entrées du moteur et quatre sorties GPIO (par exemple P1.0 à P1.3) .

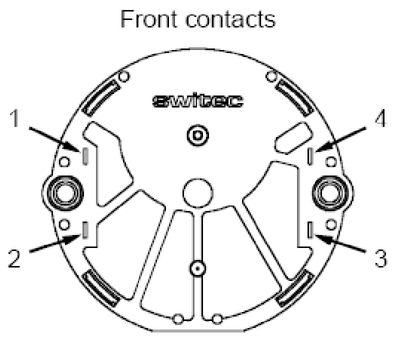


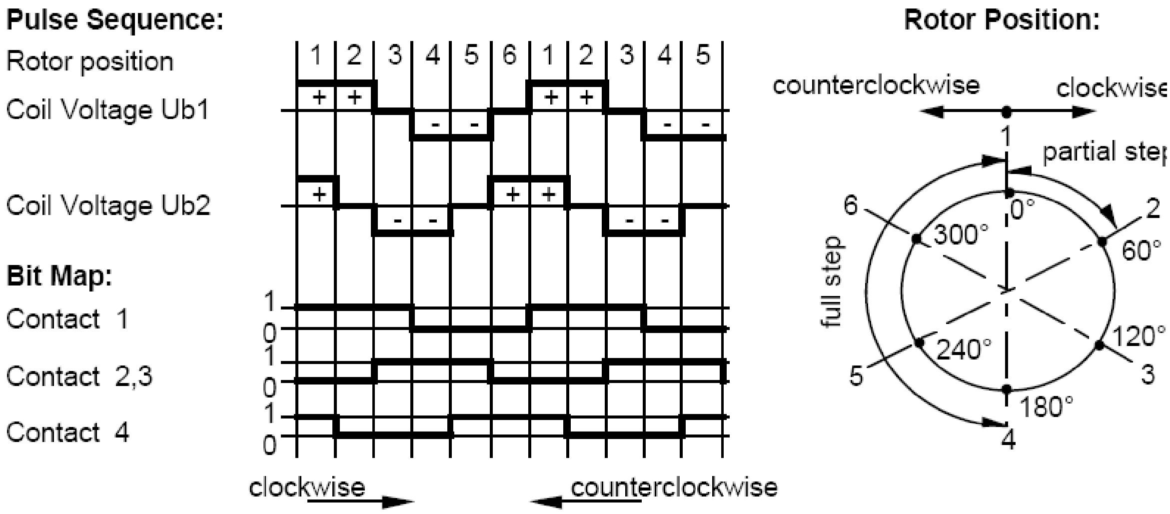




Broches (pins) du eZ430 et entrées/sorties correspondantes

3. Créez **un nouveau projet dans IAR** et programmez la rotation du moteur en séquençant dans l’ordre l’activation des ports de sortie. Dans cette phase on utilisera des simples boucles d’attente (exemple : `for (i=0 ; i<5000 ; i++);` pour « espacer » le séquencement. Il peut être utile de vérifier la séquence avec l’aide des LEDs de la carte d’expérimentation.





4. Programmer également une rotation dans le sens inverse. Vous pouvez programmer aussi les ports 1.4 et 1.5 pour qu’ils servent par exemple d’interrupteur général et de commande de signe. On pourra ensuite commander le moteur en connectant ces broches les cas échéant à la masse (broche P14) et au VCCOUT (broche P1).

5. **Commande de rotation par timer**.
   Avec des boucle d'attente « `for` » on peut réaliser la rotation mais on n'en contrôle pas vraiment la vitesse précise. Ceci est par contre possible si on utilise un Timer.

   Créez un nouveau projet et utilisez le Timer A, en le basant sur le SMCLK (en principe 1'048'576 Hz) pour générer une interruption avec la période voulue pour un « pulse » (il y 3 pulses par pas, ou deux par tour – voir la figure précédente).

   Ensuite l'activation des ports de sortie est faite dans la routine d'interruption du Timer A0. Une variable d'état (en fait un compteur) déclaré globalement - avant le main() – est incrémenté de 1 à 6 puis remise à 1 et permet de gérer la séquence. En variant la fréquence du timer on commandera ainsi la vitesse du moteur.

6. Etudier la partie sur la *Start-Stop Frequency* dans la spécification du moteur: au delà d'une certaine fréquence le moteur n'arrive plus à exécuter les pas. **Déterminez expérimentalement cette fréquence limite et donc la vitesse maximum du moteur sans charge**.

