1 Introduction

The JST X10 is a stepper motor for Automotive purpose and Analog Car Clocks (ACC) or for any application which requires time display with pointers.

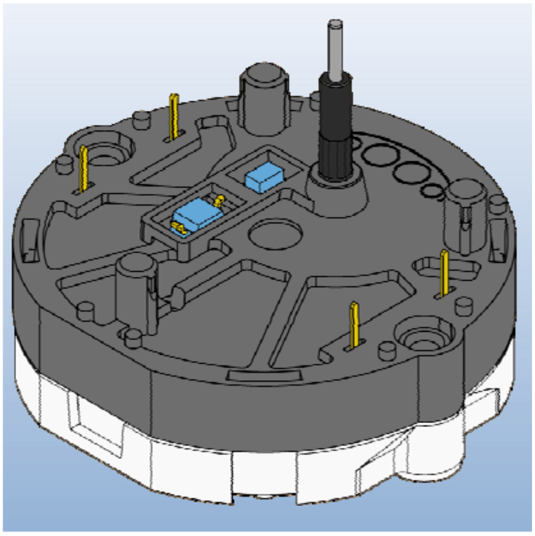
The stepper motor has an accurate and repetitive movement and can operate directly with digital signals from a micro-controller or an ASIC. The JST X10 stepper motor has an electro-magnetic circuit and a gear train with 1/60 reduction to generate the minute indicator movement. A cascaded gear train with 1/12 reduction generates the hour indicator movement.

With an additional set of components, it is possible to detect a unique reference position and to add functionalities like automatic time set, time zone adjustment, daily time verification and any other based on a time reference. For those applications is only needed to add an Infra-Red emitter and an Infra-Red sensor for the detection.

This technology comes from the watch industry and is an evolution of existing products well proof in Automotive market over many years and large volumes.

The construction is simple and robust without concessions to versatility or longevity. The high quality of the assembly process and material employed grant an excellent lifetime and liability of the product.

1.1 Summary of features



- Reference for optical position detection
- low current consumption
- small dimensions: Ø 30 x 9 mm
- can be directly driven by a micro-controller
- large static torque
- high static torque without current
- large temperature range: -40° C ÷ 105° C
- qualified for automotive applications

2 Functional description

The JST X10 is a stepper motor and the rotative movement is generated by an electro-magnetic circuit. The circuit is composed with 2 coils, a stator and a rotor with a bipolar permanent magnet. With specific signals applied to the coils, a magnetic field is driven through the stator. This magnetic field orientate the rotor and generates a rotative movement, in steps. The shape and voltage of the signals applied to coils define the step dimension and position.

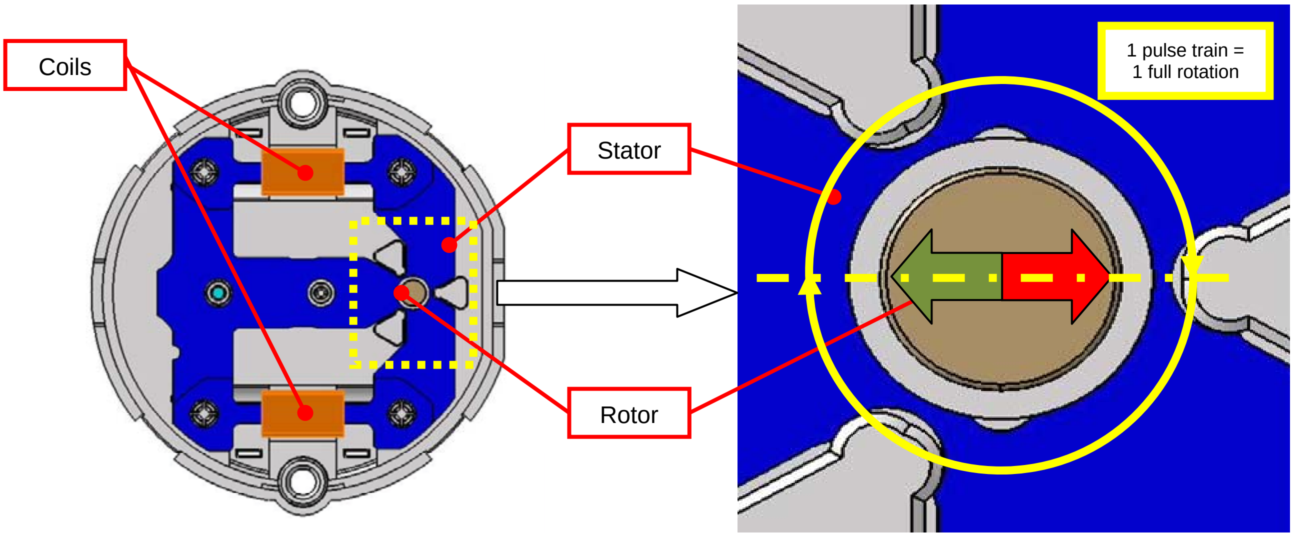


Figure 1: Magnetic circuit

The rotor of the motor makes one full rotation each pulse train (Figure 3). The steps are carried out according to the applied pulse sequence. The bit map shows the logic levels at the motor contacts 1 to 4 (Figure 2) and the corresponding coil voltage pulses.

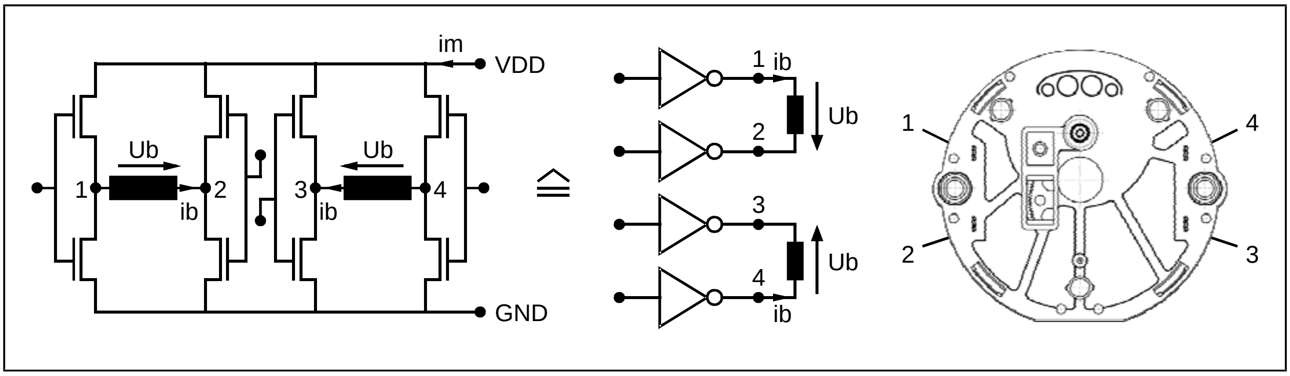


Figure 2: X10.504 stepper motor contacts

The direction of rotation is determined by the bit map sequence chosen. The inversion of the rotation sense can be realized on each point of the sequence, by inverting the pulse train sequence. The start-stop frequency fss is dependent on the mechanical load applied and has to be respected.

The driving diagram (Figure 3) shows how the M-S can be driven using standard logic components capable of supplying 20 mA output current at Vdd of 5 volts.

Full step positions 1 and 4 provide a static torque even in the absence of the current Ib in the coil.

