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
- No electromagnetic interference

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

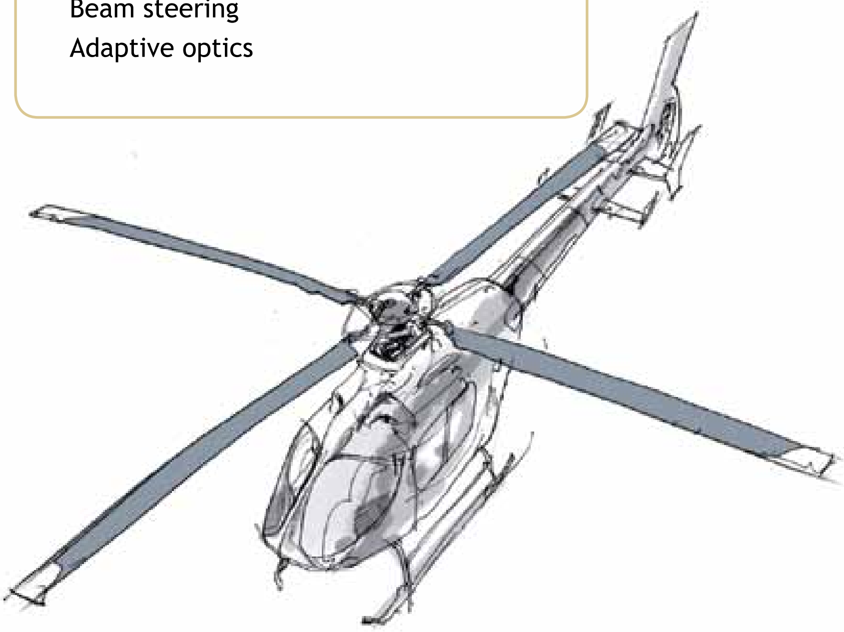
Camshaft adjustment
Exhaust Gas Recirculation (EGR)
Adaptive spoiler
Weight compensated trunk deck
Seat adjustment/window lifters
Variable Valve Timing (VVT)

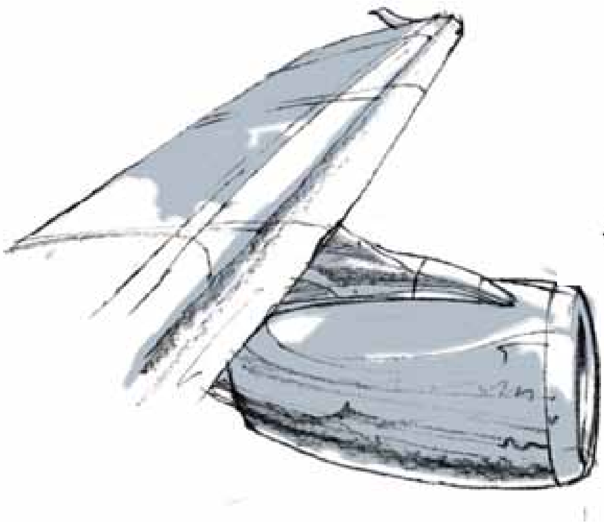
Aviation/Military

Servo valve/Electro-hydraulic actuator
Flight control surface actuation
Positioning/ adjustment of surveillance of reconnaissance systems
Antenna adjustment