4. Rapport

Le rapport sera une mise au propre de vos propres notes prises durant ce travail : un simple log-book et enregistrement des divers programmes réalisés et testés.
Il inclura pour chaque tache effectuée

- Titre de la tache.
- Copier-coller des *parties significatives* des listings produits.
- Les réponses à toutes les questions posées.
- Remarques, résultats, conclusions et suggestions applicables pour chaque cas.

M-S Motor X25

Description

The Miniature Stepper Motor M-S X25 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

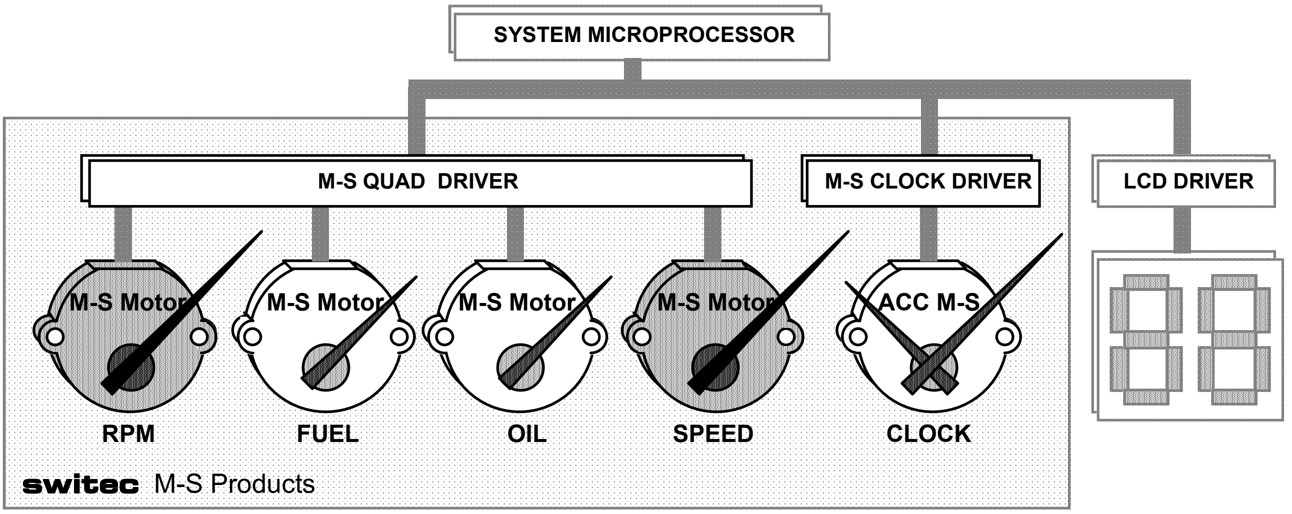
Motor versions

This specification applies only to the following motor versions.

Without stop :	X25.156, X25.158, X25.278, X25.559, X25.579, X25.679
With stop :	X25.166, X25.168, X25.288, X25.569, X25.589, X25.689

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

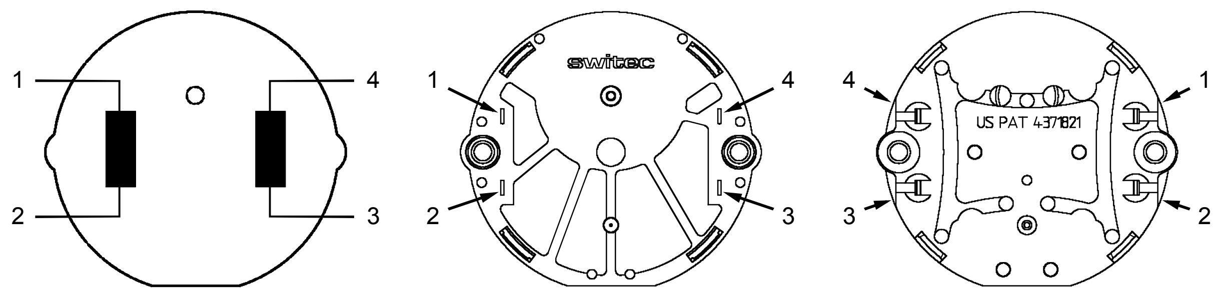


Fig. 2

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
(5 sec)		270 °C

Table 1

Stresses beyond these listed maximum ratings may cause permanent damage to the M-S X25. Exposure to conditions beyond specified operating conditions may affect the M-S X25 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	°/s
Maximum driving frequency	fm	@ $J_L = 0{,}2x10^{-6}kgm^2$			600	°/s
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)