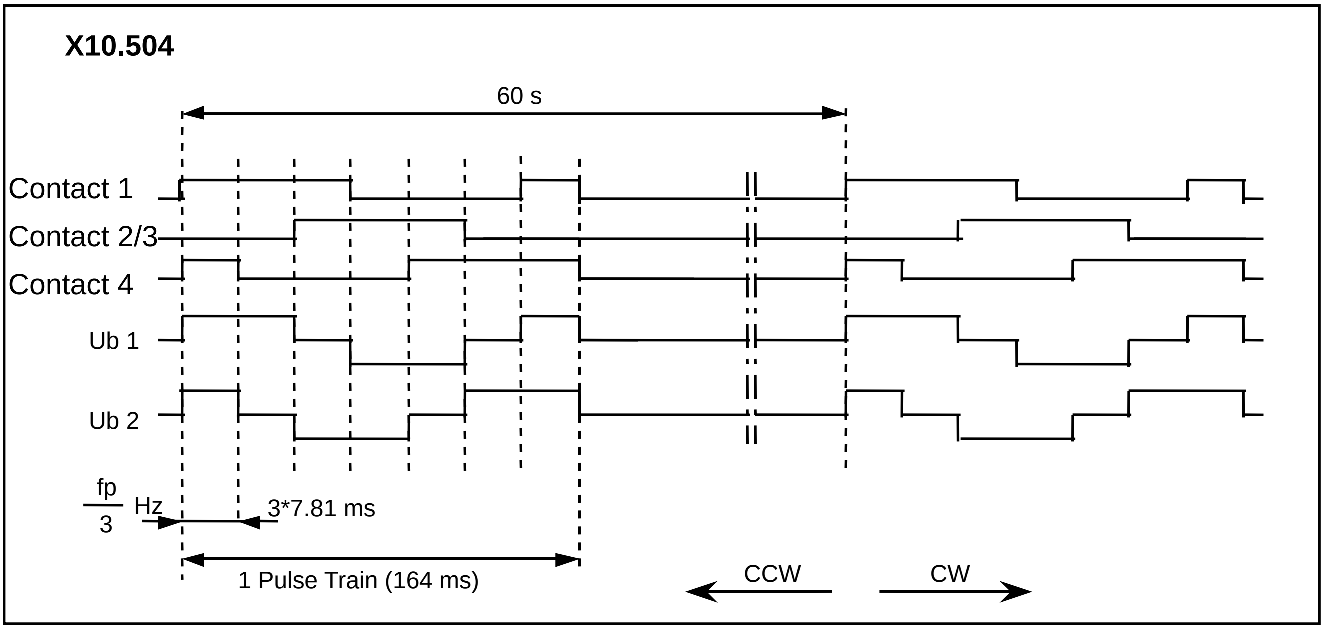
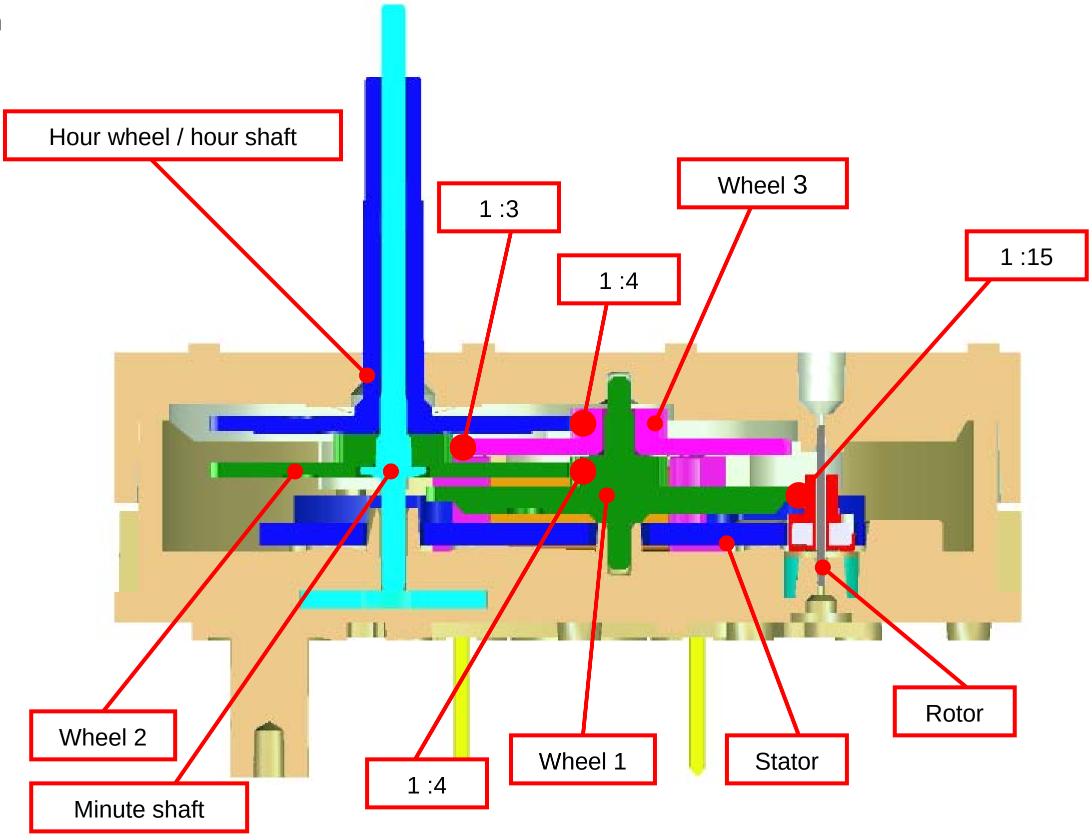


Figure 3: Pulse train

2.1 Hour – Minutes indication

Figure 4: Gear train



The X10.504 consists of a two levels gear train and a "Lavet" type stepper motor.

The first level gear train (rotor – wheel 1; wheel 1 – wheel 2) reduces the rotation of a factor of 60.

Consequently a full revolution of the rotor makes a displacement of 6° on the minute shaft, so 1 minute.

The second level gear train (wheel 2 – wheel 3; wheel 3 – hour wheel) reduces the rotation by a factor of 12. This is needed to turn the hour shaft by the corresponding factor.

2.2 Reference position detection

The X10.504 is a front contact stepper motor with reference position detection. Over the full revolution of the motor each position is unique, and it corresponds to a given hour and given minute. The motor has a single position that can be sensed. This is called reference position.
This reference position corresponds to an accurate hour – minute position depending on where the pointers have been stacked during the assembly.
Let says the motor has 12 (hours) by 60 (minutes) different positions, i.e. 720 positions.

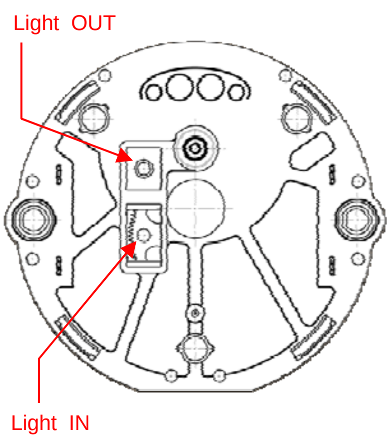


Figure 5: Detection holes

When the motor is on the reference position, the wheels of the internal gear train are aligned and a tunnel allows a light beam to go through. When a light beam is projected through the tunnel at the input side it can be sensed at the output point. In the other 719 positions the tunnel is closed.

In the final application we recommend an Infra-Red based Light Emitting Diode (IR-LED) on the input side and a Infra-Red sensor on the output side of the tunnel. Both sides of the tunnel are on the cover of the X10.504 stepper motor, toward Printed Circuit Board (Pcb side). With Surface Mount Devices (SMD) for IR-LED and IR-sensor we have a single Pcb for all functions of the motor.

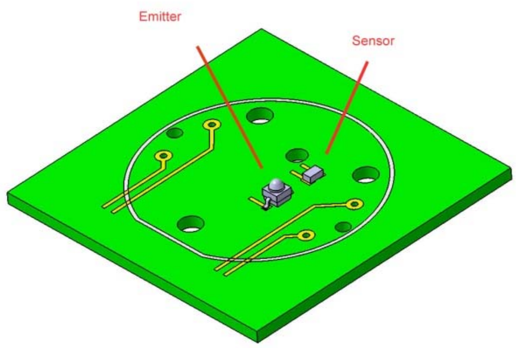


Figure 6: PCB with IR-components

Below a diagram showing an example. Assumption is that pointers have been stacked on the motor shaft pointing midday (12:00), when X10 is at reference position. Every time the “watch” indicates 12 hours and 00 minutes, light can pass through the tunnel and can be detected. On the graph, nominal light intensity outgoing is represented with a “1” state.

