PiezoMotor®

Product Catalogue 2014/2015

ABOUT PIEZOMOTOR AB

PiezoMotor is one of the world-leading developers and manufacturers of direct drive, micro motors based on piezoelectric materials. Simple, precise and very small, piezoelectric motors are replacing traditional electromagnetic motors when these no longer meet the demands. Piezo LEGS® motors minimize total product size and deliver much greater precision.

At the company head office in Uppsala Sweden we make sure to have full control from piezo powder to delivering the final motor. This means that within our facilities we have a team of developers designing our motors, a production team to manufacture the piezoceramic material and assemble the motors, and the sales team to support our customers and distributors.

Across the world, there is an ever increasing need for small, strong motors. Miniaturization combined with precision is driven by demand for higher accuracy in manufacturing such as precision machinery and measuring tools. In the medical sector, we see analytical instruments and manipulators becoming more and more advanced and exact. The development of nano technology is further enhancing this development. In the semiconductor industry, there are continuous efforts to develop higher precision instruments in order to scale down devices on the silicon wafer.

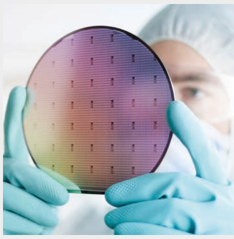
In many of these applications, conventional electrical motors do not meet the required features. Our small, strong motors are precise down to the nanometer range. In addition, it has instant response time and does not suffer from the backlash problems which no gearbox can escape from.

Markets

Piezo LEGS® motors are very flexible. They find use in a wide range of applications and markets, a number of which are outlined below.

OPTICS

Moving mirrors and lenses in optical applications is a traditional PiezoMotor application. The motors' open-loop and closed-loop operation makes them particularly attractive in this market. High resolution, high stiffness and high holding force – even without power applied – are additional key success factors. Our LTC type Piezo LEGS motors have dedicated solutions for different mirror mounts. We also offer customized solutions



SEMICON

Trends in the semiconductor sector indicate a shift in focus from ever-finer trace width to greater emphasis on advanced packaging. Production capabilities and throughput remain very important. Piezo LEGS motors deliver high throughput, thanks to fast settling times plus high stability and resolution. PiezoMotor continuously develops new products for this market – both motors and drivers. We know this sector. Its demanding environment is part of our everyday life. Most of our solutions are customized.

SEM/TEM

Requirements for higher resolution and newer, faster automated sequences continue to drive motor and driver development in the SEM/TEM sector. The extremely high resolution of Piezo LEGS motors matches this need perfectly. Fractions of an Ångström plus high stiffness and stability are combined with low heat dissipation into systems. Our motors are fully compatible with the vacuum environment. For the most demanding applications, they can be made completely non-magnetic.

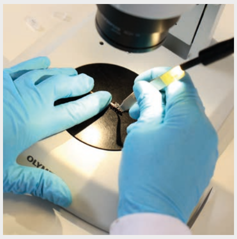
FACTORY AUTOMATION

This market is still in its early stages, but a steady increase in the use of Piezo LEGS motors is already evident. Driving forces include increasing demands on high-end assembly equipment plus smaller and smaller parts. Piezo LEGS motors are suitable for slow-speed, high-precision applications. We work together with many motion control specialists, mixing different technologies with Piezo LEGS motors and thereby building optimized motion solutions. Piezo LEGS motors perform well in many applications, but if other solutions appear better, e.g. those offered by our Faulhaber Group partner, we don't hesitate to recommend them.

MEDTECH

Compact high-resolution solutions are key success factors for many medtech applications such as probing and cell manipulation. Our motors find many uses here and their very fast settling time is much appreciated by end-users. Fast settling time, in combination with high resolution and slow-speed, makes Piezo LEGS solutions very competitive.

STAGE



Linear and rotary stages are common building blocks in almost all of the markets mentioned above. PiezoMotor offers a wide range of products for motorizing stages. Our motors can be fully integrated for very compact solutions or mounted externally with a minimum of components. Moreover, Piezo LEGS technology makes it possible to replace an existing DC/Brushless/Stepper solution with a high-resolution piezo alternative. Systems also require position sensors to provide feedback for closed-loop operation. We offer sensors from Renishaw and MicroE Systems, and we help find the solution that best matches your application needs.