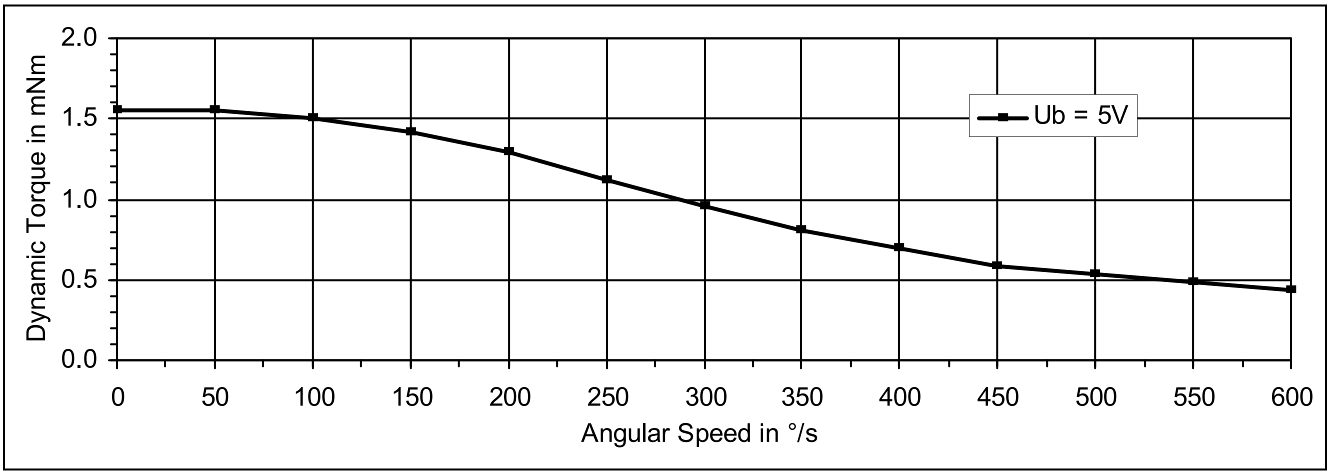


Fig. 3a

Dynamic Torque Md = f(Ub)

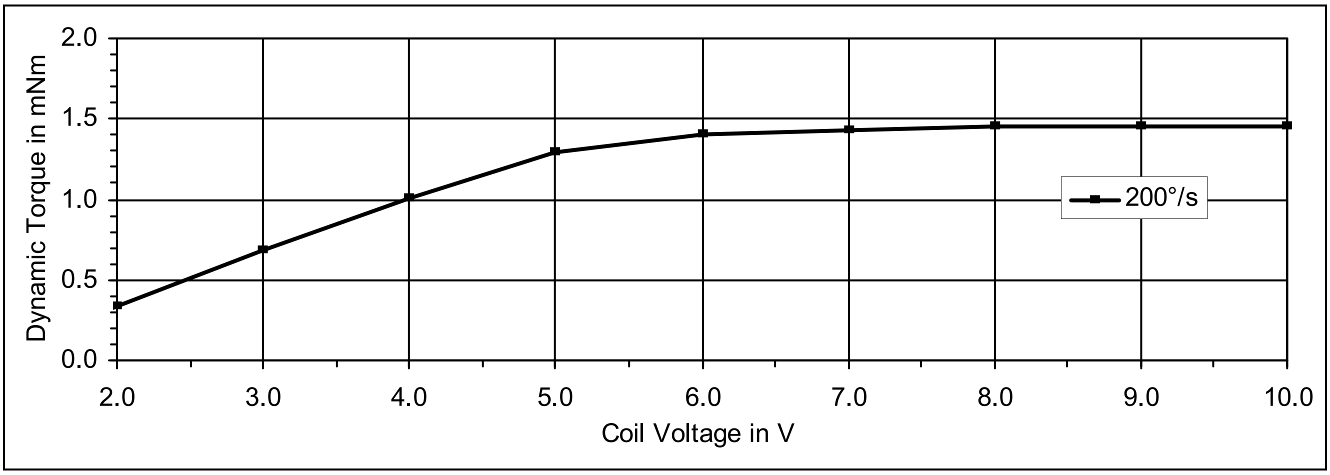


Fig. 3b

Dynamic Torque Md = f(Ta)

