PIEZO LEGS™ DRIVER

PDA 3.1

DATA AND USER INSTRUCTIONS

PiezoMotor®

CONTENTS

GETTING STARTED

GETTING STARTED

To get started with the PDA 3.1 driver follow the procedure below:

1 Put the driver in front of you. The figure below shows the front side of the PDA 3.1 with its connectors.

2 Connect the PDA 3.1 to a Piezo LEGS™ linear or rotating motor (e.g. nr 200006) with a motor cable (e.g. nr 200007). The motor connector is short circuit proof.

3 IMPORTANT NOTE before connecting the +12 V, Rst and An terminals:
The +12 V terminal is not overvoltage protected and should be within ±0.5 V.
The An signal should not exceed ±20 V and the Rst signal should be open collector (active low).

4 Connect the +12 V and GND terminals on the PDA 3.1 to a stabilised 0.3 A power supply with an output voltage of 12 ± 0.5 V.

5 Connect a ±10 V adjustable voltage source to the An and GND terminals.

PDA 3.1

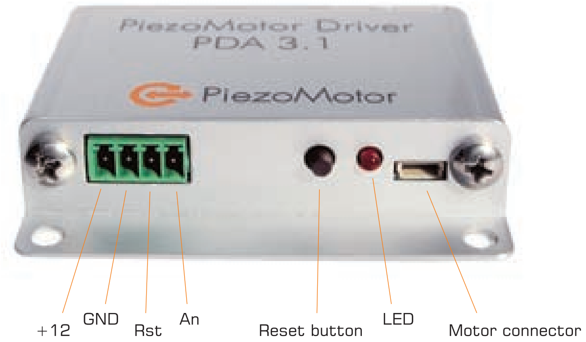
GETTING STARTED

6 About 0.4 s after power ON, the driver checks the capacitance of motor phase 1. After this check, the LED is turned ON. If the LED remains OFF, please check the +12 V power supply.

7 The following error indication may occur:
If the LED starts to blink after power ON, this indicates that the motor capacitance check failed, e.g. no motor is connected.

8 After power ON the driver will wait until An=0 V in order to prevent motor motion if no external An signal is available.

9 Now the motor is ready to be run.

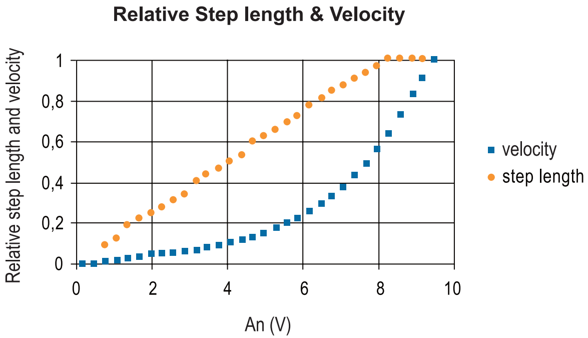


DRIVER

GETTING STARTED

10 Run the motor by varying the voltage of the An signal.

- For an An voltage level less than ±0.6V the motor motion is extremely slow, about 0.5 µm/s, with nanometer resolution. Below ±0.3 V the motor motion is stopped.
- For an An voltage level above ±0.6V the motor velocity is set according to the figure below. Positive voltages refer to forward motion.



Resulting relative step length and velocity for a given voltage level of the An control signal.

11 The reset button can be used for manually resetting the driver. This could be useful if e.g. there is a need to change the motor while the driver is powered up. By pushing the reset button, a new capacitance check is initiated. See also positions 5–7 above.

GETTING STARTED

12 Connecting the Rst terminal to ground will switch off the power for all driver logics. This can be used to implement an emergency stop. The external Rst signal should be open collector type.

13 The driver is shut down by simply disconnecting the power supply.

14 The driver specification is shown in the table on the right. For linear motors, the driving rod should preferably not be driven out of the motor. You may stop or move the rod by hand.

PiezoMotor Driver PDA 3.1 data

Dimension controller [mm] (L×W×H)	73.6×71×17.2
Weight [g]	70
Frequency range (430 nF/phase)[1] [Hz]	0–700
Waveform	Trapetzoidal
Capacity range motor phase (μF)	0.1–3
Analogue speed control[2] (V)	±9.6
Power supply voltage (stabilized) [V]	12±0.5
Power supply current, max. speed (A)	0.3
Standby current (mA)	<20
Number of motor phases	4
Phase voltage (V)	47±3
Operating temperature range [°C]	10–50
Storage temperature range [°C]	-25 to +85
Thermal protection on PCB	~70°C
Connections	Screw terminals

1) For calculation of maximum drive frequency for any given motor phase capacitance the product of the phase capacitance and drive frequency should equal 300 nF × kHz.