DEFENSE

Military applications often require very robust solutions and even here, friction-based Piezo LEGS motors offer a very good fit. Friction-based motors can be subjected to impact or even being manually moved without any damage to the motor; if the force applied to the motor is higher than the holding force, it will just start sliding. Automatic locking without power consumption is a unique feature that makes our motors suitable for battery-operated equipment. In airborne applications, the very high force-to-weight ratio is also an important success factor.

CUSTOMIZED PRODUCTS

Over the years, we have gained much experience with custom adaptations, both with mechanics and electronics. We have the building blocks, skills and experience to make motor solutions to meet your needs. We do in-house sub-assembly of full-motion systems (i.e. motor, guiding, encoder). Contact us to discuss details with our skilled engineers.

How it works

OLD PHENOMENA USED IN NEW AND EXCITING WAYS

The piezoelectric effect was discovered in the 1880's by the Curie brothers. By applying voltage to a piezo electric material, they were able to change its shape. This effect has since been used in many applications; submarine sonars, ultra-sound equipment at hospitals, as well as loudspeakers, for example. A more recent application – piezo-actuated fuel injectors – has improved the fuel economy of modern cars and trucks. This would not be possible without robust piezo electric components able to endure billions of cycles in the harsh environment of the combustion engine.

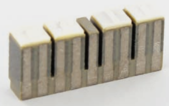
Until PiezoMotor demonstrated its first commercially available piezo motor in 2002, only a handful of manufacturers existed. Since then, the acceptance of piezo technology has increased dramatically and more and more customers are today enjoying the benefits that our motors deliver.

ROCHELLE SALT

AN OUTSTANDING SUCCESS STORY

The conventional electromagnetic motor is one of the most successful industrial products of all times. Since its conception some 175 years ago, it has made inroads into every aspect of our lives. Today, close to 10 billion small electric motors are produced each year. What's more, the numbers keep growing as new applications are added to the list.

In the most basic modern car, for example, we find some 30 to 40 motors handling everything from adjusting rear-view mirrors to opening windows. In a luxury car, close to one hundred motors are used.



PIEZO LEGS® MOTOR ELEMENT

SO WHY DO WE NEED ANOTHER TYPE OF MOTOR?

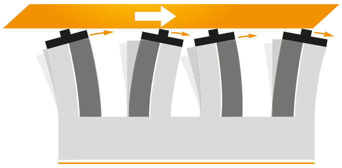
The answer is that for most applications we don't; the well-proven electromagnetic motor will work just fine. But for a growing number of applications and products, this traditional solution has reached the end of the road. A new type of motor is replacing it – a piezoelectric motor – and the demand is growing. All underlying trends support this growth; we want smaller and smaller products, more and more portable devices with more features and longer battery life, plus greater energy efficiency and higher and higher precision.

PIEZO LEGS® TECHNOLOGY

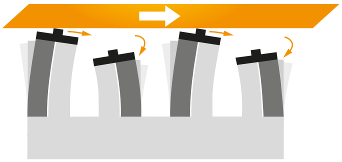
Piezo LEGS is in essence a walking machine constructed in one solid piece. Constructed so that each leg can be elongated as well as bent sideways, it moves incrementally by synchronizing the movement of each pair of its four legs, just as an animal would. Note that Piezo LEGS operates directly – there's no need for gears or mechanical transmission, and the material itself is virtually impossible to wear out. Even if the motor moves incrementally in the nanometer range, it can still be very quick. By taking thousands of steps per second, it can cruise along at centimeter per second speeds.

How it moves
STEP-BY-STEP

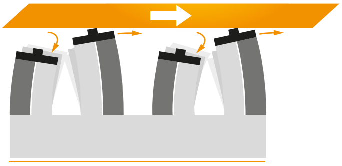
Orange arrows show the direction of motion of each leg tip. They move as alternate pairs. White arrow show the movement of the rod.



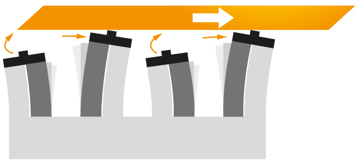
1 All four legs are electrically activated. All are elongated.



2 The first pair of legs maintains contact with the rod and moves right. The second pair retracts. Their tips bend left.



3 The second pair now extends and repositions on the rod. Their tips move right. The first pair retracts and their tips bend left.