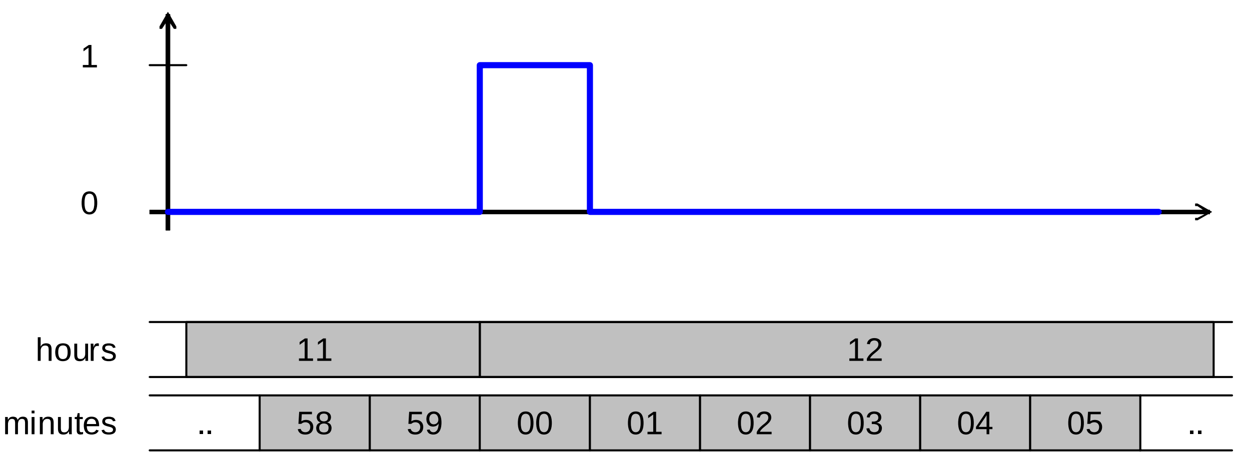


Figure 7: Detection signal

2.3 Static Torque without current

A static torque on the X10.504 without current is obtained by adding a small asymmetry to the pole piece positions. This asymmetry creates a preferred position of the rotor in absence of current in the coil.

The drawback of this solution is that the driving of the rotor will also be influenced by this asymmetry, but it is not embarrassing for the clock application

3 Mounting the motor

The Miniature Stepper Motors can be secured in place by a variety of methods. For all automotive applications even when the motor is subjected 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.

Examples for Motor Mounting

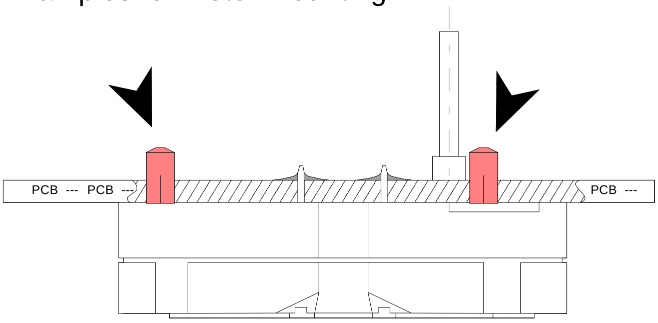
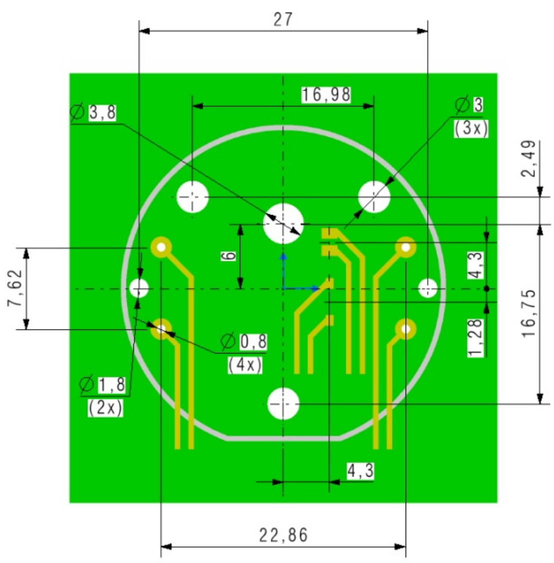


Figure 8: Front contact mount for X10.504

3.1 Holes and insertion force

For the recommendations about holes, how to drill support for the stepper motor and the insertion force, refer to the application note AN-JST-001 “Mounting the M-S/ACC Motor”.

3.2 PCB layout



This is a suggestion for a Printed Circuit Layout (PCB). Each user can adapt to the needs of the application according to general specification of the product.

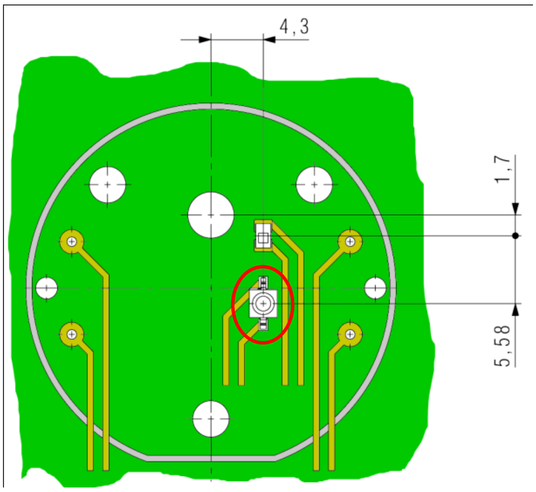
Figure 9: PCB layout

3.3 Screwing

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 or the shafts.

For further details, refer to the application note AN-JST-001 “Mounting the M-S/ACC Motor”.

3.4 IR-LED positioning

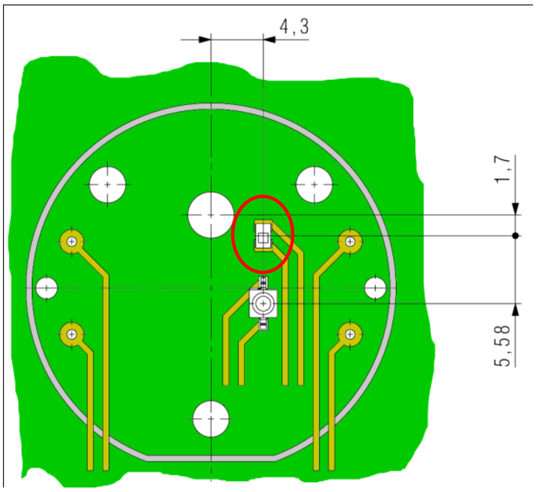


The position for the IR-LED is given on the following drawing. The regular tolerances for a pick and place system for SMD has been taken in count, i.e. ±0,3 mm from the nominal position X-Y.

Concerning axe Z, the component has to be positioned flat on the PCB, any angle will have influence on the efficiency of the IR-sensor to detect the signal.

Figure 10: IR-LED position on PCB

3.5 IR-sensor positioning

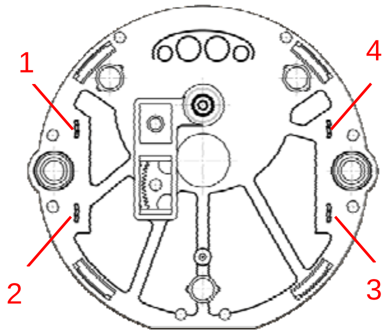


The position for the IR-LED is given on the following drawing. The regular tolerances for a pick and place system for SMD has been taken in count, i.e. ±0,3 mm from the nominal position X-Y-Z.

Figure 11: IR-sensor position on PCB

4 Driving the motor

4.1 Pinout



The motor has two coils, called Coil1 and Coil2. The contacts to Coil1 are pin1(+) and pin2(-), the contacts to Coil2 are pin4(+) and pin3(-).

