PIEZO ACTUATOR DRIVE

PAD (Piezoelectric Actuator Drive) is a drive technology transforming the linear motion of high performance piezoelectric multilayer actuators into a powerful and precisely controllable rotation.

Advantages of PADs:

- High precision/accuracy
- High dynamics
- System simplification
- Scalable technology

noliac

PIEZO ACTUATOR DRIVE

Applications

Medical devices

Surgical robots/biopsy robots

Treatment tables for Magnetic Resonance Imaging (MRI)

Fluid management in fusion/insulin pumps

Mammography

Automation

Precision valves

Positioning drives

Pick and Place Automation

Microdosing systems

Rotary modules for robots

Micro production and assembly

Extreme condition remote handling

Robotics

Personal assistants for handicapped people

High precision welding robots

Human machine interface with force feedback

Automotive

Camshaft adjustment

Exhaust Gas Recirculation (EGR)

Adaptive spoiler

Weight compensated trunk deck

Seat adjustment/window lifters

Variable Valve Timing (VVT)

Aviation/Military

Servo valve/Electro-hydraulic actuator

Flight control surface actuation

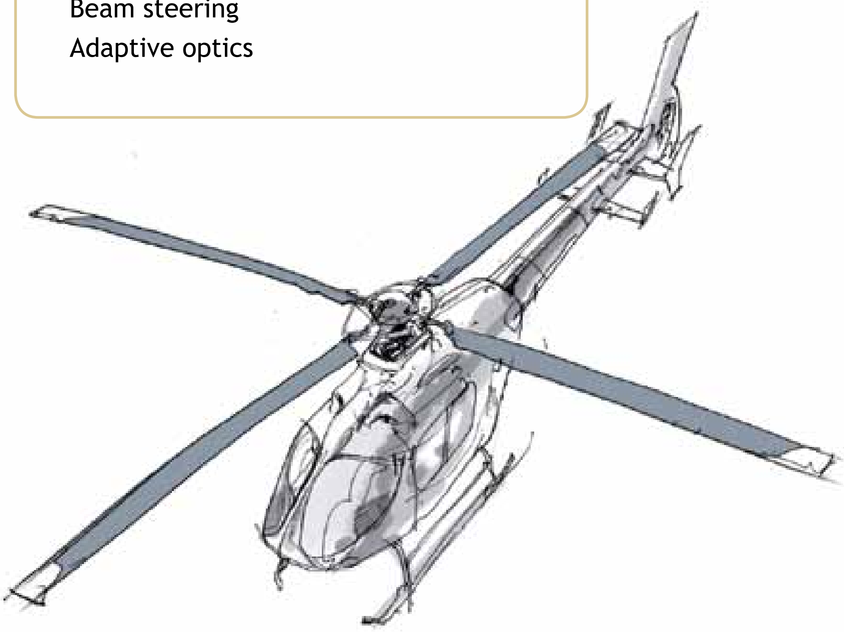
Positioning/ adjustment of surveillance of reconnaissance systems