2) In each direction there are 32 speed channels, 0.3 V wide.

Specifications subject to change without prior notice.

PIEZO LEGS DRIVE PRINCIPLE

This section describes in detail the drive principle for Piezo LEGS linear motors.

Drive leg

The Piezo LEGS motor consists of a number of piezoceramic drive legs. The number of legs depends on the motor configuration. A drive leg can be considered as a piezoceramic bimorph. In principle, a bimorph can be described as two piezoelectric layers with one intermediate and two external electrodes electrically separated from each other. In this way, it is possible to activate each layer independently of the other by an electric voltage.

Figure 1 shows the two modes of motion, extension/contraction and bending, for a drive leg. In Fig. 1a, no voltage is applied to the drive leg. In Fig. 1b, a voltage is applied to the leg's right side. Due to the applied voltage (shaded blue), the right side will expand and cause the whole drive leg to bend to the left. Fig. 1c shows equal voltages applied to both sides. Compared with Fig. 1a, the drive leg has now made a linear expansion. Finally, Fig. 1d shows the opposite effect to that seen in Fig. 1b.

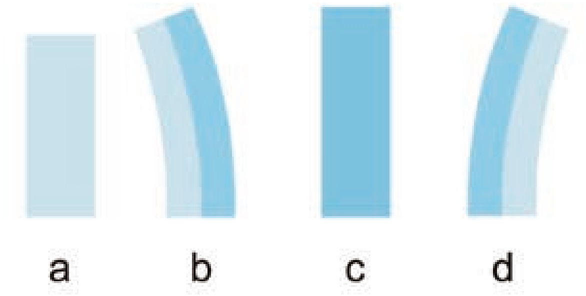
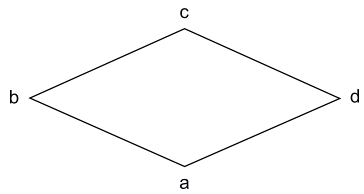


Fig. 1. The two modes of motion, extension/contraction and bending, of a drive leg. The blue shaded parts illustrate an applied voltage.

The tip of the drive leg can move arbitrarily within a certain area if no load is present. For an ideal bimorph and for small strokes, this area constitutes a rhomb. Fig. 2 shows the position for the tip of the leg with voltages applied as in Figs. 1a to d.

Fig. 2. The rhombic area within which the tip of the drive leg can move arbitrarily.



The bending x and extension/contraction z of a drive element can be written as:

$$
\begin{aligned}
x(t) &= k_1\left[u_1(t)-u_2(t)\right] \\
z(t) &= k_2\left[u_1(t)+u_2(t)\right]
\end{aligned}
\qquad (1)
$$

where k_1 and k_2 are constants depending on material, geometry, drive conditions, etc. If phase-shifted repetitive voltage signals are applied to the respective sides of the drive leg, the tip of the drive leg will move along a certain trajectory within the allowed motion area. As an example, drive voltages u_1 and u_2 are applied to the drive leg as shown in Fig. 3. The tip will traverse the sides of the rhombic area. The phase shift affects the geometry of the trajectory, in this case, the lengths of the major and minor axes. The optimum phase shift depends on drive conditions, geometry, material of the leg, etc., and has to be adapted for each individual application.

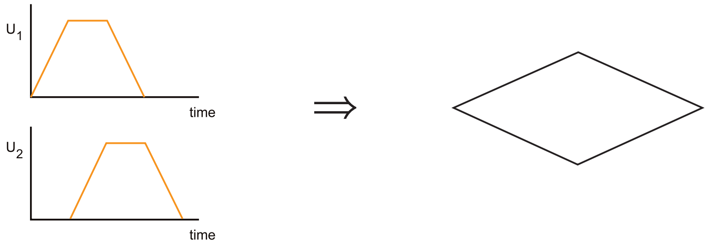
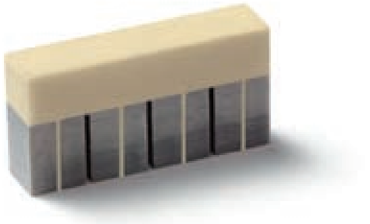


Fig. 3. Example of a trajectory due to drive voltages u_1 and u_2 applied to the respective sides of the leg.