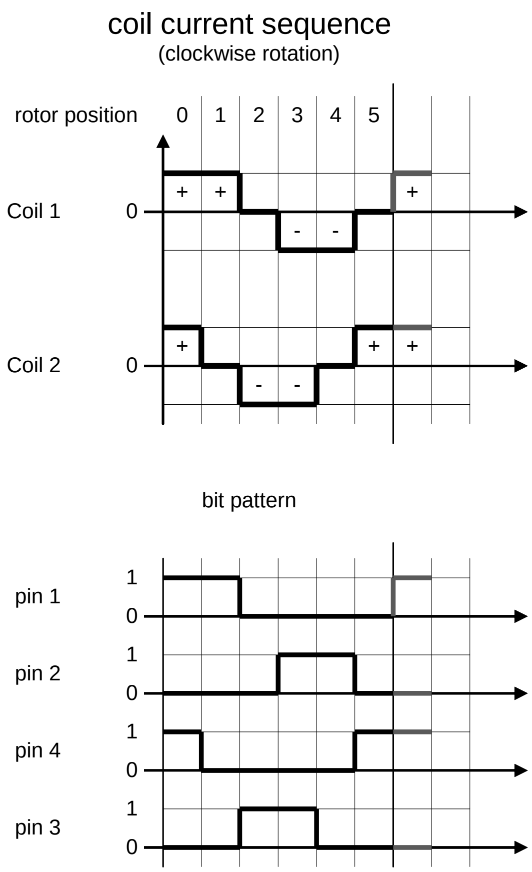
The “polarity” on the contacts is indicated to have a reference for the sens of rotation of the motor.

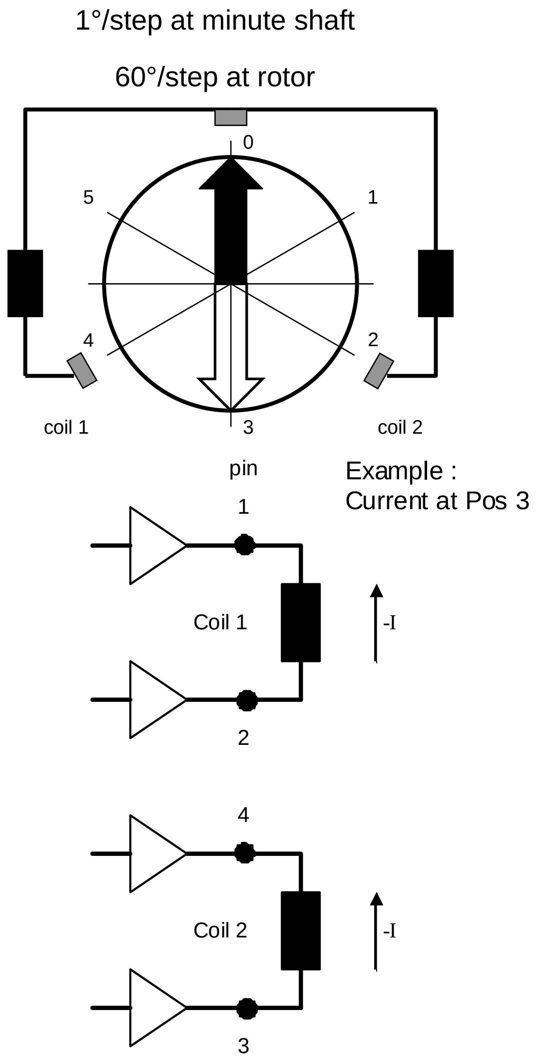
Figure 12: X10.504 pinout

4.2 Driving methods

To drive the X10.504 stepper motor two coils have to be supplied. The typical methods are partial steps or micro-steps. We recommend to choose between partial steps and micro steps. Tha first has the advantage to require simple output stages with only two levels of voltage, the second has the advantage to create more smooth movement and more noiseless.

Figure 13: Partial steps mode





The X10.504 stepper motor has a gear reduction of 1:60 for the minute shaft and additionaly of 1:12, means total 1:720 for the hour shaft. In other words a full rotation of the rotor makes a rotation of 6° on the minute shaft and a rotation of 1/2° on the hour shaft.

Micro steps mode

For micro-step mode most of the time the inductance characteristic of the coil is exploited. This kind of signals can be generated with a PWM circuit method and output circuit.

X10.504 Microstepping waveform; 24 steps mode, VDD = 5.0V

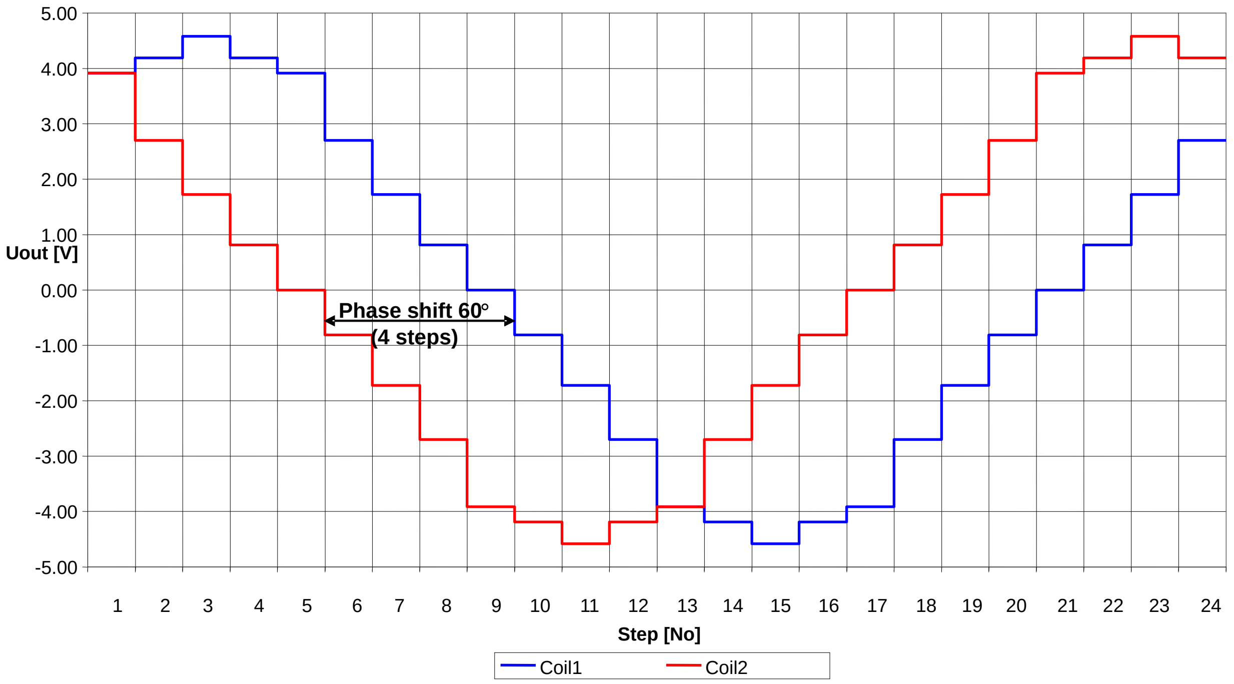


Figure 14: Micro steps mode

4.2.1 Clock forward

Here a suggested diagram for driving the X10.504 stepper motor to indicate time. This is an example with partial steps mode. The same principle could be applied with micro steps mode. The idea is to show the pulse train needed to move the pointers from current minute-hour indication to following minute position (+60s). The move is done within 164ms which corresponds to a rotational speed of 42°/s on the minute shaft. Faster or slower speed can be applied according to application needs.

