PIEZO

LEGS™

DATA AND USER INSTRUCTIONS

PiezoMotor®

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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.

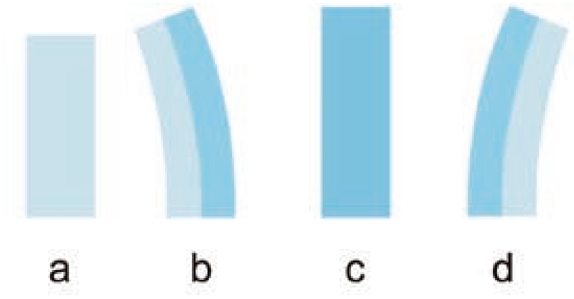
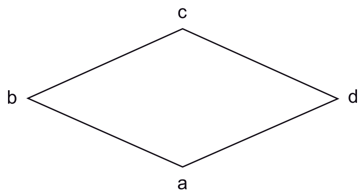


Fig. 1. The two modes of motion, extension/contraction and bending, of a drive leg. The blue shaded parts illustrate an applied voltage.

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 side 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 according to Fig. 3. In Fig. 3a, the tip will traverse the sides of the rhombic area. In Fig. 3b, the drive voltages are phase-shifted sinusoidal voltages, which give an elliptical trajectory. The phase shift affects the geometry of the trajectory, in this case, the lengths of the major and minor axis. The optimum phase shift depends on drive conditions, geometry, material of the leg, etc., and has to be adapted for each individual application.

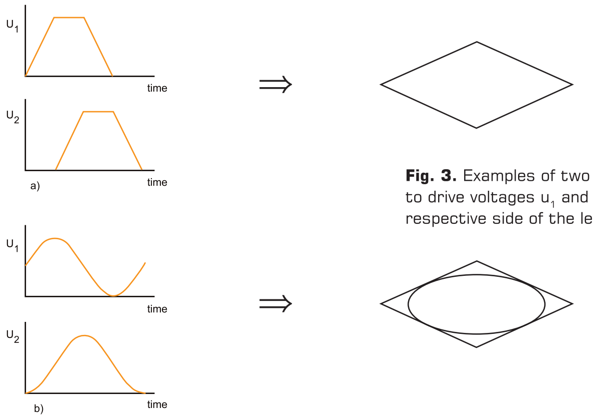


Fig. 3. Examples of two trajectories due to drive voltages u_1 and u_2 applied to the respective side of the leg.

The walking drive principle

The utilized drive principle of 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 a 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 at right, when repeatedly cycled, results 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.

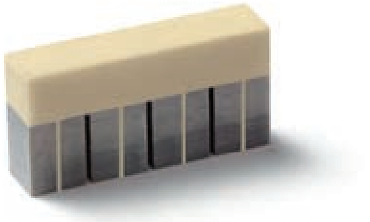
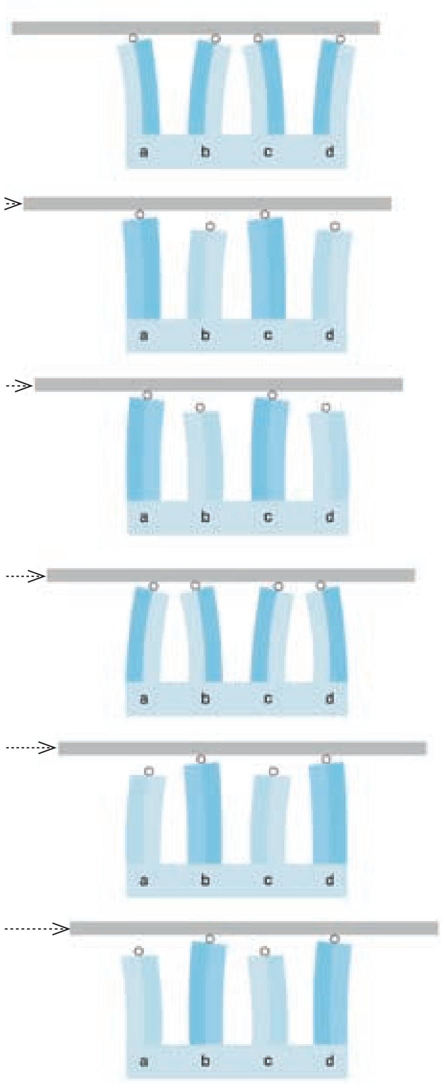


Fig. 4. Schematic illustration of the walking drive principle.



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 instead move in a 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 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, in this case with sinusoidal voltages. The solid line corresponds to one pair of drive legs and the dashed line to the other.