4 The second pair of legs moves right.The first pair begins to elongate and move up towards the rod.

DIFFERENT TYPES OF PIEZO LEGS® MOTORS

Piezo LEGS motors are designed for 'move-and-hold' applications where precision, minimal space, low energy consumption and simple mechanical design are important factors. As the motor is non-resonant, it is also very easy to scale up and down in size. Unlike resonant piezoelectric motors, which only operate at a given frequency, Piezo LEGS motors offer extraordinary speed dynamics. They can be operated at extremely low speeds (nanometers per second) up to 20 mm/second with full control in the complete dynamic range. A further unique feature is their ability to take extremely small steps (single nanometer range) in combination with long strokes. This means that one Piezo LEGS motor can often replace two motion systems – a DC-motor plus a piezo actuator, for example – without sacrificing performance.

So what do you need to design and integrate a motion system based on Piezo LEGS? To start with, we offer standard Piezo LEGS motors in various sizes plus a range of drivers/controllers. We also help select suitable position sensors as well as guidance and/or design of the mechanical interface of the motor. Our experienced mechanical and electronic designers help you throughout the process.

WHY USE AN ELECTROMECHANICAL PIEZO MOTOR INSTEAD OF A TRADITIONAL ELECTROMAGNETIC

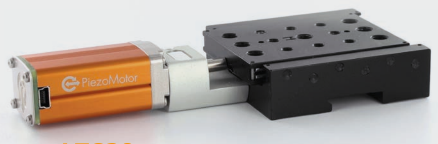
The electromagnetic motor has continuously improved since Michael Faraday converted electrical energy into mechanical motion in 1821. The principle has now reached a stage of very high refinement and precision and is the most widespread industrial product in the world. Piezo LEGS rely on an electro-mechanical principle rather than an electromagnetic one. So what are the differences and what benefits do you get by switching to the new technology?

To answer these questions, let's take a look at the basics of the different principles. The electromagnetic motor works by creating force through magnetic poles that repel each other. Electrical current fed through wound coils create a magnetic field, where polarity is sequentially reversed to make the rotor spin. Piezo LEGS instead works with direct friction drive; force is created by the inherent preload of the piezoceramic actuator legs in direct friction contact with the rotor or drive shaft. When the legs start walking they are always in mechanical contact. In the following text we will explain how this is beneficial.

RESPONSE AND SETTLING TIME

When using a magnetic field to accelerate the rotor of a DC motor, you will always have lag due to inertia. More so, the electrical impedance in the windings of the motor will negatively affect the response time; it simply takes time to push current into the motor to create the electromagnetic field. When settling in on a target position with a DC motor you will have an overshoot and must deal with oscillation. The time to settle and the continuous dithering may be a killer for any precise application.

Piezo LEGS motors work with direct friction drive and will hold the load tightly. Response and settling time is limited by the load and friction between the piezo actuators and the component to be moved. Responsiveness of the piezo actuators is instantaneous and settling time is much faster compared to any traditional motor technology.



LTC20

STIFFNESS

In many high accuracy applications, motion stiffness is essential. A system designed for holding force by magnetic field is of course a bit spongy in its nature. Stiffness can be increased with different tricks, but in comparison with the Piezo LEGS the traditional motor technologies fall short. Piezo LEGS are firmly holding the rotor or the linear shaft, and consequently you will make use of the high stiffness of the ceramic material. With increasing motor size the level of stiffness will only get higher.

FORCE

In relation to its size, the torque of a rotating electro-magnetic motor or the force of a linear electromagnetic motor is much lower than for Piezo LEGS. This is especially significant in small diameter motors. That's the reason why electromagnetic motors need a gearbox to create high force and torque. Piezo LEGS motors do not need gearboxes. Piezo LEGS is self-locking and will hold load even when powered off.

RESOLUTION, MINIMUM INCREMENTAL MOTION

In precision positioning, the term Minimum Incremental Motion (MIM) is often used. This is the smallest practical mechanical motion on the outgoing axis. Traditionally, we always see a big difference between the MIM and the resolution, since the latter is more closely related to the smallest detectable motion. In contrast, Piezo LEGS dramatically decrease the gap between MIM and resolution, in many cases eliminating it entirely. Resolution is more dependent on the electronics and the position sensor; the limiting factor is not the motor itself. Piezo LEGS thus achieve resolution so high that traditional electromagnetic motors are not even close. You will be able to easily position on a sub-micron level, or even down to sub-nanometers. For the rotary Piezo LEGS we're talking sub-microradians.