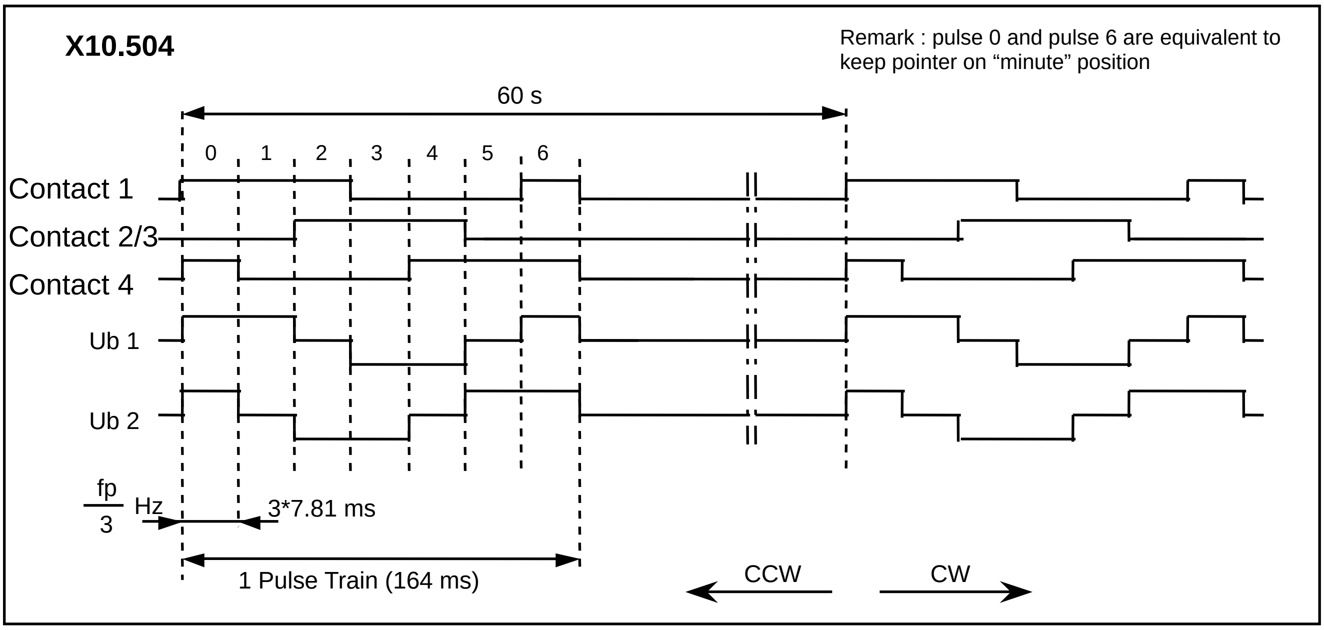


Figure 15: Driving signals

4.2.2 Clock fast forward (backward)

For the adjustment of the time indicated a fast forward or fast backward movement of the pointers is needed. The upper limit of the fast speed depends on the characteristics of the driven pointers, i.e. inertia and weight. A good range which cover most of the applications is to keep rotational speed between 40°/s and 170°/s. Below a suggestion how could be done with en emulation of acceleration:

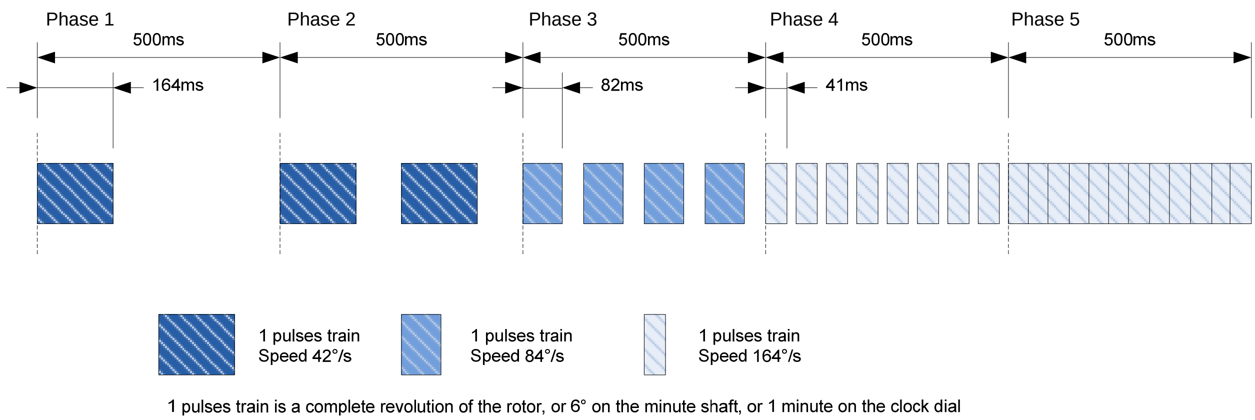


Figure 16: Acceleration diagram

During phase 5, the pulse 6 has to be omitted to obtain a continuous movement of the pointer.

4.3 Current consumption

There are two contexts where the current consumption has to be taken in count. While the motor is moving and while is on the position to indicate time (hour/minute).

When is moving the current consumption is given by the Coils characteristics (resistance and inductance). The current consumption is directly connected to the torque produced during the movement and can not be changed.

When the motor is standing on the position to indicate time, the X10.504 has a special structure which gives an holding torque to keep pointers in place. This doesn't need power supply and saves current consumption.

This reduces dramatically the mean value of the current consumption. According to previous diagrams on driving methods, the consumption is "active" only during the application of the pulses train. During left time before next minute there is no power consumption needed. Finally the current consumption is divided by the ratio between pulses train duration and 1 minute (time between each movement).

5 Connection with a pointer

The physical link between the pointer and the shafts is a key point. On the X10.504 we have two differente shafts, one metallic for the minute hand (pointer) and one plastic for the hour hand (pointer).

5.1 Pointer shape

For the metallic shaft (minute hand) it is suggested a geometry for the hole in the pointer as follow:

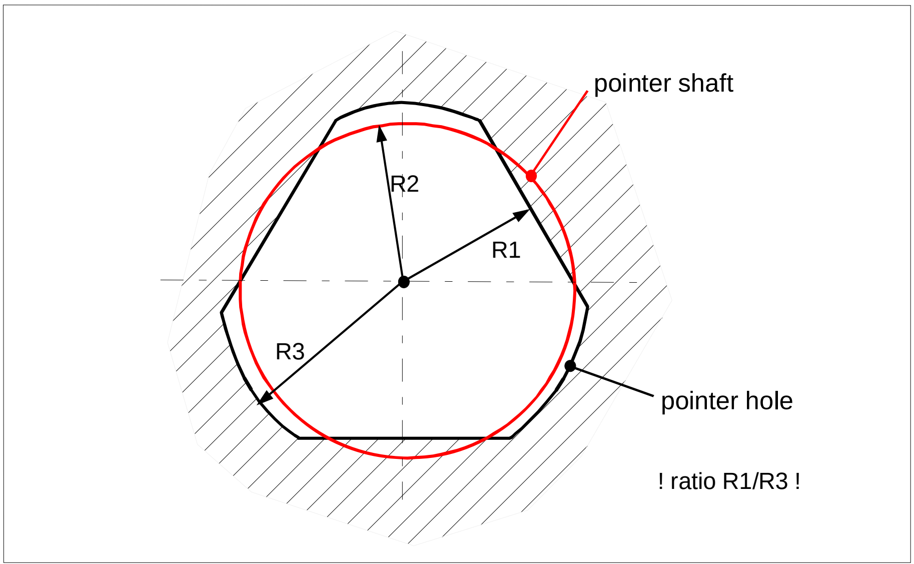


Figure 17: Pointer hole geometry

+ High holding torque
+ Low insertion force
+ Larger tolerances of the parts
+ Very high process capability

For the plastic shaft (hour hand) it is suggested a geometry with a minimum of 5 sided polygon. A round shape is also possible with accurate tolerances.

5.2 Pointer stacking

The mounting of the hands on the shafts is usually done in a pressing operation. When using this technique, care should be taken that the forces (FA and FQ) do not exceed those given in the specifications.

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 X10.504 motor!
A typical mistake is to apply compressed air on the motor for cleaning purpose and making the pointer accelerating and damage the internal gear train.