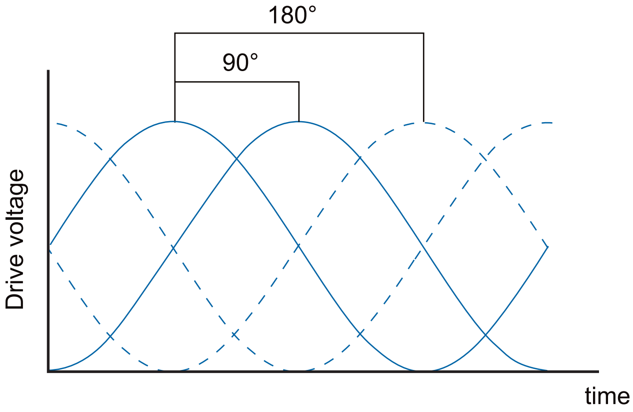


Fig. 5. Normal phase shifts between drive voltage signals.

PIEZO LEGS MOTOR CONSTRUCTION

Since the motor principle is based on friction forces between the drive rod and drive legs, a normal force is needed. There are a number of ways to create normal force, but using some type of spring is one of the simpler. The motor construction described below is for the demo-kit motor. This construction exemplifies the Piezo LEGS linear motor technology and can be altered and optimized for a given application.

In the Piezo LEGS linear motor, a minimum number of components are used, giving a simple and robust construction. The exploded view on the left of Fig. 6 shows the components of the motor. From the bottom to the top these are; the motor housing where the motor element and connector are mounted plus the drive pads (made of aluminum oxide) mounted on top of the drive legs, the drive rod, bearing holder, ball bearings and finally the springs. The drive rod is pressed against the drive pads via the ball bearings, which are preloaded with a certain force by the spring. The spring is mounted in the bearing holder, which in turn is screwed into the motor housing.

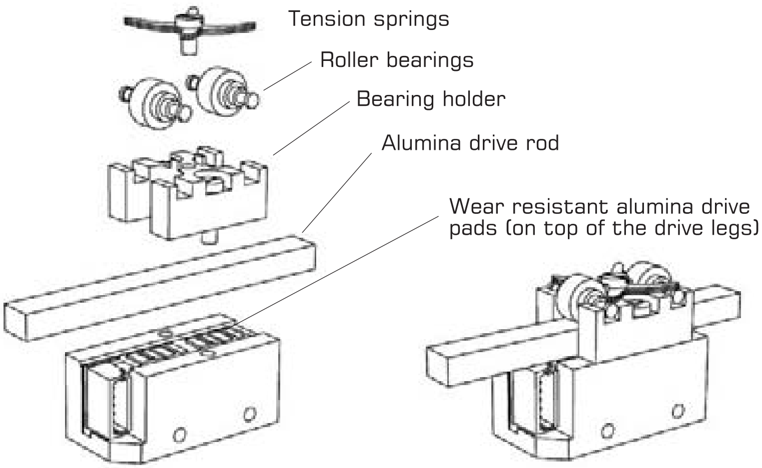


Fig. 6. The Piezo LEGS linear motor. The exploded view on the left shows the components for a complete motor. The assembled motor is shown on the right.

PIEZO LEGS MOTOR DRIVE DESIGNS

This section illustrates examples and discusses aspects of motor drive designs suitable for Piezo LEGS motors. In addition, one example of a simple positioning algorithm is given.

Waveforms and resolution

As mentioned above, the motor consists of two pairs of drive legs. Each pair is controlled by two analog signals normally having a voltage span of approximately 46 V. From an electrical point of view, the four motor phases may be considered as capacitors. Each phase of the Piezo LEGS demo 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 waveform 3 and 4 are identical to waveform 1 and 2, but phase-shifted half a cycle (180°). Fig. 7 shows one example. As Fig. 3 above has demonstrated, this waveform makes the drive legs move along the rhombic trajectory. Such a waveform is optimal for high speed, but the motion might be non-linear and a reversed direction of motion may occur during some parts of the drive cycle (gripping and releasing parts). Another waveform shown in Fig. 8 (only waveforms for one pair is shown) gives some 40% lower speed, but the motion is much more linear and even. 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.

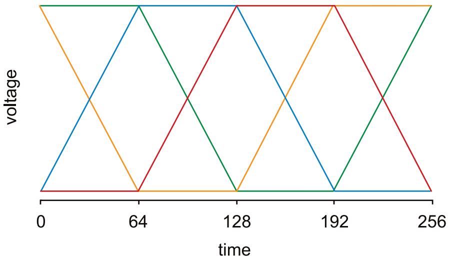
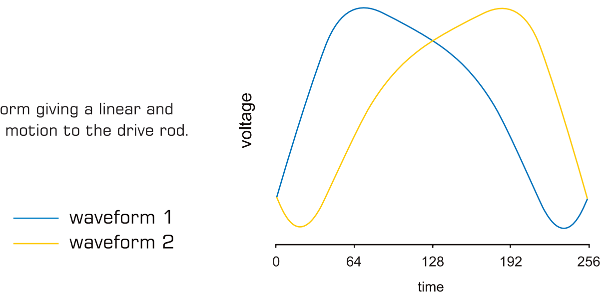