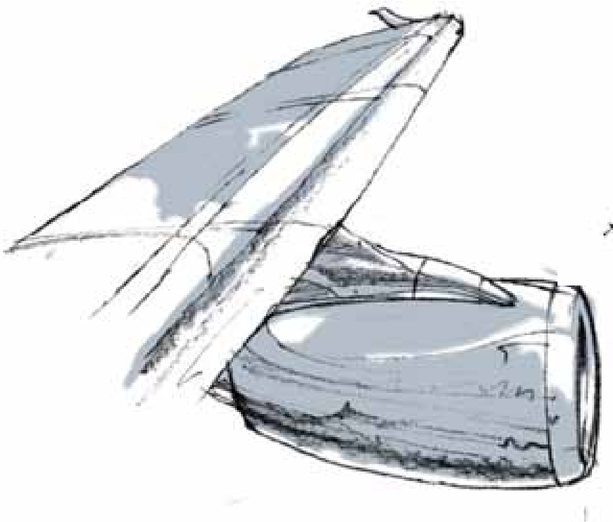
Antenna adjustment

Optics

Beam steering

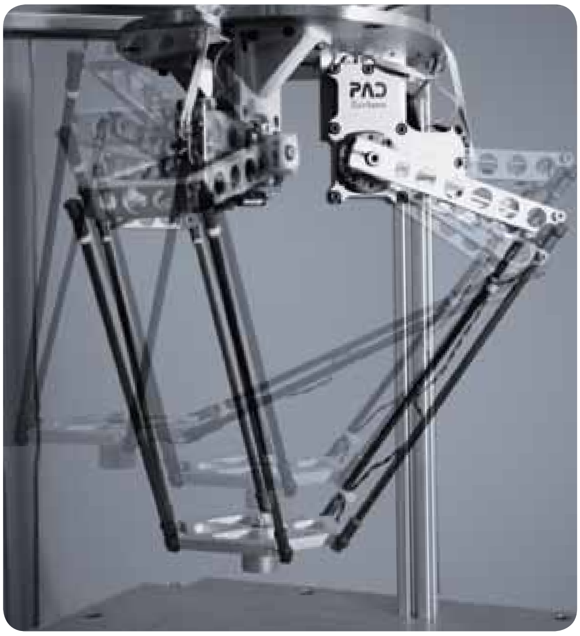
Adaptive optics





PIEZO ACTUATOR DRIVE

Introduction



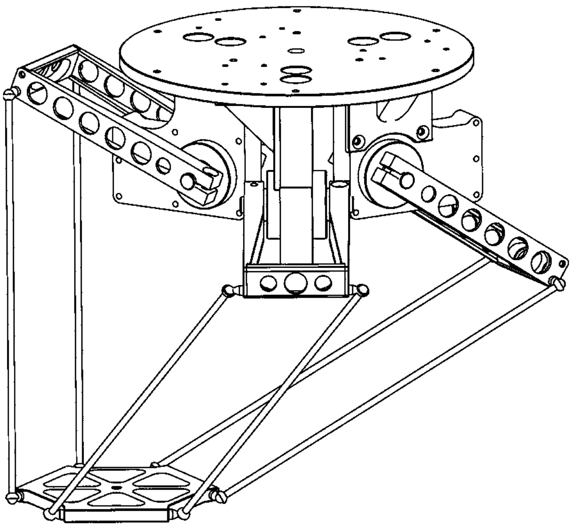


Figure A: Delta-3 Robot Design

Siemens AG initiated the development of the PAD technology from 2000-2008, but a partner with an extensive knowledge in the field of piezo technology for commercialization of the technology was needed. Noliac was selected to acquire the PAD technology in 2010. The transaction included more than 20 patent families, fully equipped laboratories, PAD prototypes, demonstrators and training of engineers.

Since then, extensive work by the skilled Noliac engineers has optimized, scaled and customized the PAD drives for specific industrial partners.

SIGNIFICANT IMPROVEMENTS

Among many improvements, Noliac has developed a special piezoelectric bender actuator increasing the efficiency of the drive and making assembly easier as the number of parts thus was decreased from 29 to 19 parts. Also, this design makes it possible to fit the kinematic parts into a much smaller and cylindrical housing, which is preferred because it facilitates the replacement of existing motors in the market.

Further, new shapes of the micro-toothing have been designed with the effect of optimizing performance.

OVERCOMING ELECTROMAGNETIC MOTOR LIMITATIONS

Within industrial, medical, and robotic application areas, powerful, precise and small electrical drives coupled with sensing capabilities are becoming increasingly important. Mechatronic system solutions are strongly recommended as the tasks become more and more complex and high-level integration of encoders, gearbox, mechanics, sensors and electronics is becoming mandatory. As a result of these requirements, there is increasing interest towards piezoelectric drives, which in principle are able to overcome some of the limitations of conventional electromagnetic motor drives by utilizing the smart sensor/ actuator properties of piezoelectric materials. Moreover, due to the direct acting principle, piezoelectric motors in general do not necessarily require a gearbox. Thus, weight, size and complexity may be significantly reduced.

