Reliability of Q-Motion® Systems

Lifetime, Vacuum Applications, Wear

Contents

1 Working Principle of a Q-Motion® Piezomotor

Drives for Q-Motion® positioning stages are based on the principle of inertia (stick-slip drives). Piezo inertia drives save space, are inexpensive, and have relatively high holding forces in addition to a virtually unlimited travel range. Cyclic alternation of stiction and friction between the moving runner and a piezoelectric actuator ensures continuous feeding of the runner. With an operating frequency of max. 20 kHz, the drives acting directly on the runner and achieve velocities of up to 10 mm/s.

Essentially, every Q-Motion® stage uses a compact motor consisting of a piezo actuator, a base body for the motor and the coupling element. This element is pushed against a runner with defined preload, which then provides the desired drive force.

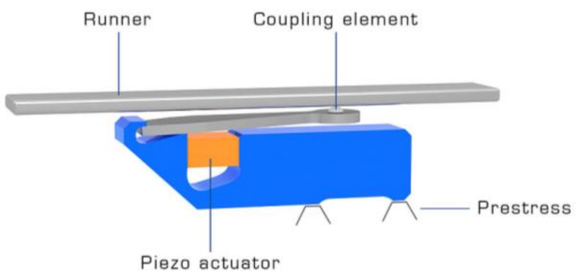

Fig. 1: Schematic diagram of a Q-Motion® inertia motor

The actuator is based on a piezoelectric ceramic that is completely free of wear and designed for a high number of cycles. It is displaced by an electrical control voltage (sawtooth profile), which results in forward or backward motion of the runner.

The contact point of the coupling element and the runner involves friction and is therefore subject to wear.

2 Lifetime

2.1 Lifetime in a Standard Environment

The lifetime is influenced mainly by the ceramic coupling element and the ceramic runner. The friction (slip-phase) resulting from the underlying inertia principle is subject to wear. However, this wear can be considerably reduced or avoided by using suitable materials.

To reduce / avoid wear and the resulting ceramic particles, a vacuum-compatible grease is used that is applied to the runner. The use of grease does not have a negative influence on the motor force to be generated but actually ensures a softer sliding phase and therefore improved controllability.

Continuous lifetime testing began 2 years ago and already indicates an endurance of at least 80 km with the following parameters:

- Full travel range for linear actuators
- Complete rotation for rotational axes
- Load acting against the motor force; weights for linear motion and weights for generating a torque for rotational motion.
- Max. 50% duty cycle
- Mounting by screwing the positioning stages to robust bodies made of aluminum or steel.

2.2 Lifetime in the Vacuum

The use of vacuum-compatible grease is even more important when the stages are operated in a vacuum.

In a standard environment, a ceramic stores water in its structure in the same way as a sponge, which, without lubrication, leads to light wear. After some time, a sort of saturation occurs, which means that the runner or the coupling element grind against each other and the surface is polished as a result.

If the stage is then operated in a vacuum, the water molecules stored in the ceramic detach themselves and this increases wear dramatically.

To compensate this, all friction bodies of the Q-Motion® series are coated with a vacuum-compatible grease that prevents the ceramic from "drying out".

Despite the use of grease, the lifetime in a vacuum is still considerably shorter when compared to a standard environment.

Durability tests in the Q-Motion® vacuum chamber indicate an endurance of at least 1.2 km with the following parameters:

- Full travel range for linear actuators
- Complete rotation for rotational axes
- In some cases with a static load in both a horizontal and a vertical direction.
- 10% duty cycle and reduced velocity. Due to the lack of air for cooling the piezoceramic, the duty cycle must be reduced significantly to keep the energy input and the resulting heat generation within the limits tolerable for the motor.

It is absolutely necessary to screw the Q-Motion® stages to a solid metal surface to allow the heat to dissipate from the motor via the metal.

2.3 Power Consumption of the Positioning Stages

Motor controller performance	Q-Motion® Stages	~15% piezo hysteresis and heat input
10 W @ 20 kHz	Q-614, Q-622, Q-632	Approx. 1.5 W
10 W @ 20 kHz	Q-522, Q-521, Q-821	Approx. 1.5 W
30 W @ 20 kHz	Q-545, Q-845	Approx. 4.5 W

The table shows the power consumption of the different Q-Motion® stages with respect to the individual axes. The respective maximum values apply to an operating frequency of 20 kHz. In this case, it is necessary to make sure that the piezoceramic works with a hysteresis of 15 % (reactive power proportion) and also that the electrical energy introduced into this reactive power proportion is converted to heat.