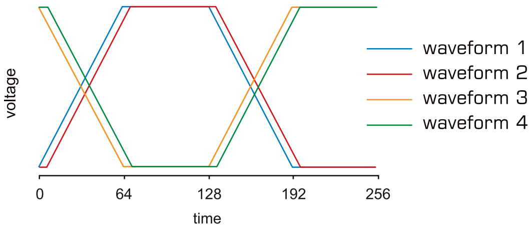
Fig. 7. Waveform to make the drive legs move along a rhombic trajectory.

Fig. 8. Waveform giving a linear and smooth, even motion to the drive rod.



Often, better resolution is 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. 9 gives around 10% of the step length of the waveform given in Fig. 7.

Fig. 9. 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. One solution is to divide the waveform into a number of points and step through the waveform point by point. This will be referred to as nano-stepping or the nano-step mode.

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 in the order of 200 nm. The nano-step mode can, however, increase resolution considerably. The achievable resolution will be a combination of the resolution of the D/A converter and the number of points in the waveform. Consider 256 points in a waveform, for example. This gives a resolution in the order of 20 nm (for a 4 μm cycle step-length). In this case, an eight-bit D/A converter gives high enough resolution.

Piezo LEGS drivers

Fig. 10 outlines a motor drive circuit suitable for nano-stepping. Here, waveforms 1 and 2 are stored in a 16-bit FPROM whose address is controlled by an 8-bit up/down counter. Further address lines can be used to select different waveforms. For instance, if the address clock speed gets too high for a control unit, a less resolved waveform with two or four full waveform cycles included in the 256 point address cycle can be chosen. Note, however, that changing waveform is recommended only when the two waveforms are close in voltage. If they are not, the drive legs may move and the position of the drive rod will be changed during change of waveforms. A suggested procedure is to design the waveforms to allow switching at address = 0. More address logic is needed if waveforms 3 and 4 are to be stored in the same FPROM. Furthermore, to avoid spikes, a capacitor may be connected over R1 and the motor phase may be connected via a low ohmic resistor. The voltage resolution must be considered with respect to the drive leg voltage response. If both waveform 1 and 2 are at +48 V, the corresponding drive leg is fully extended (see Eq. 1 page 3). If waveform 1 is set to 0 V (48 V differential voltage between waveforms), the drive legs will bend (see also Eq. 1), for example by 2.4 μm, i.e. 50 nm/V (this figure is dependent on the motor element design).

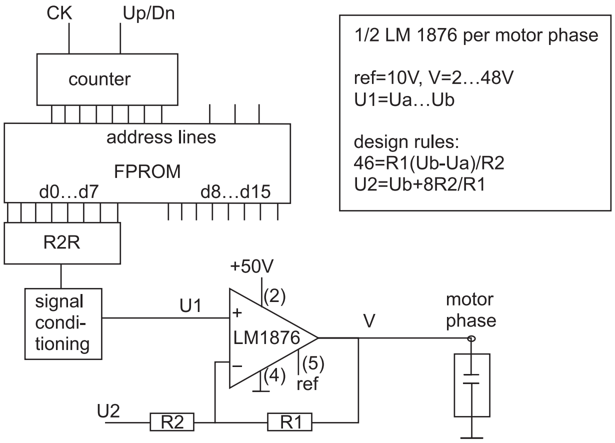
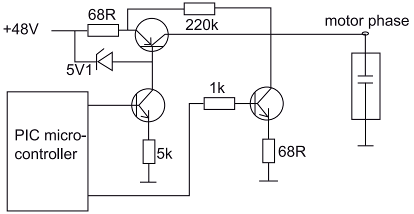


Fig. 10. Motor drive circuit suitable for nano-stepping Piezo LEGS motors.

An inexpensive and small footprint piezomotor driver has been developed. This uses constant motor phase currents to produce waveforms similar to the ones shown in Figs. 7 and 9, whereas the final fine-positioning is done in a special mode in which the motor phase voltage is ramped down until stopped according to sensor signal, and thereafter slowly recharged via a high-ohmic resistor until the sensor signal triggers a new discharge of the motor phase. This kind of driver is part of the demo-kit described in the section "Piezo LEGS demo control unit". The driver is schematically shown in Fig. 11.

Fig.11. Schematic drawing for a driver with a small footprint.



Drive voltage

The maximum drive voltage should not exceed 50 V. The drive voltage should always be positive since the drive legs are made of piezoceramic materials. If negative voltages are applied, the piezoceramic material may depolarize, jeopardizing motor function.