OPEN-LOOPED AND STRONGLY SYNCHRONIZED

As PAD is open-loop controlled, PADs can be strongly synchronized to each other, allowing the PAD to be perfectly suited for robotic applications. In this context, a so-called Delta-3 robot has been designed to prove its capabilities. A common field programmable gate array (FPGA) synchronously drives the precise and efficient power stages of all three motors. This ensures that the Delta-3 robot not only shows very high resolution, but also is capable of high repeatability.

PIEZO ACTUATOR DRIVE

Technology

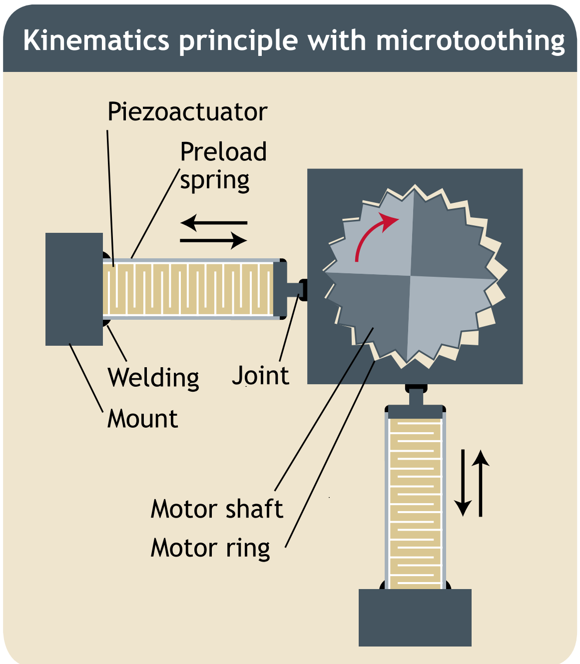


Figure B: New approach transforming linear movement into controllable rotation

The principle of the PAD technology rests upon the conversion of the periodic elongation of powerful multilayer actuators into precise rotation of a motor shaft. To improve the performance of the PAD even further, a newly developed micromechanical interlock between the motor ring and the motor shaft was applied, increasing torque and precision while avoiding backlash and slippage.

The approach, as shown in Figure B, is an arrangement of two orthogonally orientated piezo multilayer stacks directly attached to a motor ring covering a motor shaft, the diameter of the shaft being slightly smaller than the internal diameter of the ring.

Thanks to the innovative design, the PAD drive uses very few components compared to servo-controlled drive systems, allowing a more straightforward, compact and reliable design.