Attention must be paid to this characteristic when operating in a vacuum or when operating continuously in air to avoid overheating and failure of the motor.

3 Test Environment

3.1 In the Standard Environment

Durability tests were performed for the following stages

Q-Motion® Stages	Minimum endurance
Q-614	Approx. 1 million rotations (360°). With load, open loop
Q-622 / Q-632	Max. 570,000 rotations (360°). With load, closed loop
Q-522	50 km, no load, closed loop
Q-521	77 km, with load, closed loop
Q-545	72 km, with load, closed loop

Durability tests were performed for the following controllers

Motor controller and driver
E-870.1G
E-871.1A1
C-885 / E-873.10C885

Stage with and without anti-creep system

Q-Motion® Stages	Anti-creep system yes / no
Q-522	No anti-creep system
Q-521	No anti-creep system
Q-545	With anti-creep system

All systems are in continuous operation, which means that the endurance of the stages also increases continuously. The test of each individual axis is considered to be completed only when it fails.

At the beginning of the test, guides with anti-creep system were not available on the market. Therefore, the guides for the Q-522 and Q-521 were installed without anti-creep system. This can lead to so-called cage creep during operation and standstill of the axis at an undefined point in time. The cage must then be pushed back to the correct position manually and the axis can then be restarted.

Depending on the customer application (with high cycle numbers), it has been possible to equip the Q-521 / Q-522 with an optional anti-creep system since the end of Q2, 2017.

The Q-545 is already equipped with an anti-creep system and is not affected by this behavior.

At the same time, the durability of the electronics will also be tested during the course of the tests on the mechanics. It is particularly important for long-term applications in OEM projects to make a statement on both the electronics and the mechanics.

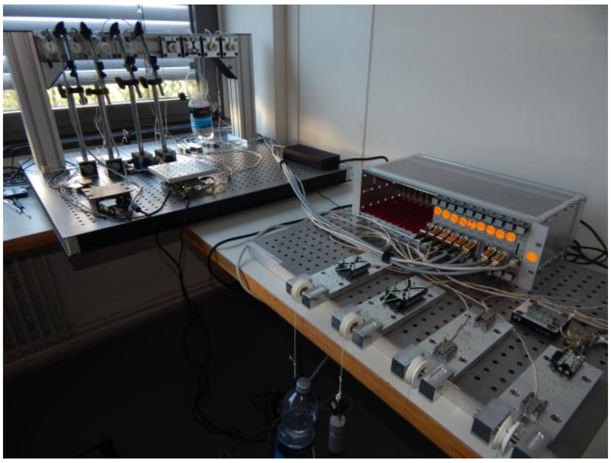

Fig. 2: Test environment in standard surroundings

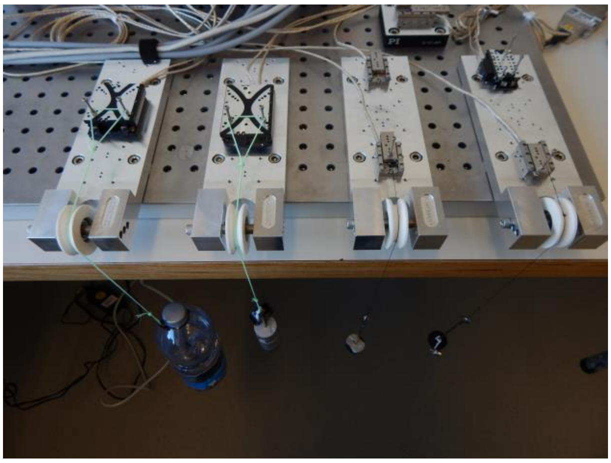

Fig. 3: 6x linear stages with partially static load for generating a force in the motion direction.