Important: Do not use negative drive voltages. A large negative drive voltage may cause permanent damage to the motor.

Drive frequency

The Piezo LEGS demo motor is designed for frequencies up to 3 kHz and should not be run at frequencies above this value. The maximum drive frequency depends on motor configuration and should be optimized for the intended application.

Important: Do not drive the motor at cycle frequencies above 3 kHz.

A simple positioning algorithm

An analog position sensor signal can be used as a digital direction command (Fig. 12) if it is compared with an analog target value so that the output is high when the sensor signal is too high, and low when the sensor signal is too low. If the position is at target, the direction signal will flicker. However, if the direction signal is stable for a given time (perhaps 1 ms), a command for adjusting the position by slowly ramping up the speed in the proper direction is called for.

Acceleration should be chosen so that when the target position is reached, the overshot should be negligible after only a few passes. Acceleration and retardation for Piezo LEGS linear motors are very fast, thus minimizing target overshot.

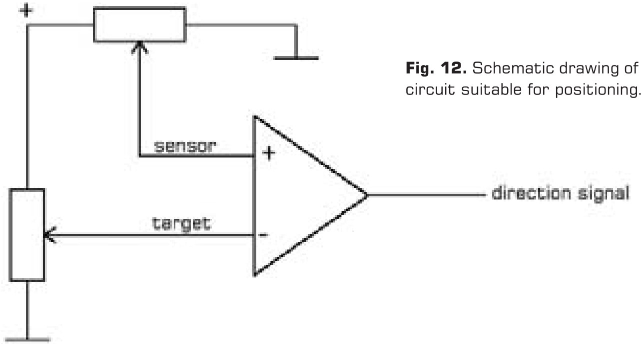


Fig. 12. Schematic drawing of a circuit suitable for positioning.

MECHANICAL INTERFACE

The descriptions given in this section are intended to give some general ideas on how to integrate the Piezo LEGS linear motor into a mechanical system. The examples apply only for the motor delivered with the demo-kit.

Motor housing

The motor housing, shown in Fig. 13, is fabricated in SS2346 stainless steel and precision lapped. In this way, the drive pad and the bottom of the motor housing are plane parallel within sub-micron. The height differences between drive pads will then be very small.

The sides of the motor housing are perpendicular within 0.1° with the bottom and drive pads.

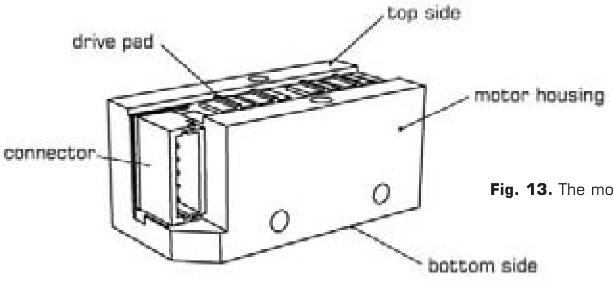


Fig. 13. The motor housing.

After precision lapping the piezoceramic drive legs are polarized to give a remanent polarization. This procedure gives a permanent elongation of the drive leg in the order of 2–3 μm (depending on motor element length, material, etc.). The top of the drive legs will therefore be about 2–3 μm higher than the motor housing.

The motor housing has two M1.6 holes on each side plus two at the bottom for mechanically fastening the motor housing to a support plate or frame in the receiving system.

Mounting the motor

It is very important that the motor housing is not deformed during mounting as deformation will alter the tolerances mentioned above. The motor can be mounted in a number of ways, some of which are discussed below.

Mounting against a rigid support

If the motor is to be mounted on a rigid support by the two bottom holes of the motor housing, the support surface has to be extremely flat, which in many cases can be difficult to achieve. If the surface of the support is not sufficiently flat, the motor housing may bend or twist, which in turn may change the height differences between the drive pads. A low height difference between drive pads is critical for motor performance. Deformation of the motor housing can be prevented by the following methods:

- Mount an angled support on each side of the motor housing (see Fig. 14). This makes it possible to mount the motor if the support surface is not perfect. The motor will also be fixed in the push/pull direction.

- Fasten the motor using the holes on either side (see Fig. 15). This fixes the motor firmly in the push/pull direction. Utilizing shims can make the mounting relatively insensitive to the structure of the support surface.

Mounting against flexible sheet metal

If the support is flexible enough, the motor may be mounted using the holes at the bottom of the motor housing (see Fig. 16). By using a flexible support, the motor housing will not bend or twist and good motor performance can be expected. The support could be a sheet metal not thicker than 2 mm and made of aluminum, for example.