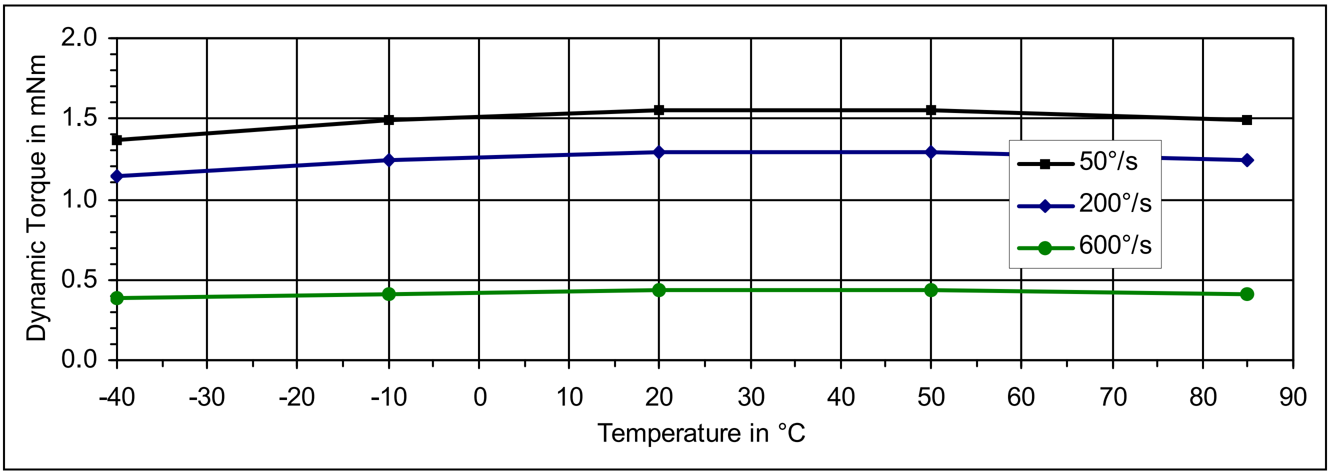


Fig. 3c

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

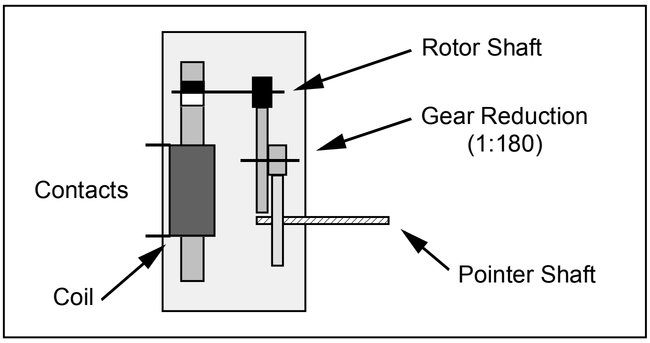


Fig. 6

Pin Configuration

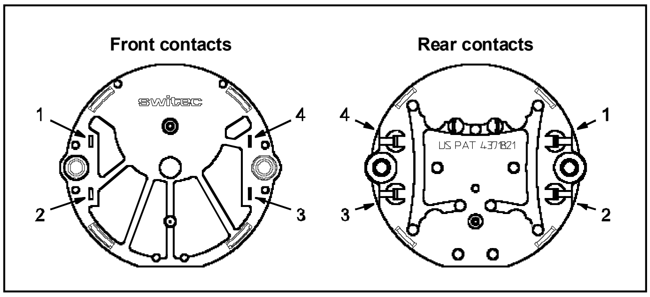


Fig. 7

Rotor Positions

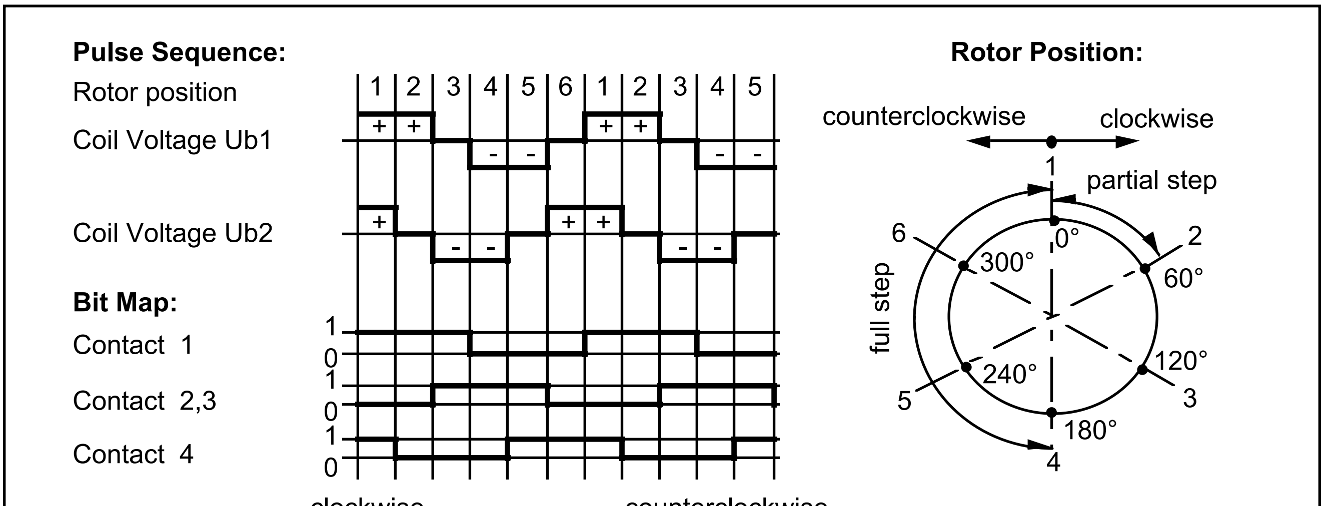