The walking drive principle

The drive principle utilised by the motor is a non-dynamic type, i.e. the position of the drive legs is known at every given moment. Fig. 4 describes the walking principle. A darker blue shade at the side of a drive leg represents a higher applied voltage. Consider a motor element as two pairs of drive legs that operate independently. Imagine that drive legs a and c are the drive legs of the first pair. These legs work synchronously. Similarly, drive legs b and d belongs to a second pair and also work synchronously. The sequences shown on the right, when repeated in the form of a cycle, result in a transportation of the moving object.

Four characteristic sequences of motion are easily distinguished. In Fig. 4a, the drive legs of the first pair are in their gripping sequence. The moving sequence takes place from Figs. 4a to 4d. In Fig. 4d the drive legs of the first pair are in their releasing sequence. Eventually the return sequence takes place from Figs. 4d to 4a. In theory, the gripping and releasing sequences could be almost indefinitely short, but in reality, gripping and releasing take place during a certain time period.



A motor element consists of a number of drive legs.

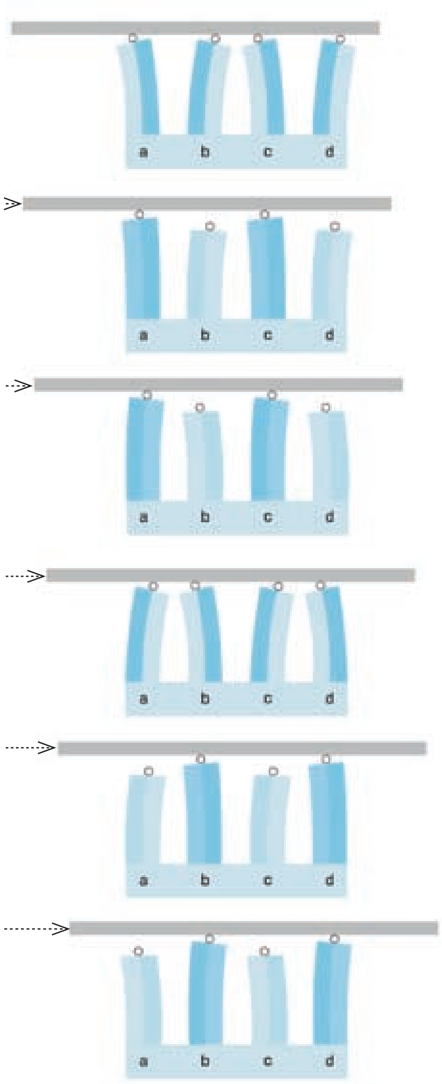


Fig. 4. Schematic illustration of the walking drive principle.

a A drive cycle starts with both pairs of drive legs in contact with the drive rod. The legs of the first pair (a and c) are bent to the left and the legs of the second pair (b and d) are bent to the right.

b The legs of the first pair move in an upper right direction. In contrast, the legs of the second pair move in a lower left direction. This means that the drive legs of the second pair will loose contact with the drive rod, and that the drive rod will follow the motion of the drive legs of the first pair.

c After some time the drive legs have changed their motion. The drive legs of the first pair will now move in a lower right direction and the drive legs of the second pair will move in a upper left direction.

d The change of motion of the two pairs of legs means that the second pair will come in contact with the drive rod again but now at a slightly different position.

e The legs of the second pair (b and d) now move in an upper right direction, while the legs of the first pair (a and c) move in a lower left direction. The result is that the drive legs of the first pair loose contact with the drive rod, which follows the motion of the second pair.

f After some time the drive legs have changed their motion again. Those of the second pair move in a lower right direction. The legs of the first pair move instead in an upper right direction.

Driving the Piezo LEGS Motor

From the description of the drive leg, it can be seen that two phases are needed to achieve motion. The walking drive principle showed that two further drive phases are needed since two independent pairs of drive legs are used in the motor. For each drive leg, the applied signals are phase-shifted relative to each other to the respective sides of the drive leg. The phase shift is normally set at 90°, and the phase shift between the two pairs of drive legs is normally 180°. Fig. 5 schematically illustrates the phase shift between drive voltages. The solid lines correspond to one pair of drive legs and the dashed lines to the other.