BACKLASH

Backlash is another factor that creates a lot of problems in motion. To illustrate this, you simply have to look at an adjustable spanner in your workshop. Changing the moving direction of the adjustment screw and nothing happens at first because of the play in the mechanics. Motion is created, but only after some delay. This is also the case in all gearboxes as the force is applied on different sides of the gears. There are of course ways of minimizing the backlash in gears, but to have a completely backlash free motion you need the direct drive feature of Piezo LEGS; friction contact is always in place, and changing direction can be done without the slightest play.

LTC20 AND LTC40

ACCURACY

Absolute accuracy is the maximum difference between absolute target position and actual position. As we have seen, accuracy is limited by backlash and non-linearity of the drive mechanics, while other factors that contribute to inaccuracy include temperature drift. What is clear is that achieving the best accuracy requires direct drive and direct metrology systems. For best accuracy the only option is to have position feedback from the point of interest; you simply place the position encoder close to where you want to measure movement.

LT40

ENERGY CONSUMPTION

Traditional electromagnetic motors use significant amounts of energy just to keep a motor in a fixed position. Continuous current generate heat in the windings of the DC motor, and can have very unwelcome effects, especially in high-end positioning. Switching off the current will cause the motor to loose its position. Piezo LEGS motors are by far less energy consuming. The capacitive load of the piezoceramic actuators means power is consumed only when moving. When at stand still the motor will hold position without any current draw. For point-to-point movements you will see a really efficient use of energy, and at stand still you will have no heat generation. More so, the torque/force Piezo LEGS can deliver for the amount of power consumed is remarkable.

CONCLUSION

Regardless of your application, it’s highly likely that your next development will have greater motion demands than the last. Many of the problems noted above will require a speedy solution. Switching to Piezo LEGS simply solves so many problems. In many cases, the improvement is dramatic.

We see a fast-growing use of Piezo LEGS. More often than not, using one of our motors is no longer an optional alternative to the electromagnetic motor – it’s a necessity for driving product development forward.

Electronics

Standard drive electronics for Piezo LEGS® range from simple and low cost to advanced controllers for closed loop control. The motor is powered by signals below 50 V in amplitude, and custom drive circuitry can even run on battery.

Piezo LEGS motors can be used in different ways depending on the requirements of the particular application. Required resolution is always the key question. As its name implies, a Piezo LEGS motor takes steps to create motion and, just as in humans, it can walk in different ways. It can move fast or slow, take long steps, short steps or partial steps, and stop at any point. All accomplished by different movement patterns and frequencies of the legs.

If we study one of the piezoceramic legs in detail, the actuator is built like a bimorph (Figure 1). Left and right side of the leg can be independently activated (0-48V). When energized, the leg can extend and bend a few microns. The tip of the leg (i.e. the friction drive pad) can move to any point within the rhombic area as illustrated in Figure 1. When the leg is not energized, the tip of the leg will be at point a. When only activating one side of the leg, it will bend to the left or to the right (b or d respectively). With both sides of the leg fully activated, it will extend to its maximum height (at point c).

A Piezo LEGS motor will have several actuator legs working together. The motion of the motor will be dependent of the input electrical waveform signals. To achieve motion, two legs (or more) are driven in parallel. In total, each motor will need four separate control signals. Each leg, however, is controlled with two voltages. In Figure 2 two different waveforms are depicted. Rhomb is a rudimentary waveform which will make the tip of the leg move in a rhombic pattern. A more advanced waveform is called Delta. The Delta waveform is optimized for smoothest walking, and is best for high precision positioning.