Adhesive bonding

The motor housing can be adhesive bonded on any of its four surfaces, i.e. bottom and three sides, except the connector side. An epoxy adhesive is recommended. If, for example, an aluminum oxide filled epoxy adhesive is used, the joint will be very stiff. It is important to take account of the difference in thermal expansion between the motor housing material and support material. This should be kept as low as possible. If not, a large strain can be built into the joint and thus cause the motor housing to bend or twist when a heat cure adhesive is used. Therefore materials with similar thermal coefficients are recommended.

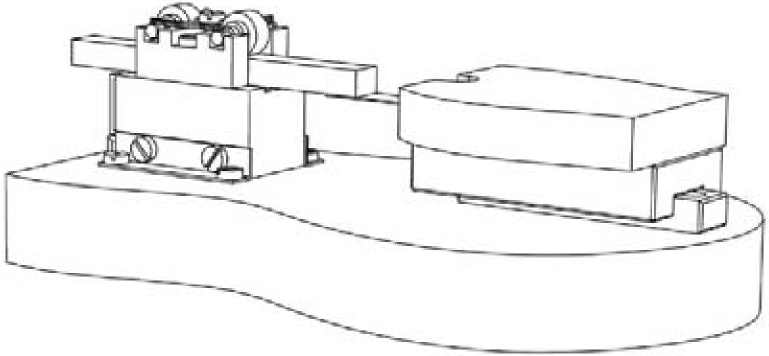


Fig. 14. Example of mounting against a rigid support. The angled supports are flexible enough to adjust to an uneven support surface, but stiff enough to be rigid in the push/pull direction.

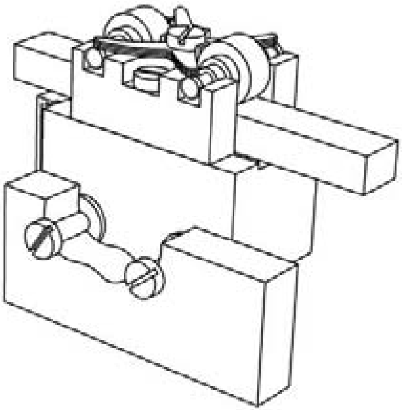


Fig. 15. Example of mounting against one of the sides of the motor housing. The shims between the motor housing and the support make the installation relatively insensitive to uneven surfaces.

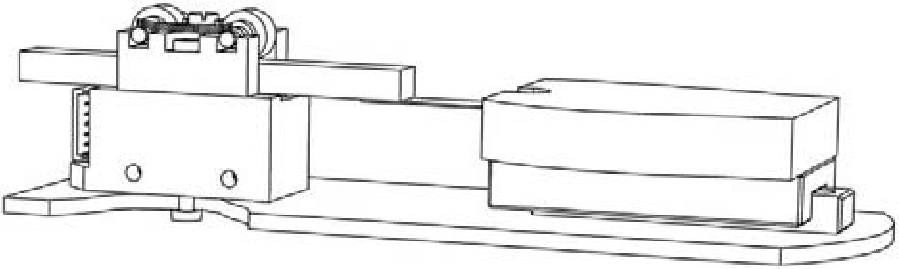


Fig. 16. Flexible mounting. The flexible sheet metal will conform to the flat bottom of the motor housing without deforming the housing.

Drive rod

The drive rod in the Piezo LEGS demo motor is fabricated of aluminum oxide and is 3 mm thick. The drive rod is plane parallel over its entire length. As mentioned above, the drive rod is pressed against the drive legs with a normal force via the springloaded ball bearings. Since the drive principle is based on friction forces between the drive rod and drive pads, it is important to avoid any kind of grease on these surfaces. If the surfaces are dirty, motor performance may deteriorate.

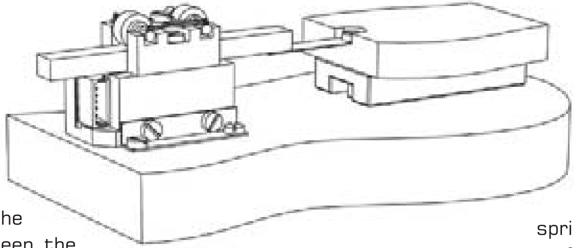


Figure 17. Example of a connection utilizing a flexure.

Connecting the drive rod

The connecting device between the drive rod and the mechanical component that is to be moved has to fulfill the following to fully utilize the motor:

- The connecting device should be stiff only in the push-and-pull direction.
- It should be adjustable for height and angle deviations between the drive rod and the driven component.
- The connection of the drive rod should be firmly fixed laterally.
- Forces lifting the drive rod should be prevented (otherwise drive rod and drive legs might loose contact).
- The push-and-pull forces should act in the same plane as the drive legs. If not, bending moments may rotate the drive rod and adversely affect motor performance.