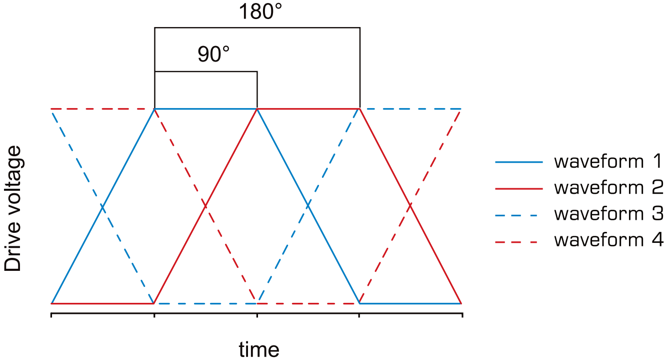


Fig. 5. Normal phase shifts between drive voltage signals.

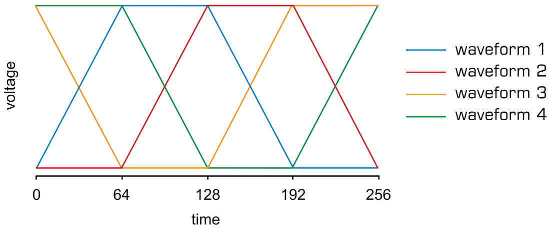
PDA 3.1 PIEZO MOTOR DRIVER DESIGN

An inexpensive and small footprint piezomotor driver has been developed. This section describes and discusses aspects of the design used in the PDA 3.1 driver.

Waveform and resolution

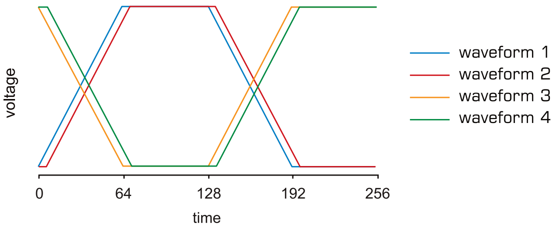
As mentioned above, the motor consists of two pairs of drive legs. Each pair is controlled by two analogue signals normally having a voltage span of approximately 50 V. From an electrical point of view, the four motor phases may be considered as capacitors. Each phase of the standard Piezo LEGS linear motor has a capacitance in the order of 400 nF. The four capacitive motor phases are cycled up and down in voltage. Consider a waveform 1 (for motor phase 1). Waveform 2 should then be a mirror of waveform 1, whereas waveforms 3 and 4 are identical to waveforms 1 and 2, but phase-shifted half a cycle (180°). Fig. 6 shows one example. As Fig. 3 above has demonstrated, this waveform makes the drive legs move along the rhombic trajectory. Note that the step length and linearity depend on external forces. A strong external force opposing the motion can decrease the step length to almost zero, whereas the step length in the other direction is enhanced.

Fig. 6. Waveform to make the drive legs move along a rhombic trajectory.



Better resolution is often preferable to maximum cycle step length. The step length can thus be made shorter by adjusting the phase shift between the waveforms. For example, the waveform in Fig. 7 gives around 10% of the step length of the waveform given in Fig. 6.

Fig. 7. Waveform giving a reduced step length.



However, fine-positioning at a level better than about 5% of maximum step length requires another solution, otherwise the “zigzagging” around the target position may be unacceptable.

The maximum cycle step-length for the motors is normally in the range 4 to 8 μm. By using the phase-shift method, the resolution may at best be of the order of 200 nm. However, increased resolution can be obtained by operating one pair of drive legs in a bending mode. At the same time the other pair is inactive. This type of bending gives a motion range of 1–3 μm with nanometer resolution.

PDA 3.1 schematics

The driver uses constant motor phase currents to produce waveforms similar to the ones shown in Figs. 6 and 7, whereas the final fine-positioning is done in a special mode. This kind of driver is used in the PDA 3.1. The driver is schematically shown in Fig. 8.

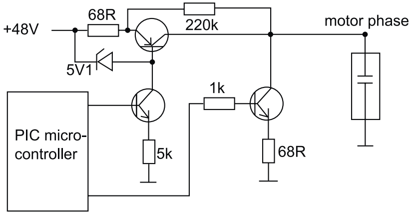


Fig. 8. Schematic drawing for a driver with a small footprint.

THE PDA 3.1 INTERFACE

This driver is intended for use with standard piezo motors provided by PiezoMotor AB and the driver outputs are designed not to stress the motors beyond their specifications.