Optics

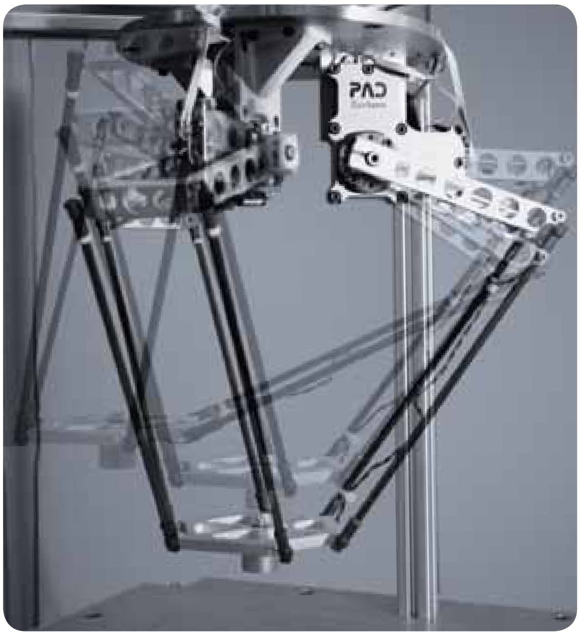
Beam steering
Adaptive optics





PIEZO ACTUATOR DRIVE

Introduction



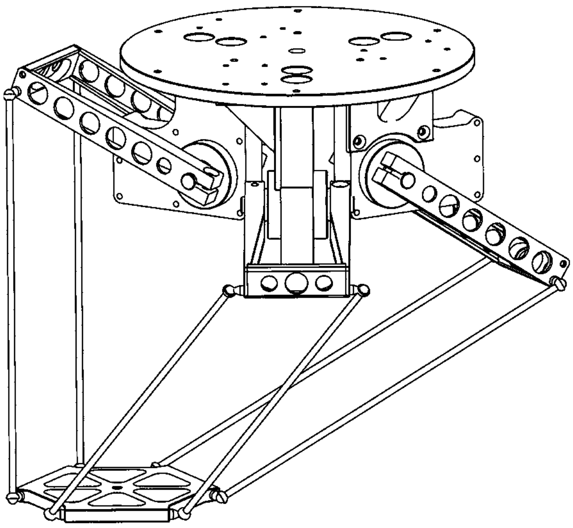


Figure A: Delta-3 Robot Design.

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 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 Delta-3 robot has been designed to prove its capabilities. A common 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

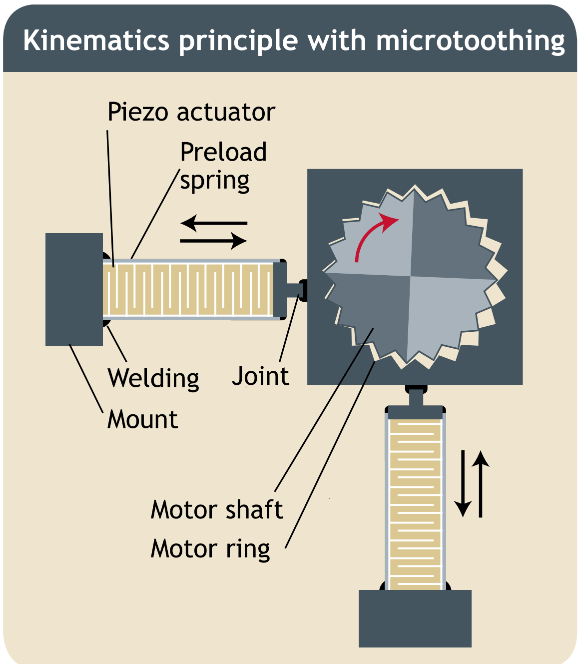


Figure B: New approach transforming linear movement into controllable rotation.

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.

