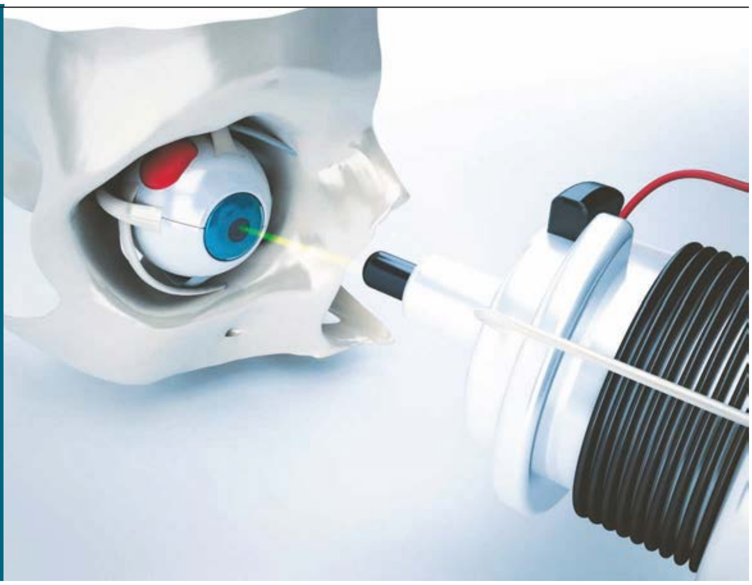
Piezo Mechanisms Improve Refractive Eye Surgery

PIEZO MECHANISMS PROVIDE MOTION CONTROL FOR OPHTHALMOLOGY



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Piezo motion-based precision mechanisms provide a number of features that are highly sought after in medical applications, such as lubricant-free design and sterile, ceramic actuation. Ceramics are also non-magnetic, an advantage in high-energy imaging/scanning based on strong magnetic fields.

Improving Vision

In contrast to many animals, humans strongly rely on their visual sense, i.e. they acquire most information visually. Successful correction of vision defects reaches back into the 13th century, when optical glasses became precise enough to make a difference. The first clinical studies investigating surgical methods to shape the cornea started in the 1930s.

With the advent of the laser, the steel scalpel has been replaced by high-energy photons, and a number of different laser methods have become established that correspondingly influence the curvature of the cornea to correct visual acuity. They all have one decisive factor in common: laser beam control and focusing that requires high-precision positioning systems. Piezo-based mechanisms usually have an advantage here. They work with the necessary precision, are fast, reliable, and can be integrated well in today's laser systems due to different and compact designs, and they offer gimbal actuation in a compact package.

Precision Shaping and Cutting

Today, ametropia – a disorder in which images do not come to a proper focus on the retina – can be corrected up to high diopter ranges with refractive surgery techniques. For this purpose, the shape of the cornea is modeled in the optical axis by removing small cornea particles with laser energy, so that the resulting refractive power of the cornea (epithelium) matches the length of the eyeball again (figure 1).

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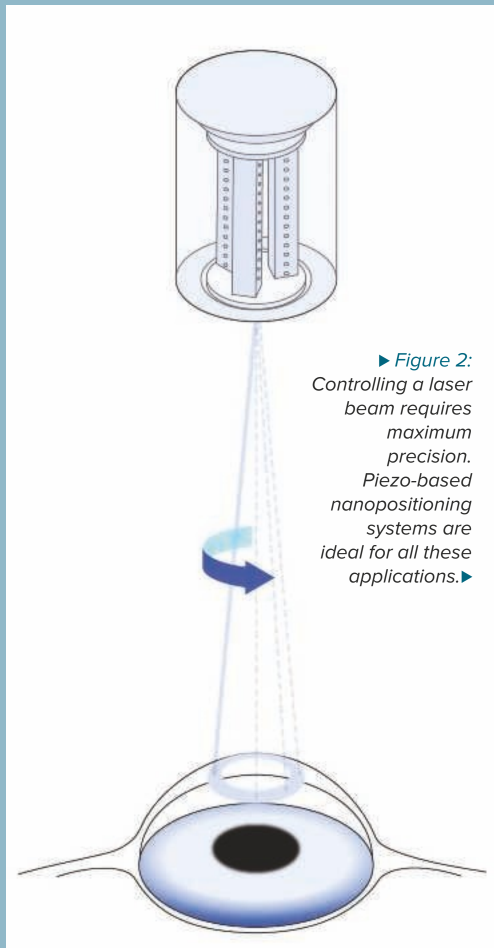
▶ *Figure 1: In order to compensate for ametropia, the shape of the cornea is modelled in the optical axis by removing small cornea particles with laser beams so that the resulting refractive power of the cornea (epithelium) matches the length of the eyeball again.* ▶