All that is needed to use the driver is a DC power supply (12 V 0.3 A) and an analogue control voltage (±9.6 V DC) which can be a part of a closed loop controller design. The velocity will depend on the magnitude of the applied control voltage whereas the direction will be according to the polarity.

Figure 9 shows the front side of the PDA 3.1. The connectors, LED and push-button is described in more detail below.

Fig. 9. Front side of the PDA 3.1 driver.

Connectors

Control/Power Supply socket

The green 4 pole socket should preferably be interfaced using a matching plug (Phoenix).

+12	DC Power Supply input (12 V 0.3 A)
GND	Ground reference for both power supply and control signals
Rst	The reset control signal
An	The analogue control signal (±9.6 V) sets the motor velocity

Motor connector

The male connector used in the driver is a JST SR connector which is interfaced with a JST SR female connector model 05SR-3S. Model SHR-05V-S female connector is an alternative. The female contact on the cable fits on the male counterpart on the motor and driver in one way only, which ensures that the motor is always properly connected to the driver.

LED – Power on

About 0.4 s after power ON, the driver checks the capacitance of motor phase 1. After this check, the LED is turned ON. If the LED starts to blink after power ON, this indicates that the motor capacitance check failed, e.g. no motor connected. If the LED remains OFF, please check +12 V supply voltage. After power on the driver will wait until An = 0 V in order to prevent motion if no external signal is available.

Reset button

The brown push button next to the LED can be used for manually resetting the driver. This could be useful if e.g. there is a need to change the motor while the driver is powered up. By pushing the reset button, a new capacitance check is initiated. Motor capacitance is temperature dependant and for optimum performance of the motor a new capacitance check is recommended if the motor temperature has changed more than than about 30 ºC. Pushing the reset button will also deactivate the motor driver outputs and can thus be used as an emergency brake. Note that the An signal must be 0 V until motor motion can start again after an emergency brake.

Control signals

Connecting the Rst pin to ground will switch off the power for all driver logics. This can be used to implement an emergency stop. The external Rst signal should be of the open collector type.

By applying an analogue signal of 0 to ±10 V, the motor velocity will range from 0 up to a maximum velocity which depends on the phase capacitance of the connected motor. For example, the standard Piezo LEGS linear motor with a power consumption of 5 mW/Hz will give a maximum drive frequency of about 700 Hz since at maximum motor velocity the power consumption for the PDA 3.1 driver is 3.6 W.

THE ANALOGUE CONTROL SIGNAL

The device controlling the ±10 V analogue signal should be able to provide 1 mA signal current (source/sink). The driver converts the voltage into 32 velocity channels in each direction. In the text below, only positive (Forward) voltages are discussed. Negative voltages give an equivalent behaviour but in the reverse direction. Each velocity channel is 0.3 V wide. For the first velocity channel, 0–0.3 V, motor motion is stopped. Below 0.6 V is a bending mode which can give slow motion at very high resolution, whereas a velocity command >0.6 V gives a fast stepping mode. The voltage range and corresponding drive mode are shown in Table 1 and further described below.

Table 1. Voltage range and corresponding drive mode (only positive voltages are given in the table)

Voltage range	Mode
0–0.6 V	Bending mode (motor motion is stopped at <0.3 V)
0.6–10 V	Stepping mode

Bending mode 0 < An < 0.6 V

This mode is for fine positioning, with the ability to reach nm resolution. With an An signal in the range 0–0.3 V the motor motion is stopped. When entering the bending mode, the velocity is set relatively high in order to reach a target position quickly. After the first target overshoot, a much lower velocity will be chosen. This will ensure negligable overshooting even for a slow sensor feedback on the nm level. It may take several seconds though, before the position is steady on the nm level.

If the maximum bending range is exceeded, the driver will issue a “parking” sequence, i.e. the drive leg is returned to its centre position, and thereafter continues to bend. This may cause some minor positional fluctuation. After parking, the driver starts with a relatively high velocity.

Stepping mode 0.6 V < An < 9.6 V

In stepping mode, the average velocity is governed by both cycle step length and the delay after each drive cycle. As seen in Fig. 10 the step length is linear to An, reaching maximum length at ±8 V. A signal of ±9.6 V is enough to reach maximum velocity, whereas higher voltages are acceptable, e.g. ±12 V.