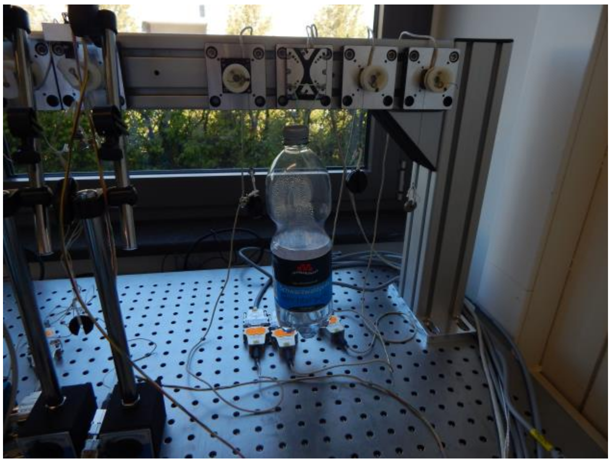

Fig. 4: 3x rotation stages with static load in Z for generating a torque. 1x linear stage with load in Z

3.1.1 Conclusion on the Lifetime in a Standard Environment

Q-Motion® systems are suitable for applications with small to medium numbers of cycles. Before starting up the systems, it is strongly recommended to define the duty cycles and the system environment together with PI.

Example: If the Q-Motion® stage is to be controlled in the application with very small steps and a higher number of cycles, premature wear and failure is possible. This is also true even if the actual endurance is lower than the values measured during the endurance tests.

In applications, in which the same part of the travel range is used continuously, it is further recommended to perform so-called lubrication runs. The positioner is moved several times over its entire travel range to distribute the lubrication.

3.2 In the Vacuum

A specially developed vacuum chamber was used for endurance testing.

The following positioning stages were tested in a vacuum

Q-Motion® Stages	Endurance
Q-622.930	Min. 5870 rotations (360°). Without load.
Q-522.14U	Min. 100 cycles
Q-521.14U	Min. 1.2 km
Q-545.X4U	Min. 0.4 km

The following controllers will be tested

Motor controller and driver
C-885 / E-873.10C885

Stages with and without anti-creep system

Q-Motion® Stages	Cage control yes / no
Q-522.14U	No anti-creep system
Q-521.14U	No anti-creep system
Q-545.x4U	With anti-creep system

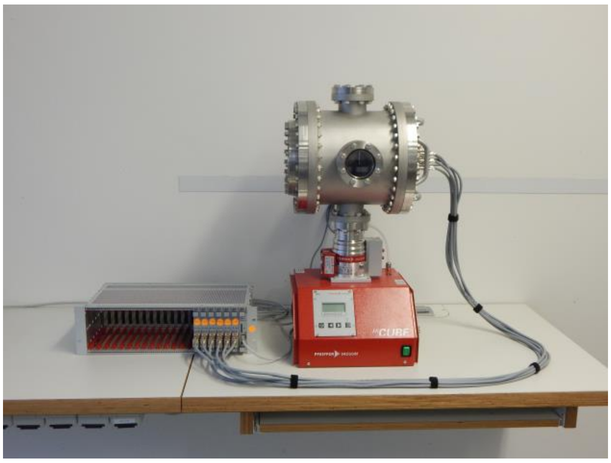
Fig. 5: Vacuum chamber and C-885 multi-axis controller


Fig. 6: View in the vacuum chamber

3.2.1 Conclusion on the Lifetime in a Vacuum

The number of cycles that have already been measured are currently low because of both the short testing time of 4 months (as of May, 2017) and the reduced duty cycles.

It is recommended to keep the number of cycles low and avoid continuous motion. Point-to-point motion is ideal for classical positioning tasks.

About PI

In the past four decades, PI (Physik Instrumente) with headquarters in Karlsruhe, Germany has become the leading manufacturer of nanopositioning systems with accuracies in the nanometer range. With four company sites in Germany and eleven sales and service offices abroad, the privately managed company operates globally.

Over 850 highly qualified employees around the world enable the PI Group to meet almost any requirement in the field of innovative precision positioning technology. All key technologies are developed in-house. This allows the company to control every step of the process, from design right down to shipment: precision mechanics and electronics as well as position sensors.

The required piezoceramic elements are manufactured by its subsidiary PI Ceramic in Lederhose, Germany, one of the global leaders for piezo actuator and sensor products.

PI miCos GmbH in Eschbach near Freiburg, Germany, is a specialist for positioning systems for ultrahigh vacuum applications as well as parallel-kinematic positioning systems with six degrees of freedom and custom-made designs.