▶ *Figure 2: Controlling a laser beam requires maximum precision. Piezo-based nanopositioning systems are ideal for all these applications.* ▶

With Epi-LASIK (epithelial laser in situ keratomileusis), the epithelium is first prepared with a microkeratome (mechanical preparation scalpel) or a laser. The resulting thin corneal flap is then lifted to the side. The top cell layer of the cornea in the treatment area can also be removed using a small special instrument in the form of a PRK scraper (photorefractive keratectomy). In the case of so-called LASEK (laser-assisted sub-epithelial keratomileusis), the surface of the cornea is perforated with a scratch ring, then briefly moistened with a weak alcohol solution for ablation, and carefully pushed to the side by hand. Only then does the actual laser treatment take place. A video animation is available at http://youtu.be/FVneEQZVjm8.

Femtosecond and Excimer Lasers

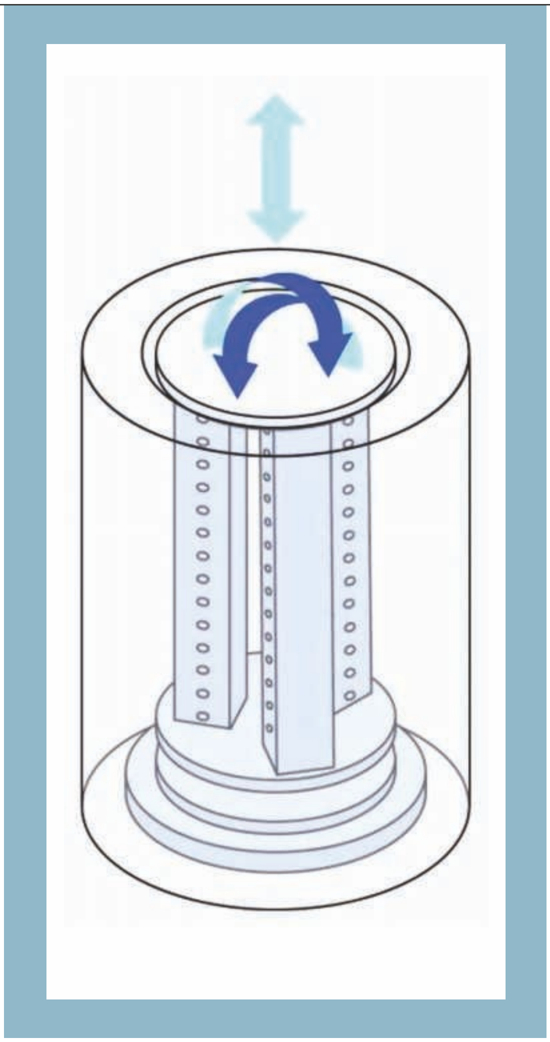
Two different laser types are used for these refractive operations: excimer lasers and femtosecond lasers. The latter work in the infrared range and send light pulses with a duration in the femtosecond range (one femtosecond is equal to 10-15 sec). The laser energy is not discharged on the surface of the cornea but inside at a predetermined depth for a duration of several femtoseconds. In this way, tissue can be cut with extreme precision and practically without generating heat. This can be used in the above-mentioned LASIK method to remove the thin corneal flap. Femtolasers can also be used to prepare corneal tunnels for intracorneal implants, e.g. for artificial lenses.

The femtolaser does not correct the ametropia, however. This is where excimer lasers come into play. They emit UV light, whereby the energy of the laser beam is discharged directly on the surface of the cornea. The laser beam only penetrates a micrometer-wide tissue layer of the cornea and vaporizes the tissue there. The cornea is shaped very precisely so that myopia, hyperopia or astigmatism can be corrected.

Highly precise beam control is absolutely crucial for both lasers used. With the excimer laser process, an integrated eye tracker monitors the position of the eye and correspondingly adjusts the placement of the light beam with a reaction time of less than 1/100 of a second. The laser beam also has to be correspondingly guided for this, as well (figure 2).