A simple and functional coupling device is a thin flexure fabricated from sheet metal (see Fig. 17). The flexure is adhesive-bonded to the drive rod and, for example, fastened by a screw to the mechanical part to be moved. The flexure is effectively fixed in the push-and-pull direction and at the same time is able to compensate for fabrication errors such as height and angle deviations. It also stiffens the drive rod laterally and prevents too high lifting forces. The push-and-pull forces act in the same plane as the drive legs, which is the ideal case. Suitable dimensions for the flexure are 3–4 mm in width, 0.2 mm in thickness, and 10–15 mm in length. A suitable material is stainless steel.

Alternative ways to mount the motor

The motor housing can be mounted against the component to be moved i.e. without the drive rod, ball bearings and springs described previously (as example see Fig. 18). There are many ways of doing this. Before you go ahead with this approach special care and consideration must be taken. We therefore always recommend you to contact us before you proceed with this integration in order to assure proper functionality of your motion system.
Some general recommendations however are given below:

- The drive surface must be plane within our specification.
- The drive surface material should be aluminum oxide or similar with regard to hardness and coefficient of friction.
- The normal force that presses the drive legs against the drive surface should be applied in the same or nearly the same plane as the plane of the drive legs. (If not, the bending moment may rotate the motor housing and adversely influence motor performance.)
- The normal force between drive surface and the motor element should be in the order of 50 N. (Note that the output force can be varied within a wide range depending on the motor element geometry and required output force.)
- A suitable spring deflection is in the order of 0.1–0.3 mm.
- A stiff spring is recommended since it will give a higher natural frequency than a soft spring.
- Leaf springs mounted in the holes at the top of motor housing is recommended since they absorb push-and-pull forces without bending in the same direction.

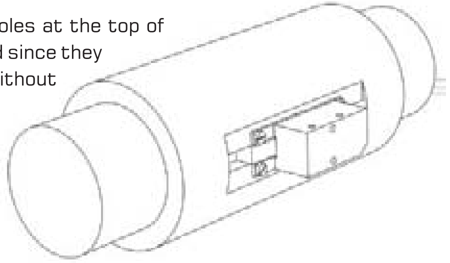


Figure 18. An alternative way of mounting the Piezo LEGS housing (directly against the component to be moved).

Vibrations

The Piezo LEGS motor works over a very wide frequency range. It is therefore necessary to consider the natural frequencies occurring in a complete construction. The motor performs best when the natural frequencies of the drive rod are avoided. A good rule of thumb is to drive the motor well below the occurring natural frequencies, i.e. up to half the natural frequency for the drive rod. Note that a drive frequency of 1 Hz means that the drive legs make contact with the drive rod twice per drive cycle, i.e. with a frequency of 2 Hz. This means that if the natural frequency of the drive rod is 12 kHz, the motor should not be driven with a drive frequency larger than 3 kHz. If the motor is driven at too high frequencies, there is a risk that the drive legs will loose contact with the drive rod and motor performance will deteriorate. Please observe that both the connecting device and the position of the motor at the drive rod will affect the natural frequencies.

If the chosen frequency range does not influence motor performance, the surrounding mechanical components may. Noise and vibrations can propagate and be amplified at resonance. In some cases it is possible to reduce noise and vibration by damping. In other cases, it might be necessary to avoid certain frequency ranges.

PRACTICAL ISSUES AND INSTRUCTIONS

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. 19 schematically shows the mounting of the male connector in the motor.

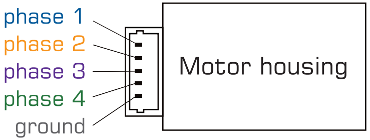


Fig. 19. Schematic drawing showing the male connector mounted in the motor. The configuration of the motor phases is also shown.

The connector configuration of the pins for the motor drive (shown in Fig. 19) is, from top to bottom; phase 1, 2, 3, 4 and ground. Phase 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.

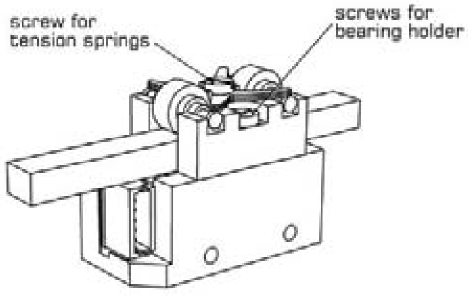
Removing the bearing holder

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. 20). Be sure to center the springs properly when reassembling. Tighten the screw with moderate torque.

Fig. 20. Schematic view of a Piezo LEGS linear motor showing the screws for the bearing holder and springs.



PIEZO LEGS DEMO CONTROL UNIT

This section contains a User Manual for the Piezo LEGS motor controller that is part of the demo-kit.

