

## The Elliptec Motor

### Applications in precision positioning, reduction of vibrations, force detection and low-cost driving concepts

#### Veröffentlichung: ACTUATOR 2006

The Elliptec Motor is a new cost effective piezo motor that is able to generate motion in 2 directions with only one piezo element. It weights only 1,2 grams and consumes a space of 0,6 cm<sup>3</sup>. It generates direct driven motion with step sizes of very few microns with frequencies of about 100kHz. Therefore a motion speed of several microns per minute can be achieved as well as a speed of several hundred millimetres per second. The Elliptec Motor already works with low voltages beginning from 2,5V and with low electrical currents beginning from ~3mA. It generates a direct force of 0,3N - 0,5N that can be increased e.g. with simple levers or gear drives.

Therefore the Elliptec Motor is suited for applications that require actuation at moderate forces, typically up to 5N. Lower speed applications can range up to 100N. Not only is the Elliptec Motor the right choice for simple applications such as for the actuation of protective lids or locks, the Elliptec Motor also satisfies the demand for motions of the highest precision with fast reaction speeds in adverse environmental conditions, and also for other specialized requirements. Through the use of a piezoelectric element in the Elliptec Motor and due to patented and patent-pending designs, entirely new applications are now possible.

Elliptec Motors distinguish themselves from traditional piezoelectric motors. They are easily adaptable and controllable, which keeps system costs low. Many attributes of the Elliptec Motor, such as speed, step size, and power are software-controlled. Many applications can utilize the cost-effective standard model X15G, but customer specific motors can be manufactured on demand where necessary.



Fig. 1: The Elliptec Motor: Size-comparison with a matchbox.

#### Working Principle

The operation of the Elliptec Motor is based on the inverse piezoelectric effect. A microcontroller and two tiny transistors are all that is needed to supply the piezoelectric ceramics with a sufficient electric voltage to cause the ceramics to expand by less than one micrometer and to let it contract again when the voltage is turned off. During motor operation, this interplay occurs about 100'000 times per second.

The repeated expansions and contractions of the piezoelectric element excite a resonator to vibrate. The research team of Elliptec AG has optimized the shape of the patented resonator so that the vibrations of the piezoelectric element are magnified and transformed into elliptical motions at the motor tip. A spring maintains a steady pressure between the resonator tip (aka the stator) and a driven element (aka the rotor), which in turn is moved by up to a few micrometers with every oscillation of the piezoelectric element. As this process occurs at supersonic frequencies, the motion of the driven element is continuous and smooth.

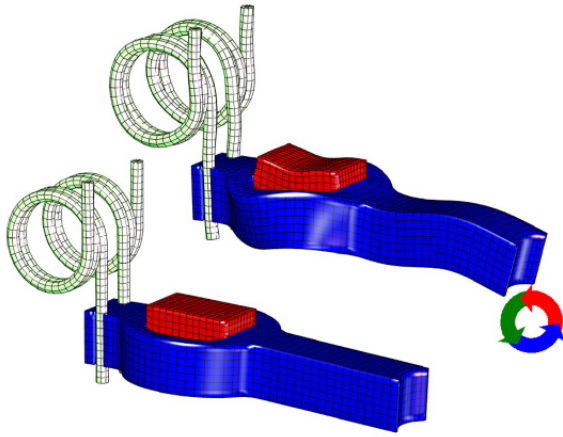


Fig. 2: The Elliptec Motor: Visualization of the motor oscillations.

The Elliptec Motor is the only commercially available actuator based on piezo-technology that delivers forward and backward motion with only a single piezoelectric element and two connecting wires.

### Stepwise motion

Because of the working principle of the Elliptec Motor the motion consists of micrometer size steps with a frequency of up to approximately 100kHz. The repetition frequency of the motor steps can easily be reduced by doing a certain number of oscillations to move the motor and introducing a waiting time in-between a bunch of these steps. Therefore the Elliptec Motor can be used to mimic a stepper motor. The difference between stepper motors and the Elliptec Motor is the variable step size of the Elliptec Motor. Therefore different step sizes can be generated. The size of one step ranges from slightly below one micrometer to continuous motion. The advantage of using an Elliptec Motor as replacement of a stepper motor is the reduction of motor size and motor costs. If the step size has to be well defined the Elliptec Motor can be used with a position feedback system e.g. a light barrier with an encoder grating. Such a setup can ensure reproducible step sizes in the micrometer range for encoder costs of only a few cents. This function of the Elliptec Motor is used e.g. for precise laser positioning systems where a mirror is tilted to certain angles.