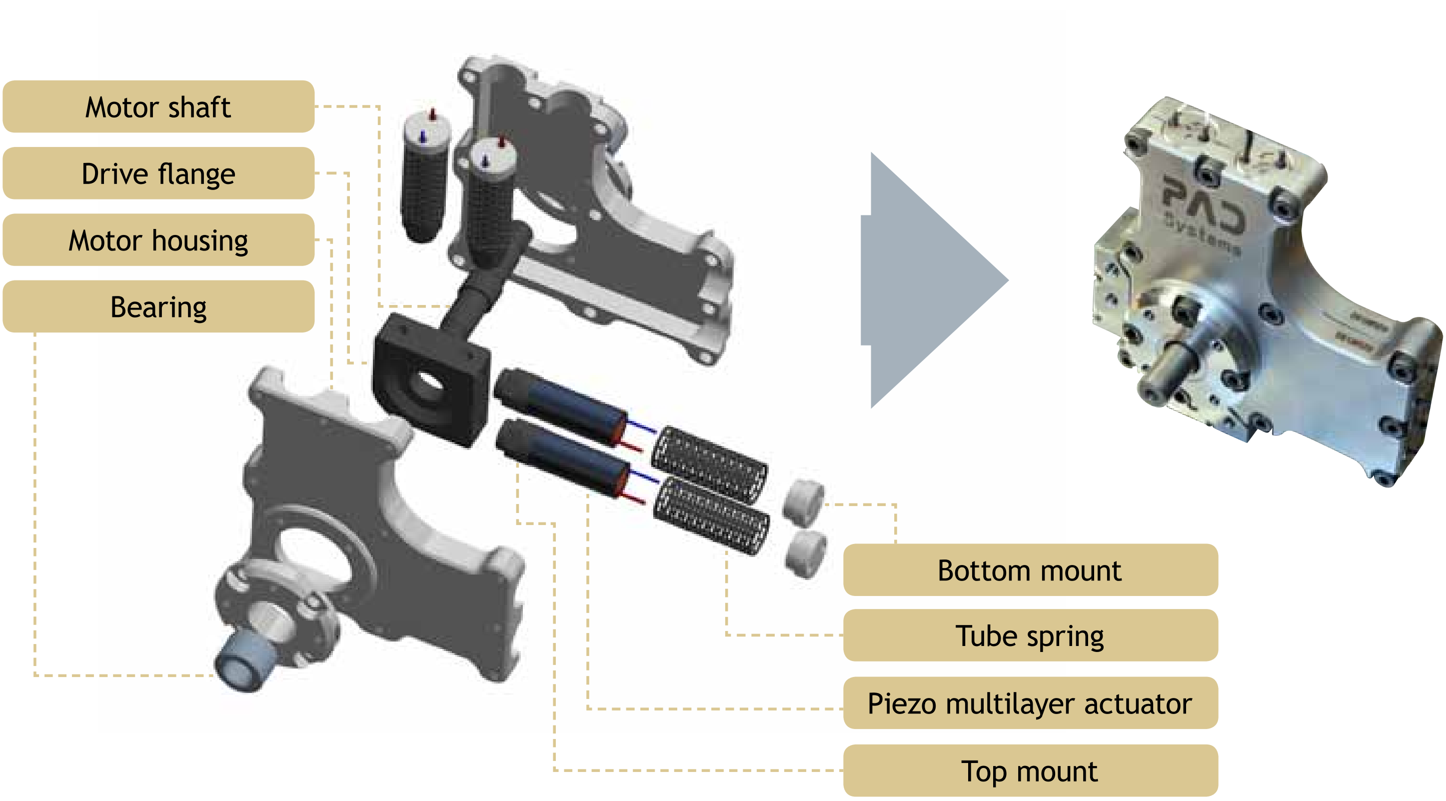


Figure C: Assembly parts and prototype

PIEZO ACTUATOR DRIVE

Features

Due to the properties of piezo components and the innovative design the piezo actuator drive offers, considerable advantages in terms of precision, dynamics, torque/ load sensing and scalability are prevailing.

Additionally, similarly to the Noliac state-of-the-art multilayer piezo components, the PAD is capable of operating under extreme conditions such as high magnetic fields, radiation, vacuum and high temperature. The PAD has no magnetic stray field.

PRECISION

- Positioning accuracy and repeatability (<2 arc seconds) without encoders/decoders
- No gearbox required/no backlash
- No overshooting

DYNAMICS

- High acceleration and deceleration without e-brake (low inertia)
- Slow and precise motion possible (0 to 60 rpm)
- Speed is independent of load

TORQUE/LOAD SENSING

- Smart load sensing without torque sensors
- High torque without gearbox/no backlash (typ. 5 Nm)
- Overload protection

SCALABILITY

- Scalability in terms of power, relative speed and torque
- Synchronization of multiple PADs possible

OTHERS

- No power consumption when holding a load
- Function not affected by strong magnetic fields
- No magnetic stray fields

PIEZO ACTUATOR DRIVE

Features

As the piezoelectric effect not only enables actuation, but also provides sensor capabilities in parallel, the PAD is capable of delivering real time torque measurement, which allows a very compressed drive system design.