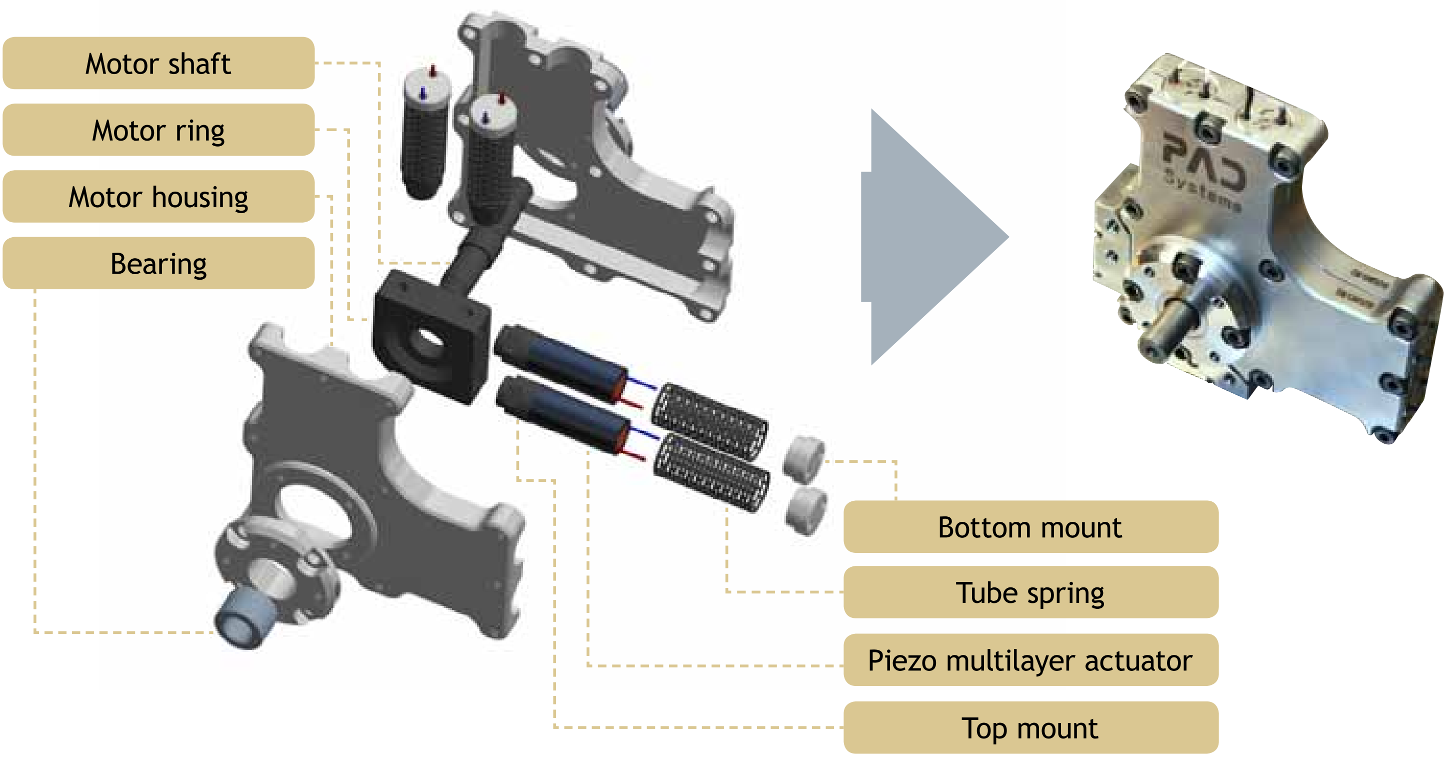


Figure C: Assembly parts and prototype.

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, repeatability and resolution (<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 (typical up to 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, radiation or UHV
- No magnetic stray fields

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 with high sensitivity, which allows a very compact 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 number of drives.

PIEZO ACTUATOR DRIVE

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.

PIEZO ACTUATOR DRIVE

Reliability and service life

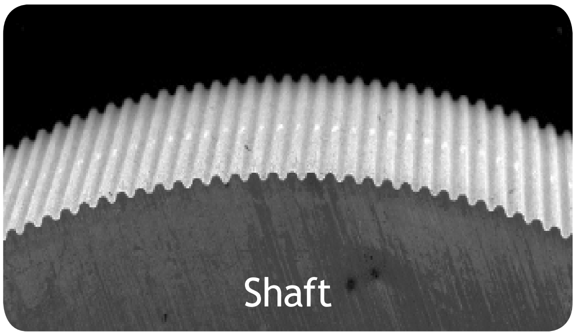


Figure D: Shaft enlargement and tooth geometry.