PiezoMotor Controller 2.1, User Manual

Connect the Piezo LEGS motor and then the DC12 V supply voltage adapter. The LED will switch ON for a short while and then remain OFF. Do not press the buttons during this period (0.4 seconds). When the LED goes OFF, the driver is ready to receive a Forward or Reverse command.

To make the motor move a small step, press the Forward (F) or Reverse (R) button. Holding the button pressed will slowly ramp up the speed. If the second button is pressed without the first being released, the speed will be ramped down. If no button is pressed, the motor will stop right away. The LED turns ON when the Forward button is pressed.

Fig. 21. The PiezoMotor controller 2.1 (Pmc2.1).

At the end of the initial 0.4 second period mentioned above, the Pmc2.1 checks the capacitance of motor phase 1. If the Reverse button is pressed during this calibration, or the motor is not connected before the power supply, the LED will start to blink, indicating a calibration error (capacitance too low). Connect the motor and press the Reverse button for about 0.5 seconds to reinitiate the calibration procedure. A new calibration may be needed for optimum performance if the piezo motor temperature changes more than 20 °C or if a new motor is connected, in which case the power supply must be disconnected for a while to reset the controller. If the LED stays ON (not blinking) after calibration, the controller has detected a far too large capacitance. This can be caused by a short circuit between motor phase 1 and another phase. A jammed Forward button will also cause the LED to stay ON after calibration.

The Pmc2.1 controller is designed to use 12 V stabilized DC voltage and consumes around 300 mA at full speed. In case of a short circuit on all motor phases, the current consumption may reach about 450 mA. If replacing the power supply, please note that this controller is not protected against reversed polarity.

The 12 to 48 V charge-pump regulates the maximum motor phase voltage to 48 V. In case of a voltage regulation failure, the voltage can reach about 60 V (5x input voltage) if no current is drawn.

Warning! The driver is not protected against reversed polarity on the power supply.

Non-manual mode considerations

The Forward and Reverse signals can be externally driven for use in automatic control applications. In the PCB photo (Fig. 22) the white circle on each of the buttons shows proposed soldering points for external signals. Please note that the signals must be open collector! If an external signal drives the Reverse signal high during the initial capacitance calibration, a capacitance-too-high error will occur. The 8-pin PIC12C508A microcontroller that controls the charging and discharging of the motor phases can be replaced with a 14-pin PIC16C505 for more user-defined instructions and I/O-pins.

The acceleration parameters determine at what speed the target position is reached. After the initial capacitance calibration is complete and the LED switches OFF (F-signal goes high), the PIC waits 0.8 ms and then checks the F and R-signals to configure acceleration parameters. When the acceleration parameters have been configured, the PIC waits for both R and F-signals to be deactivated before it reacts to them as Forward/Reverse commands.

There are currently four sets of acceleration parameters (Table 1). For instance, in manual mode, the waiting period after the first step is around 170 ms. In the following steps, the waiting period is constantly around 12 ms and the speed is increased by enhancing the step length. When the maximum step length is reached, the delay starts to decrease, i.e. the frequency is ramped up. If both F and R-signals are active, frequency is ramped down and a decrease in step length then follows.

Table 1. Acceleration parameters

F,R	max delay per step	extra delay 1st step	ramping down	note
1,1	12 ms	160 ms	freq. & step length	manual mode
0,1	9 ms	80 ms	frequency only	
1,0	6 ms	11 ms	freq. & step length	
0,0	1 ms	3 ms	freq. & step length	

All modes increase step length first, and thereafter step frequency. If both F and R are activated when the motor is running, all modes will decrease step frequency, and all modes except one will slow down further by decreasing step length. The configuration of acceleration parameters may be changed in future updates to allow more modes of operation.

In the PCB, Fig. 22, two of the discharging NPN transistors have a white circle situated on the base pin. We suggest that these soldering points are used by external signals to adjust motor position on the nm level.