Due to the adaptability of the kinematic principle, the PAD technology is perfectly scalable in terms of size, power, actuators, materials and drives.

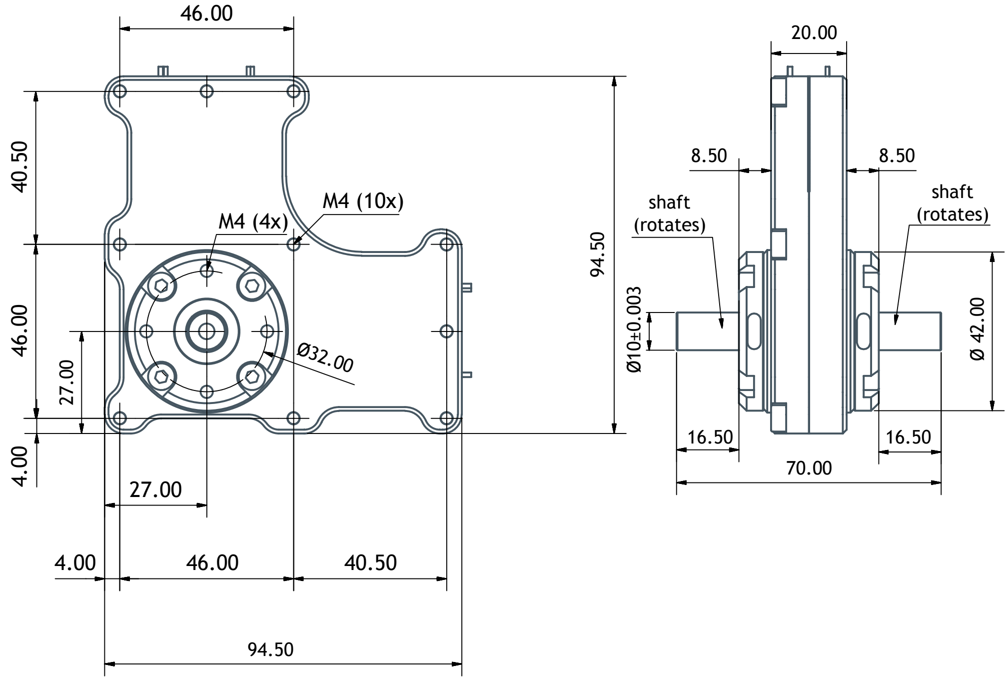


Figure D: Interface drawing of the PAD7200 prototype. Units in mm.

PIEZO ACTUATOR DRIVE

Reliability and service life

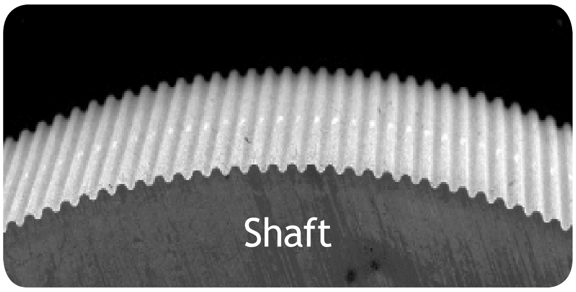


Figure E: Shaft enlargement and tooth geometry

Since internal forces in the PAD motors are comparatively low, and all structures have to be very rigid to reduce elasticity, most parts are rather oversized and will survive longer than ever needed. The two most critical parts are the actuators and the toothing. However, the actuators in the prototypes are made for more than 3×10^9 load cycles, which in case of the PAD corresponds to about 3000h operation at full speed (which only occurs in applications where PADs are not the obvious choice).

The motor has been tested on a specifically designed test bench and subjected to more than 10^7 load changes, and no breaking of teeth was observed due to the low surface pressure and the large number of teeth.