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 $3x10^9$ 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

TYPICAL OPERATING RANGE OF PAD7200

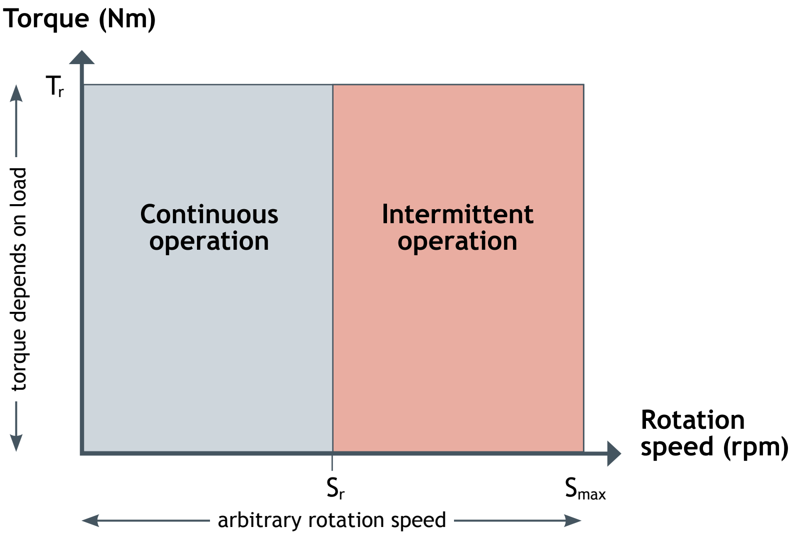


Figure E: Operating range of the PAD.

SCALABLE TECHNOLOGY

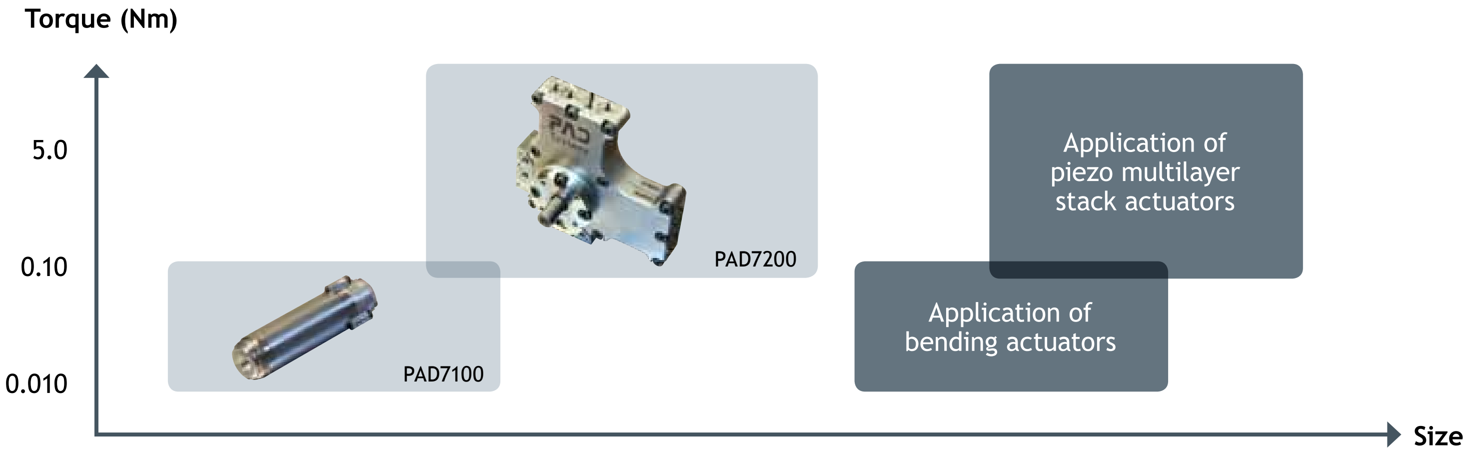


Figure F: The PAD is a scalable technology.