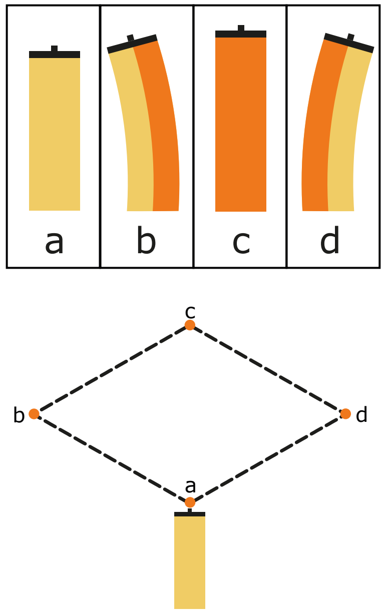


FIGURE 1. Element movement

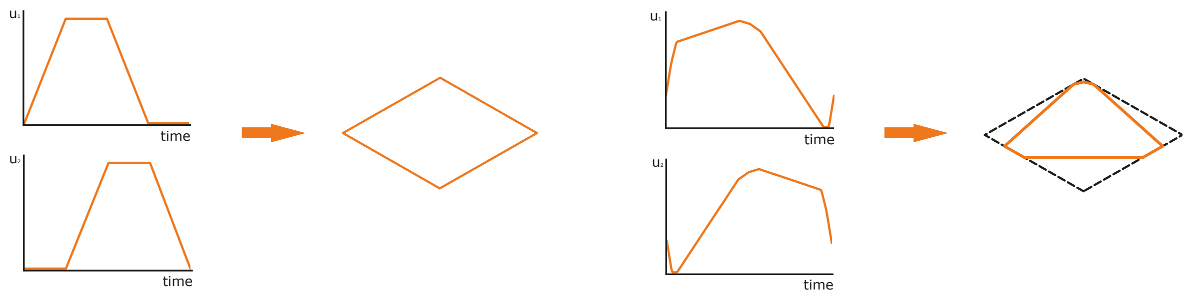


FIGURE 2. Voltage plots; waveform Rhomb (left), and waveform Delta (right). The two input signals (U_1 and U_2) will control each separate half of the bimorph leg. Resulting plots describe the motion of the tip of the leg for given waveform type.

PMCM21

PMCM31

PMD101

PMD104

PMD206

For each waveform period the leg will complete one revolution; it will take a full step, also defined as a *waveform-step* (*wfm-step*). With fine control of the generated waveform, it is possible to divide the full wfm-step in to smaller increments; so called *microsteps*. The movement of individual legs is almost linear with the applied voltage. The piezo actuator leg is an analog component, and will move approximately 50 pm/mV. In other words, if the microstep voltage is controlled on mV level, the resolution of incremental motion is ~50 picometers ($50 \cdot 10^{-12}$ m). For practical reasons we have limited our standard microstepping drive electronics to microsteps of nanometer size ($1 \cdot 10^{-9}$ m).

The piezo actuator legs can be regarded as pure capacitors. To hold the legs in a given position you need to keep the voltage stable. At stand still there is no power draw or heat generation in the piezo. When holding position the motor can respond instantaneous and compensate the slightest deviation by taking nanometer sized microsteps.

The amount of energy consumed by the Piezo LEGS depends on the size of the motor. For example, the linear 6 N motor consumes only 5 mW per wfm-step, of which ≤10% is lost as heat in the piezo. Like other ceramic capacitors the piezo actuator is temperature dependent; capacitance is increasing with temperature. Increase in temperature can be due to ambient changes or operation of the motor. Consequently, with increased temperature the motor will consume more power and put a higher capacitive load on the driver amplifier.

CUSTOMIZED ELECTRONICS

In many applications, it is advantageous for users to integrate the drive electronics into their own system. PiezoMotor is fully open with information about how to control the motion of Piezo LEGS, and will support those who decide to make customized electronics. We do however encourage customers to start using our motors with drivers/controllers supplied by us. Standard drive electronics are available for Piezo LEGS motors both from PiezoMotor as well as from independent suppliers. They range from very simple and low cost to very advanced. See our web page for guidance or contact us for recommendations.

SENSOR

Many Piezo LEGS applications will require position sensors/encoders. We will help you make the correct choice. Sensors that fit our motors are available in standard as well as custom version from several independent suppliers. If you want the sensors integrated at the factory, just contact us for further assistance.

Motor Characteristics

Piezo LEGS® linear and rotary motors positions down to nanometer range if required. We talk about taking steps but in a different way from traditional stepper motors.