TOOTH GEOMETRY

- Tooth module (corresponds to diametral pitch): 38 µm
- Depth 36 µm
- Number 312 (shaft), 313 (ring)
- Spacing 120 µm
- Length 6 mm

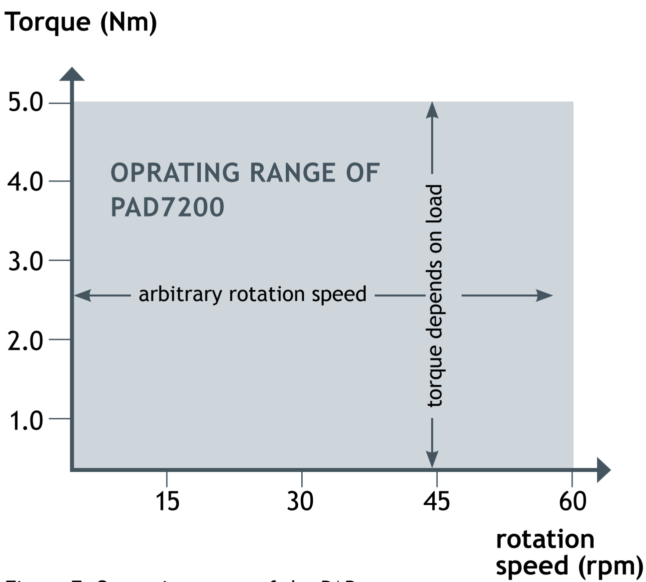


Figure F: Operating range of the PAD

PIEZO ACTUATOR DRIVE

Reliability and service life

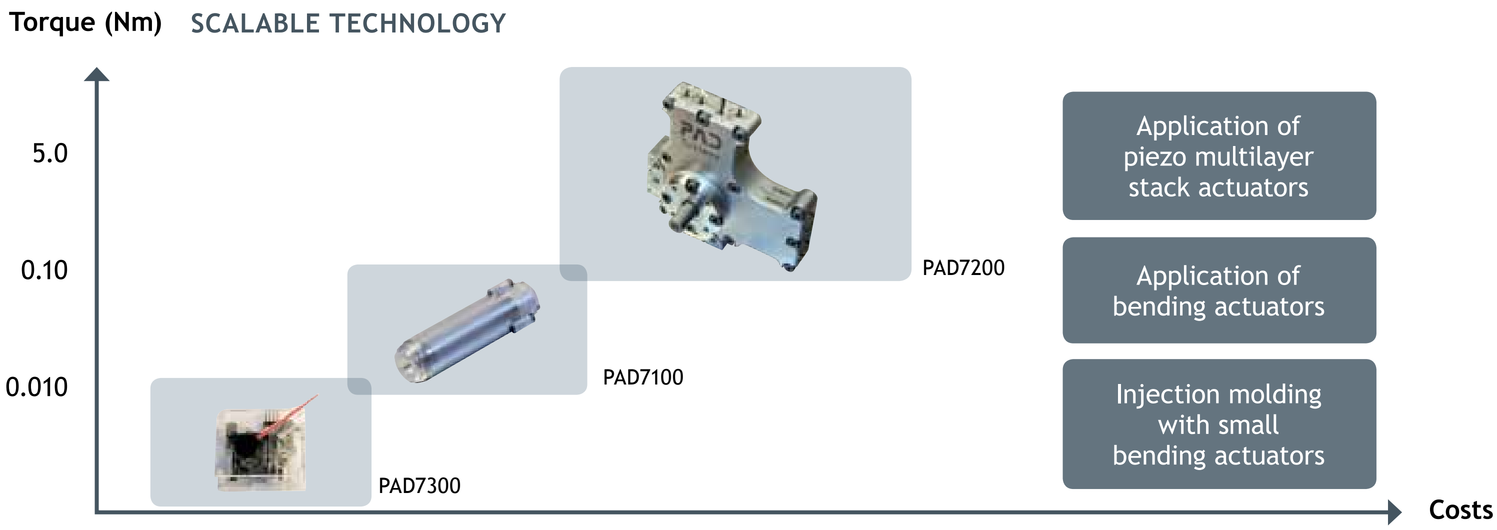


Figure G: The PAD is a scalable technology

Features

State-of-the-Art piezoelectric motors are all based on discontinuous operating principles (either resonant or non-resonant). By subsequent elongation of a few microns of the actuator, macroscopic motion is achieved. Yet, these friction based approaches continuously lead to small, self blocking piezoelectric drives which limitations are set by slippage, backlash, wear and restricted reliability.