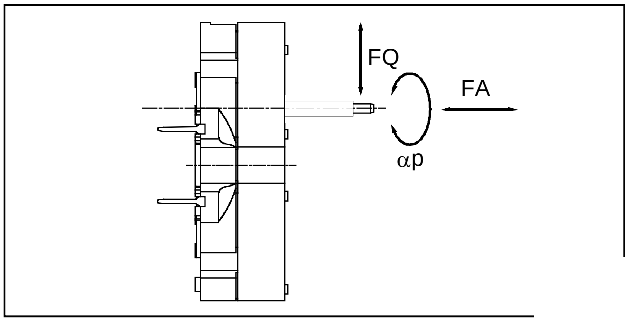


Figure 18: Forces on the pointer shafts

5.3 Pointer alignment on ACC

When the two pointers are placed on the shafts of the X10.504 stepper motor, to avoid misalignment it is recommended to compensate the gear play with a forward-backward-forward movement. See below sequence:

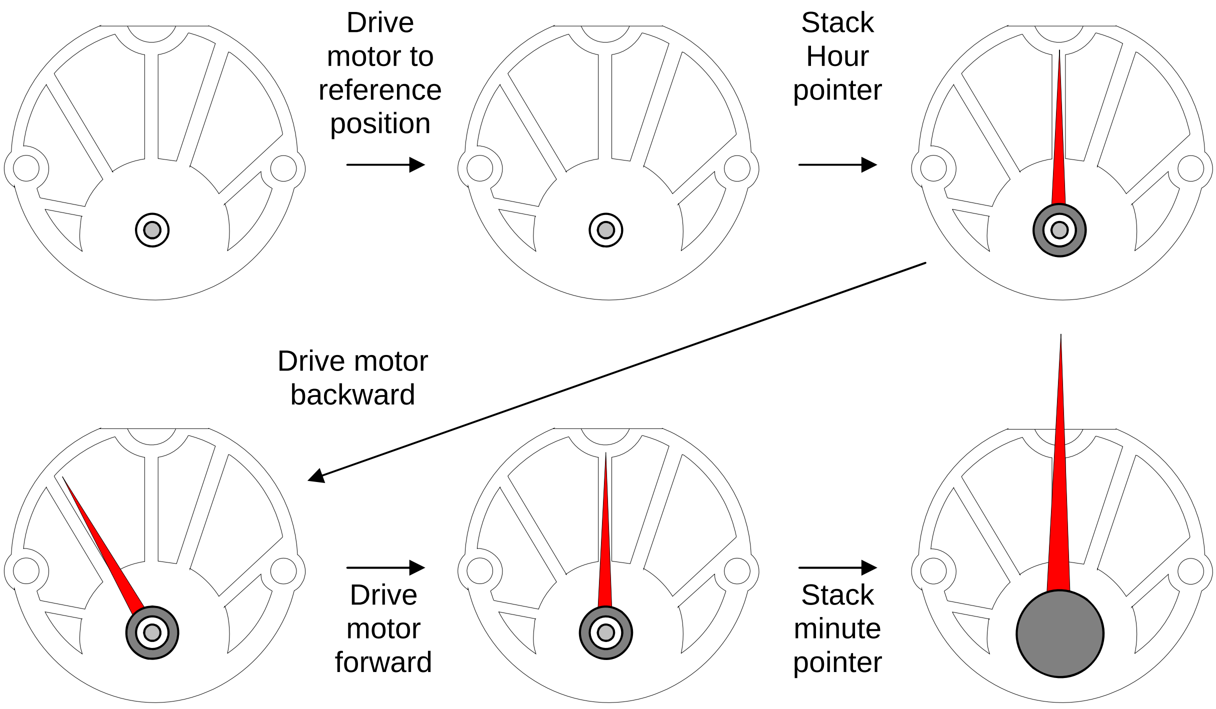


Figure 19: Alignment of hour / minute pointers

6 Components for detection

The detection of the reference position is based on optical principle. Due to materials used in the motor we recommend Infra-Red (IR) light beam. Tested, verified and suggested components are mentioned in following sub chapters. Customers are free to use others components according to their needs and performance specifications.

6.1 IR-LED recommendations

The X10.504 has been designed, tested and validated with a IR-LED from VISHAY, model VSMB2020x01. See manufacturer specifications for details. The IR-LED has to be supplied with constant current to produce constant light intensity. Below application examples:

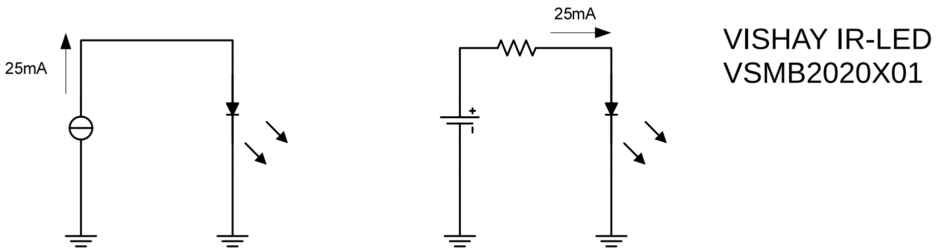


Figure 20: IR-LED schematic example

The nominal current of the IR-LED from VISHAY is 100mA but we suggest to supply it at 25mA only to have better efficiency of the detection with the IR-sensor.

6.2 IR-sensor recommendations

Many possibilities exist to sens an Infra-Red light beam. A photo-diode or photo-transistor is the most common solution used. Below application example with a photo-transistor to bring cost effective electronic circuitry:

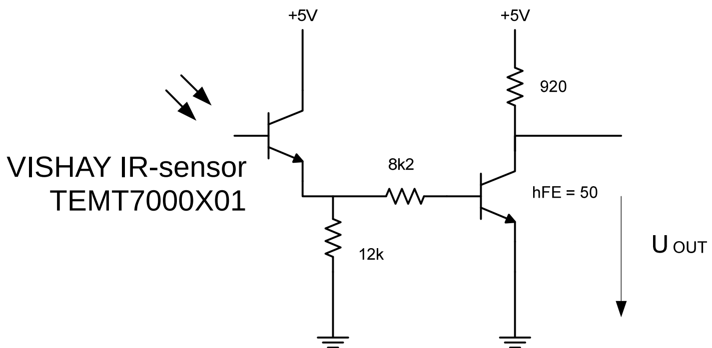


Figure 21: IR-sensor schematic example

Values of components can be adjusted to tune the output signal level in function of the supply voltage (+).