▶ *Figure 3: Compact piezo laser beam steering mirror unit with two orthogonal axes. 120 mrad optical deflection angle with 0.0005 mrad resolution; length 38 mm. Parallel kinematics design for single pivot point, no polarization rotation.* ▶

▸ *Figure 4: Parallel kinematics 3-axis positioner (tip/tilt and piston motion), based on 3 actuators. All actuators connect directly to the same platform.* ▸



Piezo High-Speed Laser Steering Mirrors

Common deflection techniques, such as galvo scanners, are basically suitable for such high-precision applications on the human eye, but they have limitations. To be able to position in two axes, two systems have to be stacked. This results in a pivot point shift, polarization rotation and additional space and alignment requirements for integration.

Piezo-driven steering mirror systems (figure 3) are the better alternative here. In addition to providing superior position accuracy, high dynamics and acceleration, they are much more compact. They provide optical deflection up to 120mrad, extremely fast response (single-digit milliseconds with mirror), as well as position resolutions into the nanoradian range.

Piezoceramic actuators are the driving force behind these scanning and positioning systems. Actuators exploiting the piezoelectric effect can move with atomic resolution, can respond to an electric control signal in microseconds, and provide scanning bandwidth with frequencies up to several thousand hertz. The motion is based on crystalline effects, and so there are no traditional mechanical parts that can cause wear and friction. There is also no maintenance. The steering mirrors also do without mechanical bearings. This means they also do not require lubricants, are sterile and can be baked out at high temperatures, ideal prerequisites for medical applications. Motion is guided by flexure joints, directly driven by the solid-state actuators. There is nothing to wear and nothing to cause backlash, or play. Piezo mechanisms present capacitive loads to the control electronics and dissipate no power in steady state operation.

In the case of tip/tilt steering mirror systems, piezo drives are used in parallel kinematics arrangement (figure 4). This structure has various advantages over traditional serial, or stacked systems: there is only one moving platform with a common pivot point, the dynamics are higher, and the size is smaller. In addition, the systems achieve a higher linearity than can be realised by stacking two single-axis systems, such as galvanometer scanners. Integrated high-resolution position sensors ensure high linearity and repeatability of typically 5 µrad.

Optical Coherence Tomography

Another ophthalmological application of high-resolution, high-speed steering mirrors is optical coherence tomography (OCT), most often used as a quick, painless approach to quantitative morphological metrology of retinal structures in clinical settings. Here, the fast scanning and gimbal actuation of piezo-driven steering mirrors are key to reliable, repeatable imaging, which provides sub-cellular resolution for identification and monitoring of many retinal pathologies. Since patients are fully conscious during OCT procedures, fast tracking of involuntary eye movements is also a requirement, and here the piezo mounts' capability of sub-millisecond responsiveness and consistent responsiveness in both gimbal axes are very valuable.

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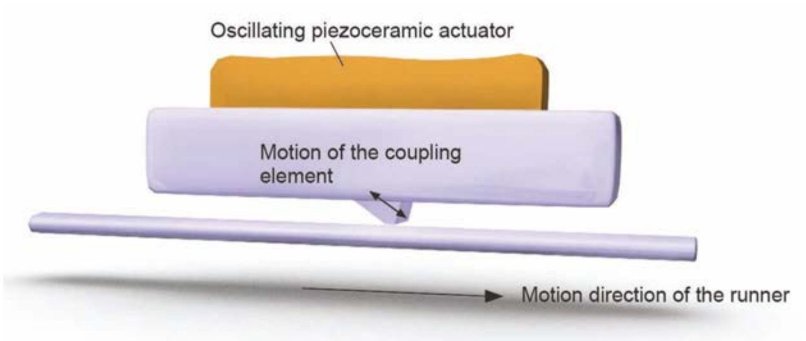

▶ *Figure 5: Functional principle of a latest-generation ultrasonic linear motor: nanoscopic oscillations with frequencies in the 100s of kHz of a piezoceramic actuator, are converted into a linear motion driving a runner of a mechanical structure.* ▶

Piezo Ultrasonic Motors

In addition to piezo flexure mechanisms, for short travel ranges, ultrasonic ceramic piezo motors open up new possibilities for laser beam control. Ultrasonic motors provide basically unlimited travel with acceleration to 10G's, velocity to 100s of mm/second in a very compact package.

The latest-generation ultrasonic drive principle (figure 5) makes it self-locking at rest, holding a position steady without jitter and with no heat dissipation or the need for a mechanical brake.

Piezo mechanisms open up new possibilities for ophthalmology and medical engineering, such as laser beam control and focusing. The advantages encompass miniaturisation, higher precision and speed, lower energy consumption, sterile design and lubricant-free operation. ●

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