### Continuous motion

Conventional DC motors in general generate motion with high rotational speeds and low torque. Therefore most applications demand a gear drive to reduce speed and to increase force. Because of the higher forces at lower speed with an Elliptec Motor a gear drive can be avoided in most of the applications. Due to the weight of only 1.2 grams and the absence of a gear drive the Elliptec Motor can significantly decrease the weight of an application and as well simplify it. Using the Elliptec Motor, Märklin und Cie. GmbH, Göppingen, have created a world novelty. The Series 103 train model can now realistically raise and lower its pantograph, a novelty on H0 gauge. The Elliptec Motor is perfectly tailored to the critical and tight space inside the model. Due to the intrinsically integrated friction clutch, this adult toy is also safe for children. Meanwhile, the technology is also available in the Series 152 models and in several coach models.

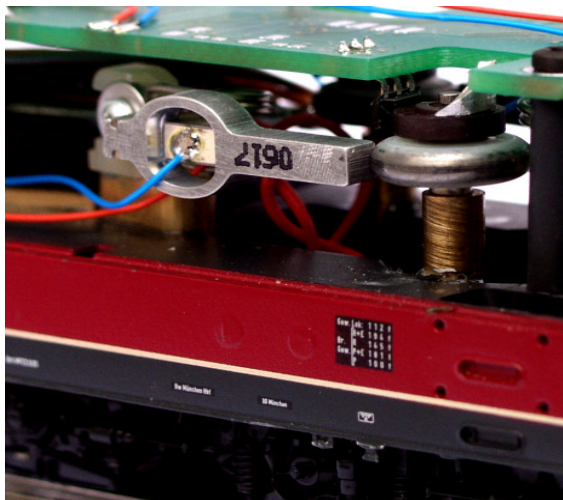


Fig. 3: Application of the Elliptec Motor in a Märklin H0 train.

### Force detection

Piezoelectric devices are capable of measuring mechanical parameters like force or vibration. The Elliptec Motor can take advantage of these attributes.

The un-powered Elliptec Motor can sense whether the driven element is being externally pushed or pulled. It generates an electric voltage of up to 0.3V in response. The polarity depends on the direction of the force.

A controller can determine if the motor motion is being blocked and react correspondingly, e.g. it can stop the motor or reverse it.

### High speed precise positioning

For precise Positioning the Elliptec Motor can be used together with a position encoder. There is a large number of different possible position feedback systems. Some of them shall be briefly introduced in the following.

Low cost positioning can be realized by the use of an encoder grating that can be read by double light barrier. By means of the change of the light signal at both light barriers from lit up (1) to lit down (0) the motion of the driven element can be monitored. In the case of a phase shift of  $90^\circ$  between the light barriers, the four situations 00, 01, 11, 10 are found when an increment is passing. The position resolution is therefore four times higher than the increment distance. By means of an analogue readout of the lit up/down procedure at the barrier we could furthermore receive interim values for a finer positioning. Such light barriers are commercially available as SMD in a cost range below 1 EURO. The advantages of this low cost precision positioning system with an accuracy of better than  $5\mu\text{m}$  are used to precisely tune a high frequency filter.

Another low cost solution is the use of a slide with an ohmic resistance as driven element. This slide is connected to a voltage divider with a center tap above the motor frame. Therefore the ratio of the voltage decrease by the motion on both sides of the motor is a reference for the position. Due to the ultra light weight of this system it is used e.g. in lightweight indoor model planes.

Capacitive position measurement systems give resolutions even in the sub micrometer range for ultra fine positioning with almost atomic resolution.

The list of the possible positioning systems could be continued at will (e.g. Hall sensors, laser interferometers...).

Because of the high motor dynamics the simplest positioning algorithm is to simply switch-off of the motor when the reference position is reached. As the motor has a very slow stopping distance it will only "overshoot" the target position a little. The slower the position is approached the shorter the stopping distance and the more precise the position can be reached by simple stopping. This regulation is particularly simple, but loses its precision when the speed is increased.