Although well established throughout applications and markets, existing conventional motors pose certain limitations and sometimes problems that may be overcome with the PAD technology. Table A lays out the generic limitation and problems to be encountered with existing motor and drive systems, while the PAD technology characteristics are set against the limitations:

LIMITATIONS ON EXISTING DRIVE SYSTEMS COMPARED TO PAD

Motor types	Problems/Limitations	PAD Characteristics
DC/EC Motor	• Low dynamics due to high stored rotational energy • Gearbox required for most applications introduces backlash • Precise gearbox very expensive • No positioning information • Matching of motor and gearbox difficult • Operation point deviates from point of highest efficiency • Most motors are oversized	• High dynamics due to low stored energy • No gearbox/no backlash in micro-gear • Open loop positioning with high resolution • No matching required • Always operating at constant efficiency • Much lower power sufficient for many applications
Servo Motors	• Same limitations as DC/EC Motors without positioning • Positioning accuracy limited to resolution of encoder • Accuracy of encoder deteriorates with higher temperatures • Overshooting due to closed loop control • Slow motion very difficult to realize • High system complexity susceptible to failures • Relatively low torque	• High resolution with open loop control possible • Accuracy independent of temperature • No overshooting • Very slow motion possible • Smart load sensing possible during operation • Low system complexity • High torque density
Stepper Motors	• Same limitations as DC/EC Motors without positioning • Step failures result in loss of positioning information	• Jumps only occur under overload • No loss of positioning information even if jumps occur
Piezo Motors	• No absolute positioning possible without encoder • Limited in terms of power (1 W) and torque (1 Nm) • No load sensing possible	• Power of up to 20 W and torque up to 20 Nm possible including smart load sensing
All above	Characteristics are highly dependent on temperature and humidity	Optimized according to needs

Table A: Limitations on existing drive systems compared to PAD

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Performance

The following Table B represents a preliminary datasheet of the PAD7200 prototype giving a summary of the essential PAD characteristics:

Specification	Value	Comment
Operating voltage	60V to 200V	Depends on the actuator that is used and can be adapted to customer’s needs within certain limits
Speed range	0 – 60rpm	Real “0” is possible, also slow movement with full torque
Stall torque	5Nm	Maximum torque, i.e. then the teeth will jump during operation. If the motor is motionless, the back drive torque is higher (around 9Nm in some cases)
Rated torque	5Nm	The motor can be used until the teeth jump.
Rated speed	0-60rpm	Since there is no ideal working point or point of highest efficiency, there is no distinction between maximum speed and rated speed.
Inertia (shaft)	0.423 kg mm^2	
Useful angular stroke	Infinite	Continuous
Angular backlash	None	Due to the form fit principle, many teeth are in contact at the same time, and there is thus no backlash.
Bandwidth	0 to 300Hz	Operating frequency
Mass	~ 0.5kg	
Mechanical output power	~ 20W	
Angular resolution	< 0.0005° (2 arc second)	Standard driver setup
Start/ stop time	1*10-3 s	
Dimensions	95mm x 95mm x 30 mm, L-shaped	Shaft protrudes from this housing (length about 60mm, depending on the shaft that is in use)

Table B: Preliminary datasheet of PAD7200 prototype

DRIVER SET-UP

Regarding a driver set-up for the piezo actuator drive, basically two things are needed:

- A signal source that generates two sine signals with a phase shift. This can be achieved with a simple signal generator or with a separate analogue or digital signal generator box including look-up-tables or with a computer program that can generate digital values for the sine signals.
- A signal amplifier that is able to amplify the sine signals put out from the signal generator with an amplitude of 0-5V for example to a piezo driving voltage of 60V or 200V, depending on the type of actuator used. This has to be done with high efficiency.