In this catalogue you will find detailed information about the standard products from PiezoMotor. Piezo LEGS are non-resonant walking motors; in several aspects quite different from DC or stepper motors. A Piezo LEGS motor is friction based, meaning the motion is transferred through contact friction between the drive leg and the drive rod/disc. You cannot rely on each step being equal to the next. This is especially true if the motor is operated under varying loads. For each waveform cycle of the drive signal, the motor will take one full step, referred to as a *waveform-step (wfm-step)*. There is dependence between external load on motor and wfm-step length. When external load is high the wfm-step length is reduced. For example, see performance curve of LT20 type motor in Figure 3. At zero external load the typical wfm-step length is ~5 µm, but as load is increased the wfm-step length is shortened one or a few microns when working against load. In opposite, and not shown in diagram, the wfm-step length will be increased one or a few microns when working with load. It should be noted that the wfm-step length will also depend on internal piezo temperature, and on the type of waveform.

The wfm-step length, as described above, can be used to calculate the approximate motor speed. Wfm-step length at a given load is multiplied with the frequency of the drive signal waveform.

EXAMPLE LT20 motor, no load, 2000 wfm-steps per second
Waveform Rhomb: ~5 µm x 2 kHz = ~10 mm/s
Waveform Delta: ~3.5 µm x 2 kHz = ~7 mm/s

EXAMPLE LT20 motor, 10 N load, 2000 wfm-steps per second
Waveform Rhomb: ~4 µm x 2 kHz = ~8 mm/s
Waveform Delta: ~2.5 µm x 2 kHz = ~5 mm/s

Fine positioning is achieved through dividing the wfm-step into discrete points; so called *microsteps*. The resolution will be a combination of the number of points in the waveform and the external load. For example, a full wfm-step of 4 µm can be divided into 8192 microsteps that are only ~0.0005 µm (~0.5 nm). The resolution of the motor is all dependent of the electronics and how well they can manage the discrete voltage levels of the waveform.

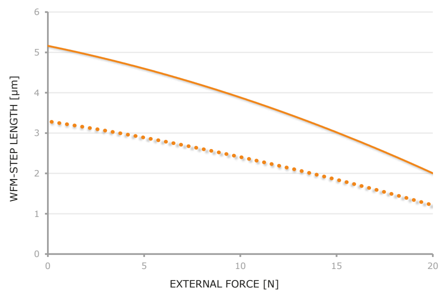


Figure 3. Waveform-step versus external load for LT20 motor. The filled line shows typical curve for waveform Rhomb, and dotted line waveform Delta. Values are typical for room temperature, and mean values for the motor type. Statistical spread is not shown.

Glossary

WFM-STEP
Waveform-step; the step taken for one full waveform period. Step size is load and temperature dependent. Typical load dependence curve is given for each motor.

MICROSTEP
An incremental step within the full wfm-step. The size of the microstep will give the resolution of the motor. For a linear motor the microstep can be sub-nanometer.

WAVEFORM
The shape and form of the electrical signals which controls the Piezo LEGS. Waveform Rhomb and Delta are commonly used, and will give different behavior in terms of speed, microstepping performance etc.

STEP LENGTH
Linear travel, specified for full wfm-steps in load dependence curve. In specification tables the value is also given for a single microstep.

STEP ANGLE
Rotary motion, angular displacement for full wfm-step in load dependence curve. In specification tables the value is also given for a single microstep.

RESOLUTION
The piezo actuator legs are analog components which bend to move the drive rod or to rotate the drive disc. Resolution depends only on how well you control the voltage levels of the control signals. It is never difficult to get extreme resolution with the Piezo LEGS.

RECOMMENDED OPERATING RANGE
The range of external load recommended for best microstepping performance and life time. Motor will handle higher loads, but the linearity within the wfm-step is impaired.

STALL FORCE / STALL TORQUE
Maximum allowed external force / torque that the motor can handle and still give motion.

HOLDING FORCE / HOLDING TORQUE
Motor will be able to hold this force / torque without slippage.

ABOUT PIEZOMOTOR

PiezoMotor is a world-leading developer and manufacturer of direct-drive, micro-motors based on piezoelectric materials. Simple, precise and very small, piezoelectric motors are replacing traditional electromagnetic motors when these fail to meet exacting space/performance demands. Piezo LEGS® motors minimize total product size and deliver much greater precision. Leading multi-national companies number among our many clients.