After each step cycle, there is a delay according to the An signal, whereafter the step length for the next cycle is determined from a lookup table. At minimum velocity, the step delay is around 9 ms. The resulting step frequency depends on the step cycle time as well, which is roughly 1.5 ms using the standard linear motor (depends on motor phase capacitance). The velocity can therefore differ somewhat from the curve shown in Figure 10. A 0.3 ms delay is inserted before the first step to allow the analogue signal to settle, and an extra 5 ms delay is added after the first step in order to make one-step operations easier. In order to minimize overshoot tendencies at target position, the An-signal is checked for a stop command (An<0.6) after every half step cycle, in which case the remaining step cycle will be truncated. However, a detailed control of the cycle step length is only done at the end of each full cycle.

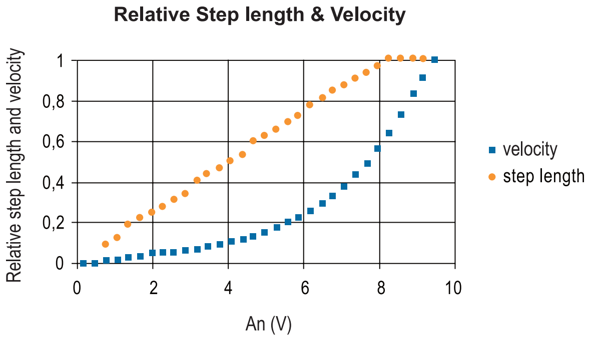


Fig. 10. Resulting relative step length and velocity for a given voltage level of the An control signal.

Additional notes for the analogue control signal

If the analogue signal is lost, the floating An pin will make the driver run at slow velocity. This can be avoided by connecting/soldering a 2k7 resistor between the An pin and ground, although this enhances the analogue signal current about five times.

The driver reacts to changes in the analogue signal within 0.3 ms. The first step mode channel (0.6 … 0.9 V) is a special case though, and the signal is monitored for an additional 1 ms. If the signal returns to bending mode, the driver will stay in bending mode. It will however assume a new target position and set the bending velocity high. The velocity for continous finewalking in bending mode is around 0.5 μm/s using the standard linear Piezo LEGS motor.

USING THE PDA 3.1 DRIVER

Manual operation

The driver can be tested manually to give a first hint on performance. Connect the motor and power supply, and connect a wire between the An pin and the Gnd pin. Then disconnect the wire, whereby the floating An signal results in a slow forward motion of the motor. Connecting the An pin to +12 V results in maximum forward speed, whereas connecting the An pin to Ground via a 10k resistor will run the motor very slowly, of the order of 0.5 μm/s using standard linear Piezo LEGS motor. For linear motors, the driving rod should preferably not be driven out of the motor. You may stop or move the rod by hand and feel the motor force.

Sensor feedback drive

Automatic sensor feedback requires a PC with the ability to read the sensor signal and control the analogue signal. Stand-alone controllers can be used as well. The analogue command signal should simply be proportional to the positional error. 8 V gives the maximum step length. If the maximum cycle step length for the motor is 6 μm, then set the proportional gain to around 8 V/6 μm=1.3 V/μm. The analogue gain factor can be tuned experimentally. If there are severe target overshoots then reduce the gain. This initial positioning should result in a positional error less than 1/30 of the maximum cycle step length (typically 200 nm using Piezo LEGS linear motor).

A typical procedure for reaching a target position may look like the following: First the driver is used in stepping mode for a quick close in on the target position. As the position error becomes smaller, the An voltage is set according to the gain factor, and when the An signal drops below 0.6 V the driver enters the bending mode. This will close in further to the target until the signal goes below 0.3 V, typically at 200 nm using the standard Piezo LEGS linear motor. One must then increase the gain in order to reach nm precision, but still avoid entering the stepping mode. For a standard Piezo LEGS linear motor the gain can be as high as 0.2 V/nm. To avoid entering the stepping mode the maximum voltage for the An signal must be limited to ±0.5 V.

HANDLING THE PIEZO LEGS MOTOR

This section describes how to handle the motor properly.

Connectors

The male connector used in the motor is a JST SR connector model BM05B-SRSS-TB. Fig. 11 shows schematically the mounting of the male connector in the motor.

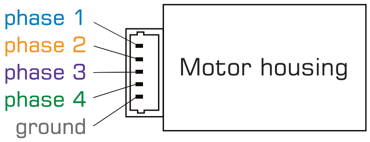


Fig. 11. Schematic drawing showing the male connector mounted in the motor. The configuration of the motor phases is also shown.