Please contact Noliac regarding driver set-up assistance.

PIEZO ACTUATOR DRIVE

Patents

The PAD technology is covered by the following granted patents:

Official No.	Full Title	Country
DE 10 2006 029 925	Verfahren zum Betrieb eines Stellantriebs und Stellantrieb	Germany
50 2007 006 197.2-08	Verfahren zum Betrieb eines Stellantriebs und Stellantrieb	Germany
2033240	Verfahren zum Betrieb eines Stellantriebs und Stellantrieb	EPO
2033240	Verfahren zum Betrieb eines Stellantriebs und Stellantrieb	France
2033240	Verfahren zum Betrieb eines Stellantriebs und Stellantrieb	United Kingdom
60 2007 018 663.3	Multi-leaf collimator with rotatory electromechanical motor and operating method	Germany
2188815	Multi-leaf collimator with rotatory electromechanical motor and operating method	EPO
2188815	Multi-leaf collimator with rotatory electromechanical motor and operating method	France
2188815	Multi-leaf collimator with rotatory electromechanical motor and operating method	United Kingdom
DE 10 2005 046 440.8	Spannfeder	Germany
DE 10 2005 046 178	Zylinderfeder	Germany
DE 10 2005 046 174	Spannfeder	Germany
50 2007 008 646.0	Solid-state actuator drive apparatus	Germany
2067187	Solid-state actuator drive apparatus	EPO
2067187	Solid-state actuator drive apparatus	France
2067187	Solid-state actuator drive apparatus	United Kingdom
7,923,901	Solid-state actuator drive apparatus	USA
10 2005 034 162.4	Schaltung und Verfahren zum Betrieb einer Last mit niedriger Impedanz	Germany
DE 500 08 082.8	Elektromechanischer Motor	Germany
1098429	Elektromechanischer Motor	EPO
1098429	Elektromechanischer Motor	Spain
1098429	Elektromechanischer Motor	France
1098429	Elektromechanischer Motor	United Kingdom
1098429	Elektromechanischer Motor	Italy
4 528 427	Electromechanical motor	Japan
1098429	Elektromechanischer Motor	Sweden
6,664,710	Electromechanical motor	USA

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Piezo actuator specifications

Official No.	Full Title	Country
100 17 138.9	Taumelmotor	Germany
US 6,441,536	Wobble motor	USA
DE 502 07 189	Bremsvorrichtung	Germany
1319859	Bremsvorrichtung	EPO
1319859	Bremsvorrichtung	France
1319859	Bremsvorrichtung	United Kingdom
7,728,484	Hybrid control circuit	USA
50 2006 008 514.3-08	Solid state actuator drive device with energy based clocked final power stage and method for controlling said type of final power stage	Germany
1883978	Solid state actuator drive device with energy based clocked final power stage and method for controlling said type of final power stage	EPO
1883978	Solid state actuator drive device with energy based clocked final power stage and method for controlling said type of final power stage	France
1883978	Solid state actuator drive device with energy based clocked final power stage and method for controlling said type of final power stage	United Kingdom
DE 10 2005 024 317	Festkörperaktor-Antriebsvorrichtung mit einer in Rotation versetzbaren Welle	Germany
50 2006 008 812.6-08	Festkörperaktor-Antriebsvorrichtung mit einer in Rotation versetzbaren Welle	Germany
1883979	Festkörperaktor-Antriebsvorrichtung mit einer in Rotation versetzbaren Welle	EPO
EP1883979	Festkörperaktor-Antriebsvorrichtung mit einer in Rotation versetzbaren Welle	France
1883979	Festkörperaktor-Antriebsvorrichtung mit einer in Rotation versetzbaren Welle	United Kingdom
DE 10 2006 008 031	Verfahren zur Herstellung von Räumwerkzeugen	Germany