Fig. 8

Driving Diagram

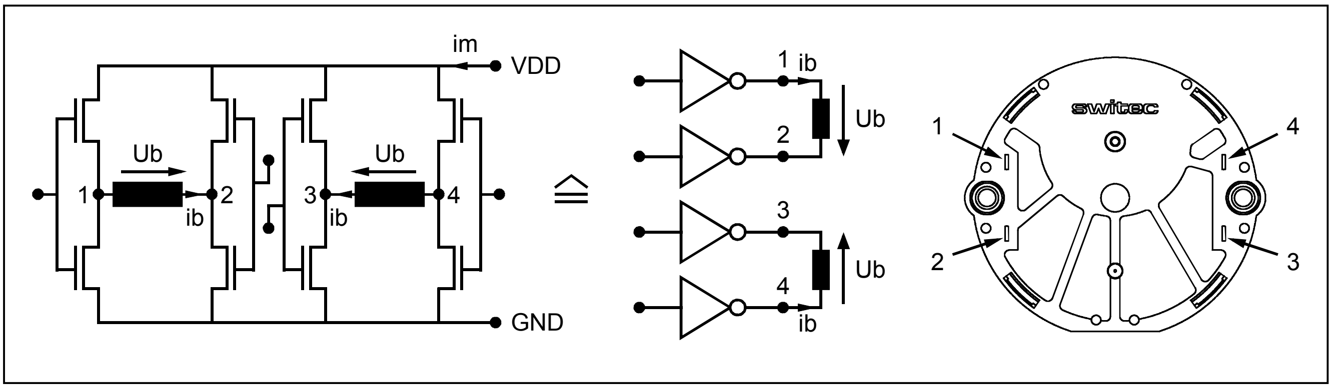


Fig. 9

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 X25 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 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 fss