The PAD family

Noliac's range of PADs is based upon different models granting our customers a broad variety of performances, sizes and designs.

The varieties are shown in the model number: PADVXYZ

V = 7. Unique internal numbering for each product type showing development and production place.

X = Main PAD family.
X = 1 is the family of PADs made with piezo bending actuators.
X = 2 is the family of PAD made with piezo multilayer stack actuators ("L"-shaped housing).

Y = Major sub-family of performance.
See specifications, table B.

Z = Minor variant.
Z = 0 is the baseline configuration.
Z = 1 to 9 is for later expansion of the PAD range.

In addition to the standard products, Noliac offers customized versions adapted to your application, e.g.:

- Specific output shaft
- Specific mechanical interface
- Different electrical configuration (voltage, wiring, etc.)
- Reduced tolerances

PIEZO ACTUATOR DRIVE

PAD7220 specifications

The first PAD released as a standard product is the PAD7220.

Parameter	Unit	PAD7220	Tolerances
Mechanical interface - See drawing on page 10			
Shaft diameter	mm	10	± 0.01
Fixed interface	-	4 x M4	-
Max. axial load	N	10	Max
Max. radial load	N	450	Max
Mass (incl. cover and connector)	g	865	Max
Shaft inertia	$Kg \cdot mm^2$	0.423	
Operating conditions - See graph on page 11			
Maximum recommended voltage, V_{max}	V	200	Max
Minimum recommended voltage, V_{min}	V	-20	Min
Rotation per PAD cycle θ_C	turns	1/320	-
Acceleration time from 0 to rated speed	ms	0.1	Max
Torque-speed characteristics at ambient temperature			
Rated frequency f_{nom}	Hz	300	-
Maximum recommended frequency, f_{max}, short operation	Hz	1,800	-
Rated torque T_r (@V_{max}, f_{nom})	Nm	4	±2
Rated speed S_r (@f_{nom})	Rpm	56.25	-
Max speed S_{max} (@f_{max})	Rpm	337.50	-
Electrical interface - See description on page 11			
Capacitance C (1 V_{rms}, 1kHz)	µF	3.5	±15%
Loss facor tanδ (1 V_{rms}, 1kHz)		2.4%	Max
Connector reference (LEMO)	-	EGG.2B.314.CLL	-
Internal construction			
Number of actuators	-	4	-
Housing material	-	X8CrNiS 18-9	
Environment			
Operating temperature range	˚C	0 – 60	
Storage temperature range	˚C	0 – 60	

Table B: PAD7220 specifications.

Data are specified for room temperature and static operating conditions.
Based on information provided by our suppliers, Noliac designates this product as RoHS compliant.