The connector configuration of the pins for the motor drive (shown in Fig. 11) is, from top to bottom; phase 1, 2, 3, 4 and ground. Phases 1 and 2 correspond to one pair of drive legs and phases 3 and 4 to the other pair. Normally, the phase shift between the phases should be; phase 1: 0°, phase 2: 90°, phase 3: 180° and phase 4: 270°.

The female connector used is a JST SR connector model 05SR-3S. Model SHR-05V-S female connector is an alternative. The female contact on the cable fits on the male counterpart on the motor in one way only, which ensures that the motor is always properly connected to the drive control unit.

Running the motor

Do not run the drive rod out of the bearing holder when running the motor as this may damage the drive pads if repeated frequently. The speed of the motor can be controlled by varying the drive frequency. The normal force exerted on the drive rod by the springs sets the holding force of the motor.

Cleaning the drive pads and drive rod

The drive pads of the motor and the drive rod are made of aluminum oxide. These surfaces are precision lapped and should not be cleaned or polished using any kind of abrasive cleaner. Use ethanol or a mild detergent to clean the drive pads and acetone to clean the drive rod. Note that acetone may damage the motor and is thus not recommended for cleaning the drive pads.

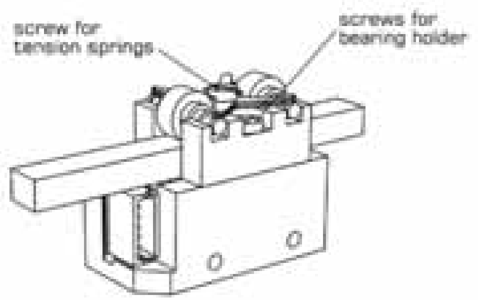
Removing the bearing holder

Removing the bearing holder is necessary when the drive rod is run out of the bearing holder and when changing the drive rod or the springs. The bearing holder also needs to be removed to clean the drive pads or the drive rod. The bearing holder is fixed in place by two screws on the top of the holder (see Fig. 20). Loosen both carefully and remove the bearing holder and the drive rod. When reassembling the holder, tighten the screws with moderate torque.

Disassembling the springs from the bearing holder

Tension springs may be replaced or the number of springs changed to increase or decrease the holding force of the motor. First remove the bearing holder from the motor. Loosen the top screw of the bearing holder and disassemble the springs (see Fig. 12). Be sure to center the springs properly when reassembling. Tighten the screw with moderate torque.

Fig. 12. Schematic view of a Piezo LEGS linear motor showing the screws for the bearing holder and springs.



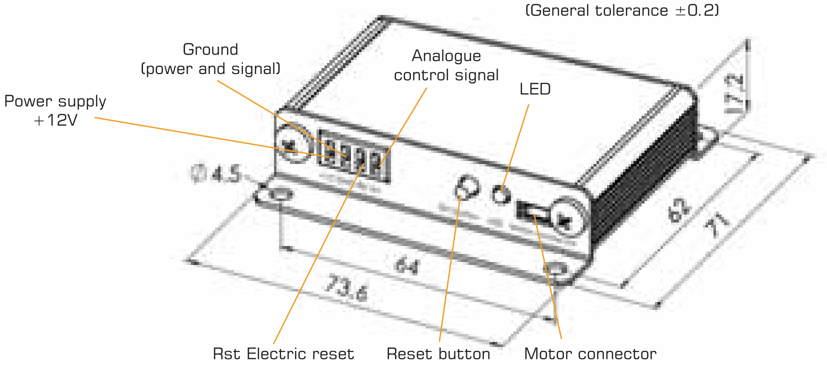
PiezoMotor Driver PDA 3.1 data

Dimension controller [mm] (L×W×H)	73.6×71×17.2
Weight [g]	70
Frequency range (430 nF/phase)[1] [Hz]	0–700
Waveform	Trapetzoidal
Capacity range motor phase (µF)	0.1–3
Analogue speed control[2] (V)	±9.6
Power supply voltage (stabilized) [V]	12±0.5
Power supply current, max. speed (A)	0.3
Standby current (mA)	<20
Number of motor phases	4
Phase voltage (V)	47±3
Operating temperature range [°C]	10–50
Storage temperature range [°C]	-25 to +85
Thermal protection on PCB	~70°C
Connections	Screw terminals

1) For calculation of maximum drive frequency for any given motor phase capacitance the product of the phase capacitance and drive frequency should equal 300 nF × kHz.