7 Physical dimensions

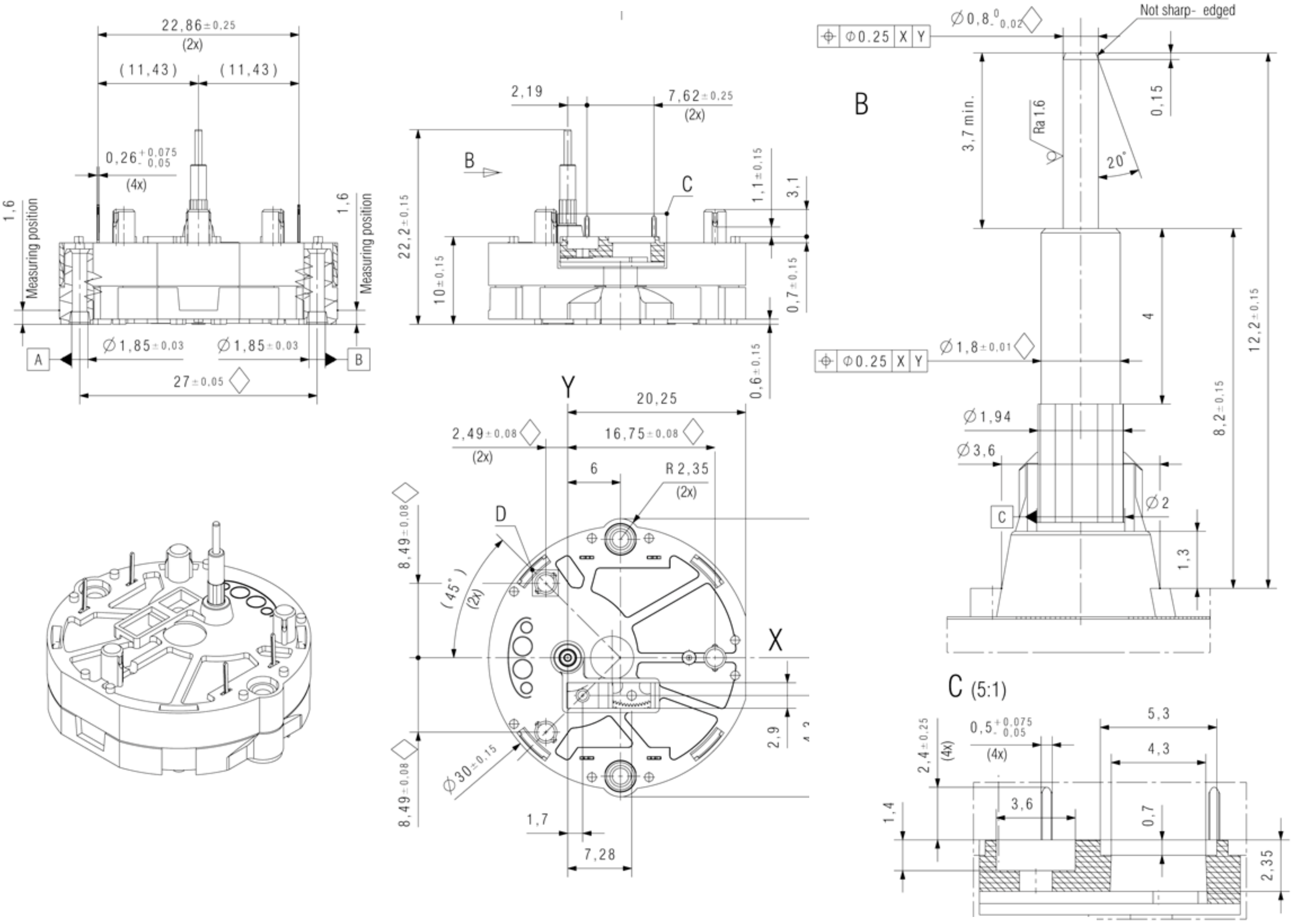


Figure 22: X10.504 physical dimensions

8 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}	105°C
Solder temperature (10 sec)	T_s	260°C

Table 1

Stresses beyond these listed maximum ratings may cause permanent damage to the X10 stepper motor . Exposure to conditions beyond specified operating conditions may affect the X10 stepepr motor reliability or cause malfunction.

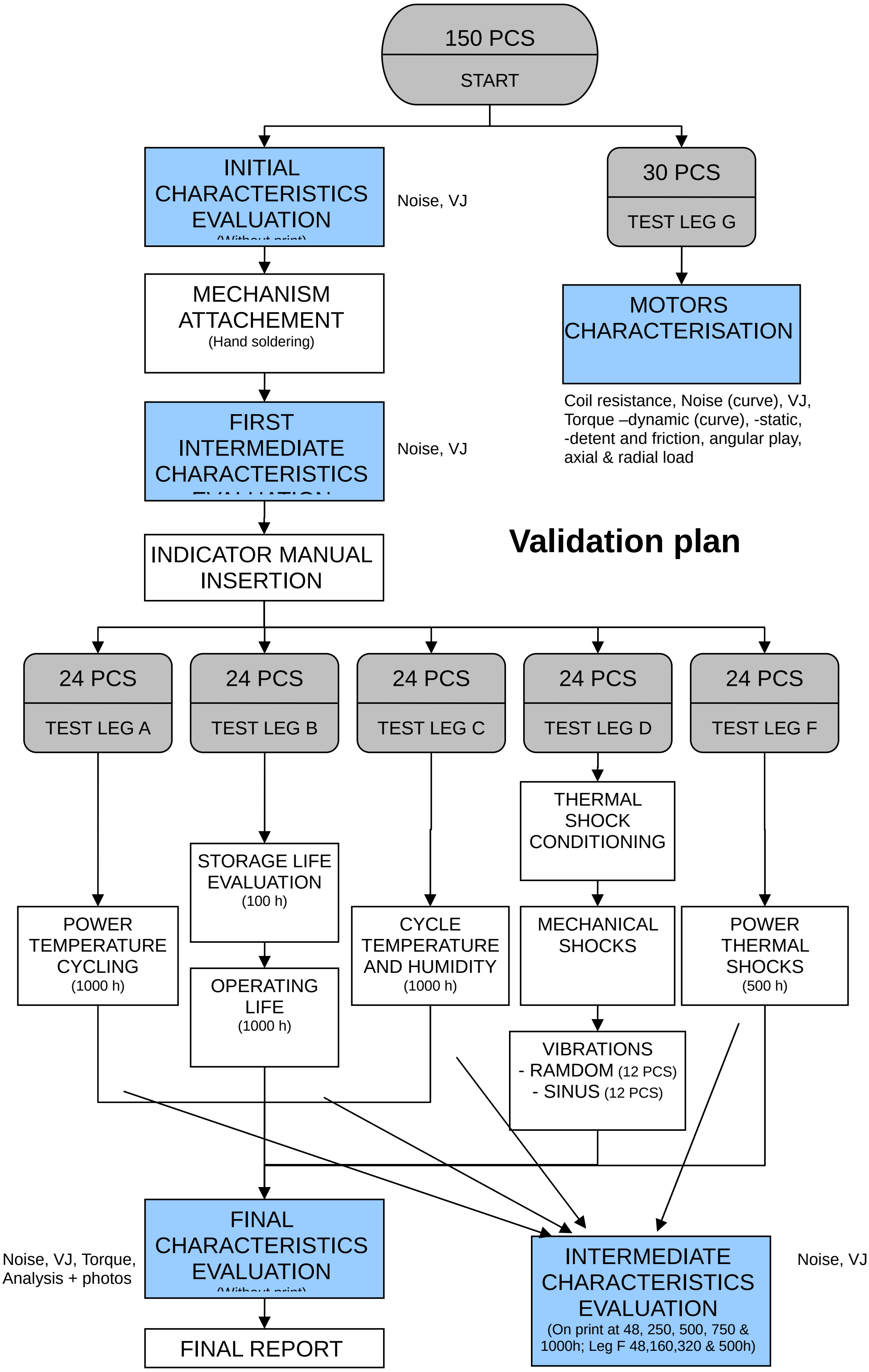
8.1 Electrical and Mechanical Characteristics

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	@ T = 20°C	260	290	320	Ω
Operating current	i_m	@ fz = 16 Hz		17	20	mA
Magnetic saturation voltage	U_{bs}			9		V
Dynamic torque (on minute shaft)	M_d	@ f_z = 25 Hz		0.4		mNm
Static torque (on minute shaft)	M_s	@ U_b = 5V		0.5		mNm
	M_0	@ U_b = 0V		0.15		mNm
Gear play				0.7	1	Degree
Forces allowed on the pointer shafts :						
Axial force	F_A				100	N
Radial force	F_Q				4	N
Noise level impulse	SPL	1 pulse train each 0.5 s		42	50	dB

Table 2

9 Tests description and conditions



Driving Cycle

The Driving Cycle consists to rotate the clocks during the 1000 h of test so many times than they do during 15 years of life. That means that the clocks are moving of 1 minute (1 pulse train) each 0.5 second.

Specific Test Conditions

Test Leg A: Power Temperature Cycling

Defect free functioning after passing 1000 h in Temperature Cycling Test during which the clocks are driven.
The temperature cycle consists of ½ h at 85°C, ½ h to cool down to -40°C, ½ h at -40°C and ½ h to return to 85°C. The time of each cycle is 2 h.

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 clocks without rotation at -40°C during 100 h. After this time all the clocks must start correctly without step loss.
The Operating Life consists of a permanent temperature at 85°C during which the clocks are driving.

Test Leg C: Cycle Temperature and Humidity

Defect free functioning after passing 1000 h in Cycle Temperature and Humidity Test during which the clocks are driving.
The cycle temperature and humidity test consists of 8 h cycle as shown on the graph below.

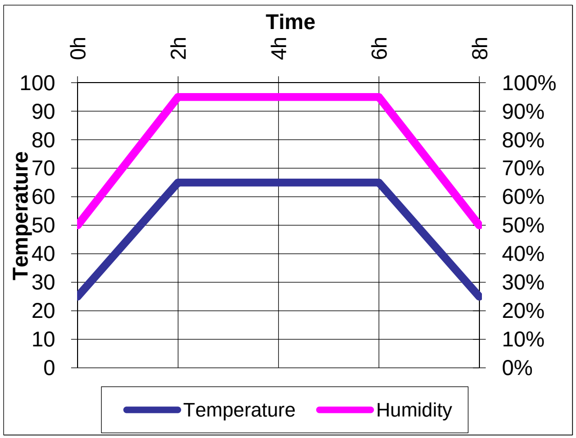


Figure 23: Humidity cycle

Test Leg D: Shocks and Vibrations Test

Defect free functioning after being subjected Shocks and Vibrations Tests.