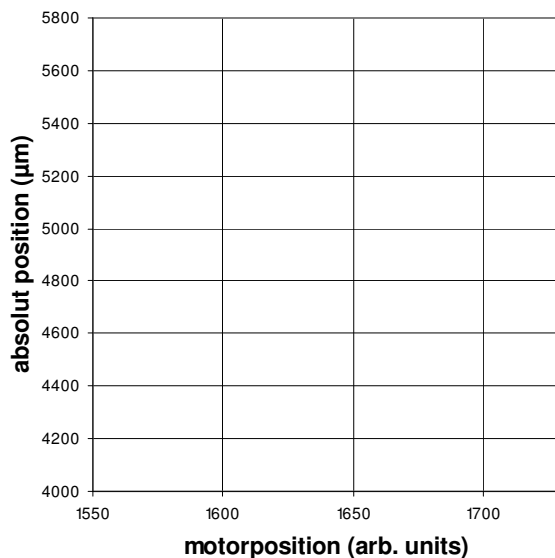


Fig. 4: Absolute position. The maximum deviation from linearity is about  $20\mu\text{m}$ .  
Reproducibility of the positions is about  $1\mu\text{m}$ .

A faster positioning can be realized by approaching the reference position with maximum speed and decreasing speed close to the target position. This procedure corresponds more or less to a proportional control algorithm. This concept needs a relatively long time (some seconds) for the precise positioning, but has proved a positioning precision in the range of  $\pm 1\mu\text{m}$ .

A very fast positioning can be reached by approaching the target position with maximum speed and a timely stop of the motor by taking into account the stopping distance. By this way the reference position can be reached directly in the ideal case. A subsequent fine positioning can then adjust some final discrepancies. The stopping distance can thereby be measured during a first test stopping and refined and corrected during each stopping.

In the case of a positioning with full braking the motor spring will be pretensioned to a maximum during the stopping procedure, so that after stopping the motor will oscillate around the stop position. In order to obtain an even quicker positioning this oscillation can be reduced. For this purpose the Elliptec Motor performs a temporally given full stimulus in the direction of the motion at the moment of the maximum spring tension (first stop after the braking/stopping period). By this the Elliptec Motor obtains its repose position without moving the driven element and there are no resp. only highly absorbed oscillations.

### **Superfine positioning by direct voltage**

By applying a DC voltage to the piezo the motor expands and causes a displacement of the driven element by approximately  $1\mu\text{m}/10\text{V}$ . This effect is used for a continuous superfine positioning with theoretically nearly atomic resolution. The limiting parameter is the friction in the bearing of the driven element. The finest position changes of the motor only pretension the motor spring, but do not generate any motion of the driven element. The motor has shown that ultra fine positioning in the nanometer scale can be achieved.

### **Integrated friction coupling for the prevention of damage**

Manual actuation is possible due to the integrated friction clutch of the Elliptec Motor. Therefore the Elliptec Motor can be used for applications where manual actuation is used as well as motorized motion like the volume control knob on a stereo, the air register in a car's ventilation system, a toy or a vibration alarm. The sensory capabilities of the Elliptec Motor indicate to the controller if a user is manually overriding the motor function.

When positioning feedback is included in the drive, the position of dials and gauges may be determined. The Elliptec Motor is able to generate a wide spectrum of mechanical vibrations to provide silent, tactile feedback to a user who touches the driven element or the housing. This capability of the Elliptec Motor goes beyond that of conventional vibration alarms, which are used e.g. in cell phones.

If audible operation is desired, the acoustic capabilities of the Elliptec Motor may be used as well.

### **Explosion prevention, motion under vacuum or in rugged environment**

Because of a motor principle that works without a collector and at very low voltages the motor avoids any sparks and is therefore suited for environments where explosion prevention is needed. Often these requirements have very rugged conditions for using Motors. The Elliptec Motor is because of its simplicity and its tolerance for particles, dust or various atmospheric conditions suited for a lot of applications where classical driving solutions fail. The motor is used even in high-vacuum applications where the simple construction without gas trapping cavities or evaporating materials insures good vacuum conditions.

### **Summary**

The Elliptec Motor is a new low-cost piezoelectric motor for various applications. It can be used like a DC-motor or like an ultra-precise stepper motor with noiseless motion. The Elliptec Motor offers new solutions for high precision positioning under a wide range of environmental conditions. Even under rugged conditions or in vacuum applications the Elliptec Motor can generate precisely controlled motion with only very little electronics. With its force detection capabilities the Elliptec Motor is also used as a sensor to detect external forces as well as blockages of the driven element. Due to the motor principle its integrated friction clutch prevents damage when extended external forces are applied.

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