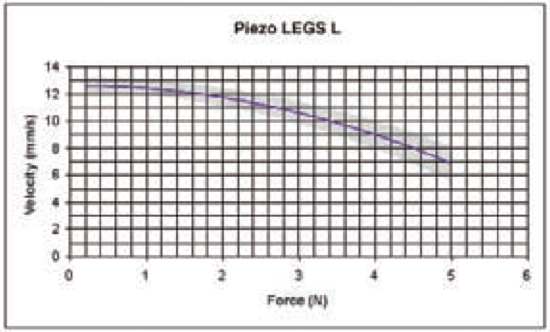
2) In each direction there are 32 speed channels, 0.3 V wide.

Specifications subject to change without prior notice.



Piezo LEGS L – Linear Piezo Motor data

Dimensions [mm] (L×W×H)	Complete 22×10.8×18	Phase voltage[3] [V]	0 to +42
Weight [g]	Complete 20	Resolution[4] [nm]	2
Velocity[1] [mm/s]	12.5 (2100 Hz)	Maximum step length[5] [μm]	3
Frequency range[1] [Hz]	0–3000	Stroke[6] [mm]	35
Force[2] [N]	Stall force 6.4 Holding force 7.3	Phase capacitance at 22 °C[7] [nF]	430
		Power consumption[8] [mW/Hz]	5
		Temperature range [°C]	-20 to +70



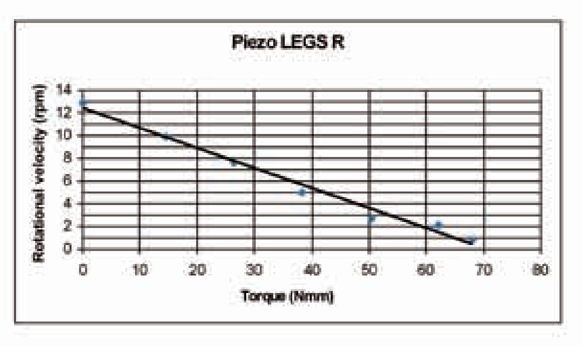
Motor performance for a drive frequency of 2100 Hz. The gray area expresses one standard deviation for the motor data.

1) The velocity is given at zero load. Absolute maximum drive frequency 3 kHz.
2) Force ± 10%
3) Maximum allowed phase voltage is 50 V.
4) Dependent on phase voltage resolution (approximately 35 nm/V).
5) Maximum ±10 % step length variations at zero load.
6) Stroke dependent on length of drive rod. Longer drive rod available on request.
7) Capacitance at 22 °C ± 5%. Capacitance at -20 °C approximately -20% and at 70 °C approximately +40%.
8) Dependent on drive electronics. The power consumption may be up to 70% lower using energy recovering electronics.

Specifications subject to change without prior notice.

Piezo LEGS R – Rotating Piezo Motor data

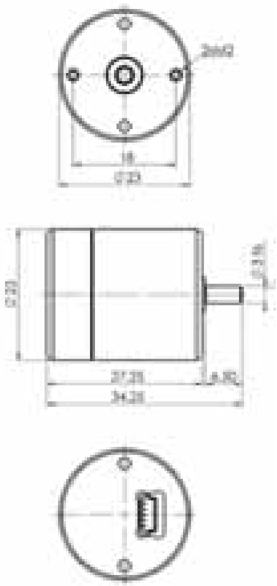
Dimensions [mm] (L×D)	32×23	Phase voltage[3] [V]	0 to 42
Weight [g]	70	Resolution[4] [µrad]	1
Rotational velocity[1] (rpm)	13 (2100 Hz)	Maximum increment[5] [mrad]	0.35
Frequency range[1] [Hz]	0–3000	Phase capacitance[6] [nF]	700
Torque[2] [Nmm]	Stall torque 70 Holding torque ≥ 80	Power consumption[7] (mW/Hz)	7.5
		Temperature range [°C]	-20 to +70



Motor performance for a drive frequency of 2100 Hz.

1) The rotational velocity is given at zero load. Absolute maximum drive frequency 3 kHz.
2) Torque ± 10%
3) Maximum allowed phase voltage is 50 V.
4) Dependent on phase voltage resolution (approximately 4 µrad/V).
5) Maximum ±10 % increment variations at no load.
6) Capacitance at 22 °C ± 5%. Capacitance at -20 °C approximately -20% and at 70 °C approximately +40%.
7) Dependent on drive electronics. The power consumption may be up to 70% lower using energy recovering electronics.

Specifications subject to change without prior notice.



Piezo LEGS R dimensions

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