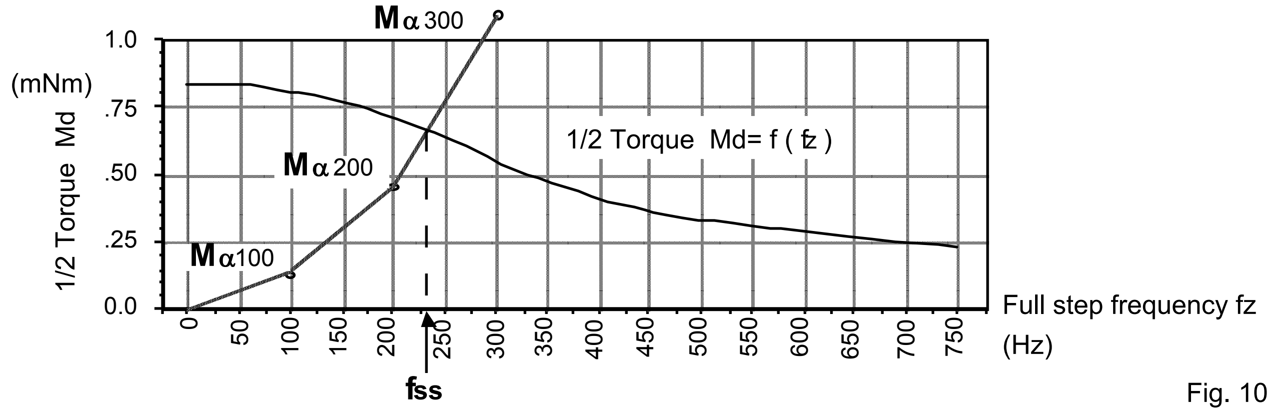


Fig. 10

Acceleration to Frequencies > fss

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

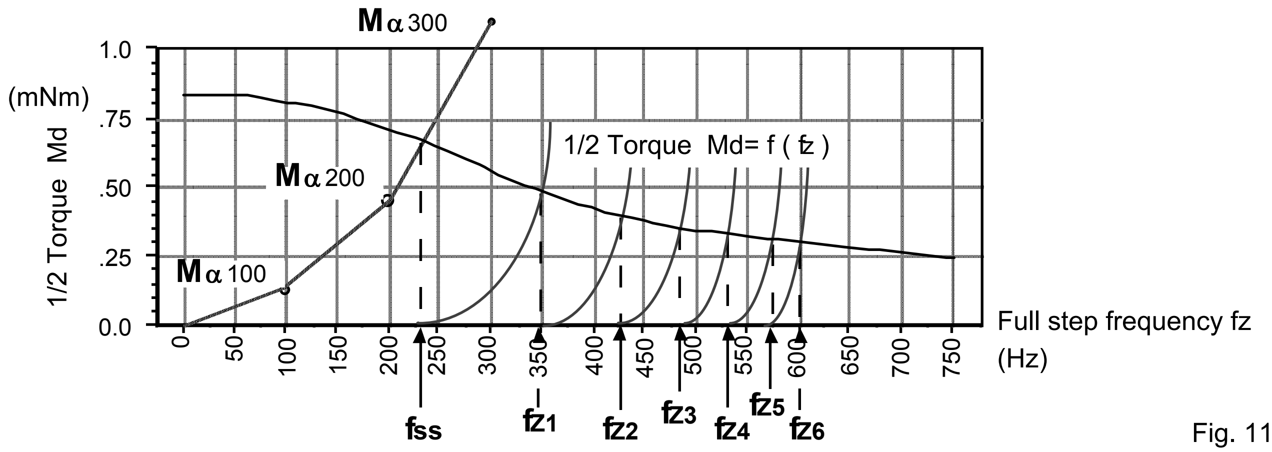


Fig. 11

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 X25. The circuit allows the user to drive four motors as it contains four identical drivers on the same chip.

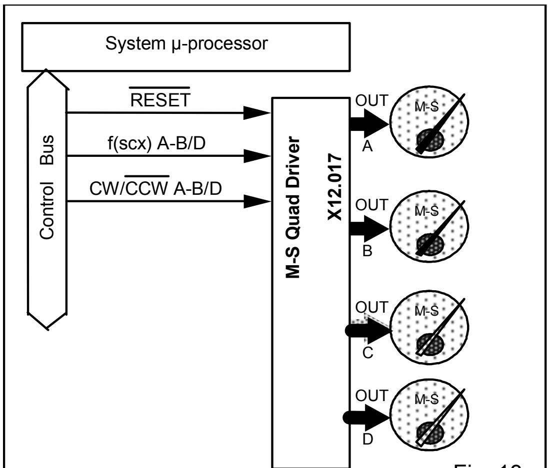


Fig. 13a

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).

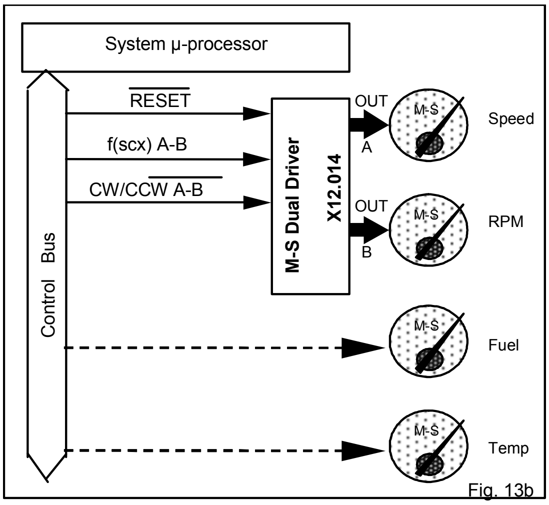


Fig. 13b

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.

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