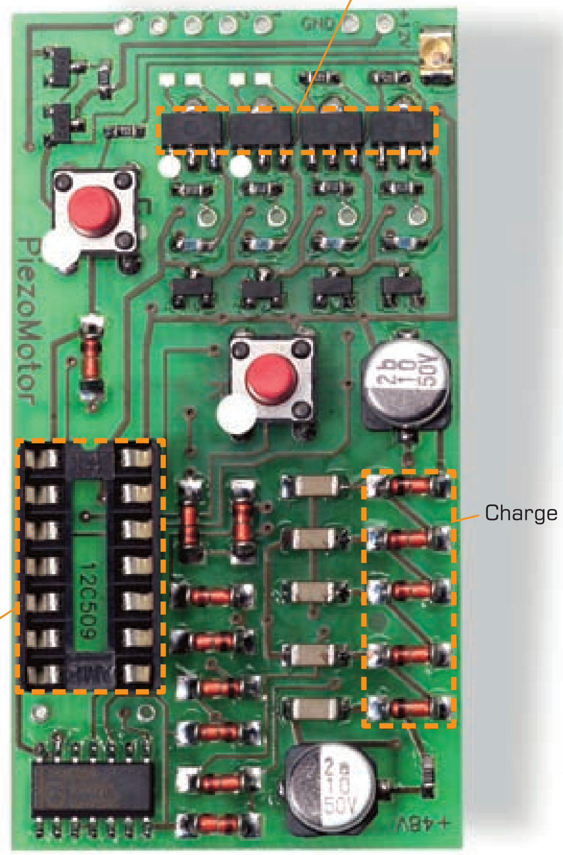
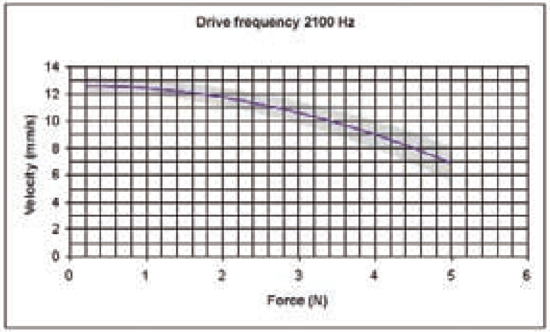


Fig. 22. The printed circuit board for the Pmc2.1 controller.

PIEZO LEGS DEMO MOTOR DATA

Piezo LEGS demo motor

Dimensions [mm] (L×W×H)	Complete 22×10.8×18	Phase voltage[3] [V]	0 to -42
Weight [g]	Complete 20	Resolution[4] [nm]	10
Velocity[1] [mm/s]	2100 Hz 12.5	Maximum step length[5] [µm]	3
Frequency range[1] [Hz]	0–2100	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) Recommended maximum drive frequency 2.1 kHz. Absolute maximum drive frequency 8 kHz.
2) Force ± 10%
3) The phase voltage is to be cycled between 0 to -42 V. Maximum allowed phase voltage is 48 V.
4) Dependant on phase voltage resolution (approximately 35 nm/V).
5) Maximum ±10 % step length variations at no load.
6) Stroke dependant 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) Dependant on drive electronics. The power consumption may be up to 70% lower using energy recovering electronics.

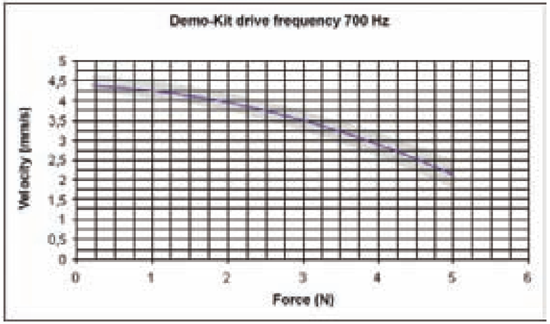
Specifications subject to change without prior notice.

DEMO CONTROL UNIT

PIEZO LEGS DEMO MOTOR DATA

Piezo LEGS demo motor with PiezoMotor Controller 2.1

Dimensions motor [mm] (L×W×H)	Complete 22×10.8×18	Supply voltage [V]	12
Weight motor [g]	Complete 20	Resolution[3] [nm]	200
Speed[1] [mm/s]	700 Hz 4.4	Maximum step length[4] [μm]	3
Frequency range[1] [Hz]	0–700	Stroke[5] [mm]	35
Force[2] [N]	Stall force 6.4 Holding force 7.3	Phase capacitance at 22 °C[6] (nF)	430
Dimensions controller (mm) (L×W×H)	73×43×18	Power consumption[7] (mW/Hz)	5
Dimensions PCB (mm) (L×W)	60×32	Temperature range [°C]	-20 to +70
EMC (Council Directive 89/336/EEC)	Emission[8] Immunity[9]		



Motor performance for a drive frequency of 700 Hz. The gray area expresses one standard deviation for the motor data.

1) Maximum drive frequency for the demo kit is 700 Hz.
2) Force ± 10%
3) Positioning resolution can be improved, even down to the nm range, if external logic is used.
4) Maximum ±10 % step length variations at no load.
5) Stroke dependant on length of drive rod. Longer drive rod available on request.
6) Capacitance at 22 °C ± 5%. Capacitance at -20 °C approximately -20% and at 70 °C approximately +40%.
7) Dependant on drive electronics. The power consumption may be up to 70% lower using energy recovering electronics.
8) EN61326-1:1997 + A1:1998 Class B
9) EN61326-1:1997 + A1:1998 Table A1

Specifications subject to change without prior notice.

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