Thermal shock conditioning

First, the clocks 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 clocks 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 20 g during 11 ms. The clocks are driving during this test.

Random vibrations

Previously subjected to thermal/mechanical shocks, 2/3 of the clocks 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 clocks 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 clocks are driving during this test.

Sinus vibrations

Previously subjected to thermal/mechanical shocks, 1/3 of the clocks 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 driving during this test.

Test Leg E: Power Thermal Shocks

Defect free functioning after passing the test 500 h in Power Thermal Shocks test.
The Power Thermal Shocks test consists of continuous sequential thermal shocks between 105°C and -40°C every 30 min during 500 h. The time between both extreme temperatures is < 30s.

Test Leg G: Motor characterisation

The measurements made in this Leg are available only to check if the motors which have to be qualified have always in the same characteristics and if the eventual modifications have an influence on them.

Coil resistance

The coil resistance test is mainly to know if the coil is open or not. The tolerances have to be respected. (See AA-370-21)

Noise

There are two different measurements.

1) The first is for the products under test Only the main speeds (50, 100, 200, 400 and 600°/s) are measured and the noise level has to be under the given limit when the product is new and measured without print. During the test up to the end, the noise level can increase, but only in the tolerable limit given.
2) The second is to make a curve of the noise level depending of the speed. This curve is measured from all speeds given by a Testbox III (16 speeds).
   The goal of this measure is to check if the noise level curve is always about the same. (See AA-370-22)

VJ

This is only a functional measurement. All the new motors have to pass in the corresponding limits. During a test or at the end, the limits can be passed. An analysis of the functionality can be made through the finding values. (See AA-370-23)

Detent torque

This measurement gives the detent torque. This is only an indication because the detent torque can be influenced by asked modifications or by the design itself. (See AA-370-24)

Pointer movement

The pointer movement is very subjective and there are no values to define a good or a bad movement. This indication can also be counted and a statistic of the good and bad can confirm or not the asked modification. (See AA-370-26)

Coupling flux

This value is given by the power of the magnet and by the magnetic circuit. This value is a check of the power of the magnet in our motors. (See AA-370-29)

Dynamic torque

This measurement gives the real torque on the output shaft.
This measurement has to be made after all other measurements because it is necessary to cut the internal stop before the measurement at all the speeds given by the Testbox III. (See AA-370-30)

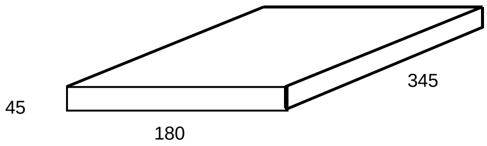
Static torque

For the same reasons than for the dynamic torque, this measurement has to be made after all other measurements. (See AA-370-31)

Loads

The motors have to be able to sustain the give loads without any deformation in accordance to the specs. The loads can be axial (push or pull force) or radial. (See AA-370-32)

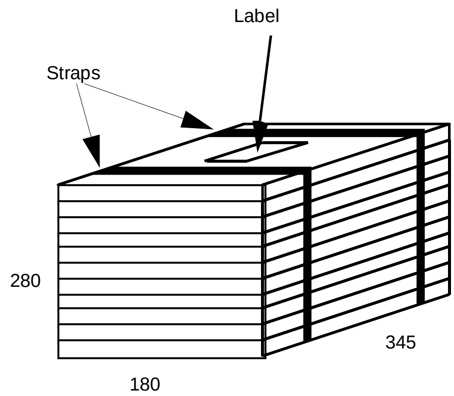
10 Packaging



Tray for 50 Analogue Car Clock Motor X10.504 :

Material: Polistyrene – Hardplastic

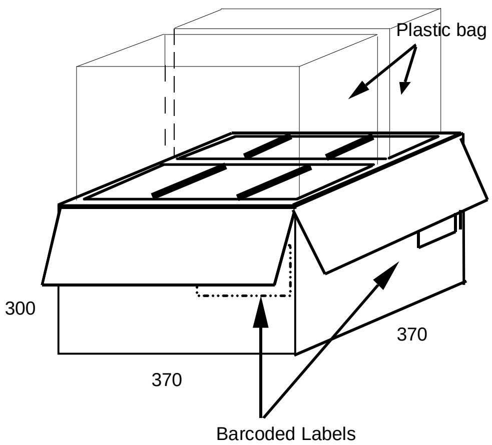
Weight:	Tray	1	x	210g	=	210g
	Motors	50	x	8.4g	=	420g
				Total	**=**	**630g**



Stack for 500 Motors:

Material: 11 Trays (including cover) strapped together with plastic band

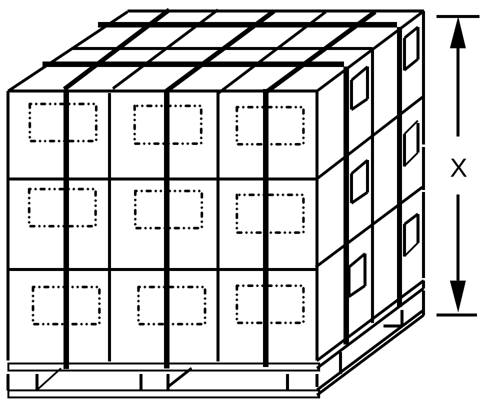
Weight:	Trays	10	x	630g	=	6'300g
	Cover tray	1	x	210g	=	210g
	Plastic strap	2	x	15g	=	30g
				Total	**=**	**6'540g**



Cardboard box for 1000 Motors:

Material: Cardboard 740 g/m^2

Weight:	Cardboard	1	x	900g	=	900g
	Plastic bag	2	x	50g	=	100g
	Stacks	2	x	6'540g	=	13'080g
				Total	**=**	**14'080g**



"Euro-Palette" for 6K/12K/18K/24K Motors:

Material: Euro-Palette (1'200x800x150)

Weight: Palette 1 x 20kg = 20kg

No. of layers	X	No. of motors	Weight *
1	450mm	6000	105kg
2	750mm	12000	189kg
3	1'050mm	18'000	274kg
4	1'350mm	24'000	358kg

*** Estimated maximum weights**

all Dimensions in mm

10.1 Product identification

Each motor is marked with a product number and its manufacturing date:

Table 3

Hour	Day	Manufact. place	Week	Year
00 | 23	1 | 7	Line 9 - Zhuhai > = Normal prod. \ = Special trace. < = Special trace.	01 | 52	0 | 9
		Line 12 - Zhuhai } = Normal prod. # = Special trace. { = Special trace.		

Table 4: Production code

Example:

114>32.9 This pieces has been produced during **11**th hour (from 11:00 to 11:59), on **4**th day (Thursday), **>** Line 9 in Zhuhai normal production, week **32** of 200**9**.

11 Table of Index

11.1 Document history

History of document editions:			
	Creation : Date / Abbreviation	Check : Date / Abbreviation	Release : Date / Abbreviation
1st edition - A	09.07.10 / R.Esposito	02.09.10 / D. Maeder	03.09.10 / G. Nambuseril
Revision - B			
Modifications purpose			
Revision - C			
Modifications purpose			
Revision - D			
Modifications purpose			

11.2 Lexic

ACC	Analog Car Clock
ASIC	Application Specific Integrated Circuit
CCW	Counter Clock Wise
CW	Clock Wise
IR	Infra-Red light
LED	Light Emitter Diode
PCB	Printed Circuit Board
PWM	Pulse Width Modulated
SMD	Surface Mount Device
X10	Product name

Parameter	Description	Unit
E	EMI tolerance	V/m
F_A	axial force on the pointer shafts	N
F_Q	radial force on the pointer shafts	N
Gnd	ground	-
I_b	coil current	A
i_m	operating current	mA
L_m	measurement distance	cm
m	mass of the driven load	g
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
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_m	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