PAD7220 interfaces

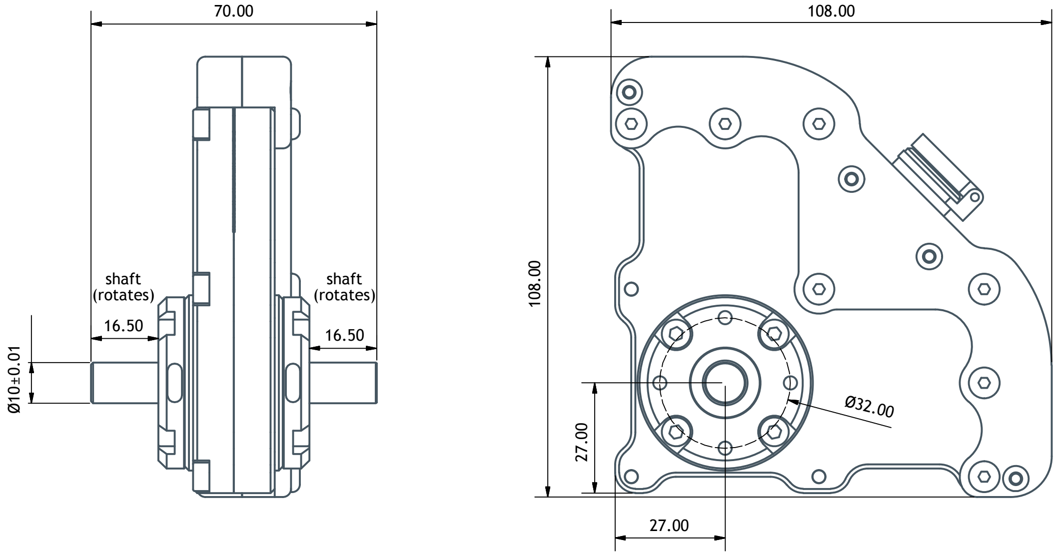


Figure G: Mechanical interface of the PAD7220. Dimensions in mm. Cover is optional.

PAD7220 interfaces

CONNECTOR

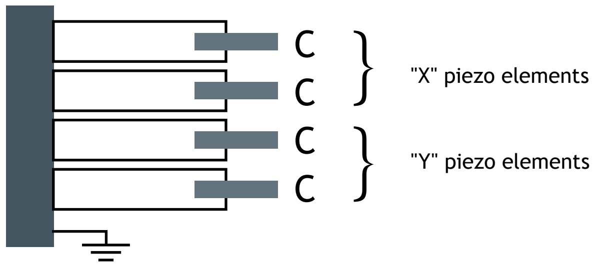


Figure H: Electrical interface of the PAD7220.

Figure I: Connector seen from the back of the male (cable) part.

Signal name	Description	Connector pin
“X1”	Voltage X1	10
“RefX1”	Voltage X1	9
“Y1”	Voltage Y1	4
“RefY1”	Voltage Y1	3
“X2”	Voltage X2	8
“RefX2”	Voltage X2	7
“Y2”	Voltage Y2	2
“RefY2”	Voltage Y2	1
Ground	Ground	5, 6
	Not connected	11 – 14

Table C: Pin-out for the PAD7220.

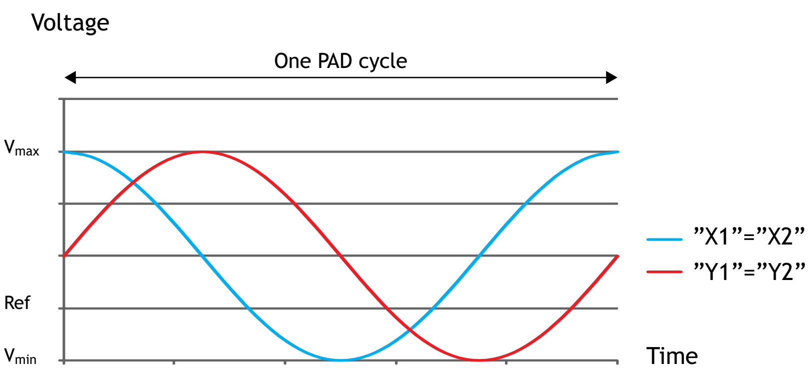


Figure J: Typical operating conditions of the PAD7220. There must be a phase shift of ±90° between “X1”=“X2” and “Y1”=“Y2”.

PIEZO ACTUATOR DRIVE

The driver companion

A perfect companion for Noliac's PADs is the dedicated driver NDRVXYZ. The driver system is tailored for a specific PAD, and the model number indicates which: NDRVXYZ

V = 8. Unique internal numbering for each product type showing development and production place.

X = Main PAD family. For example is X = 1 the driver for the family of PADs which also has X = 1.

Y = Major sub-family of e.g. energy recovery and power.

Z = Minor variant of e.g. software or interfaces

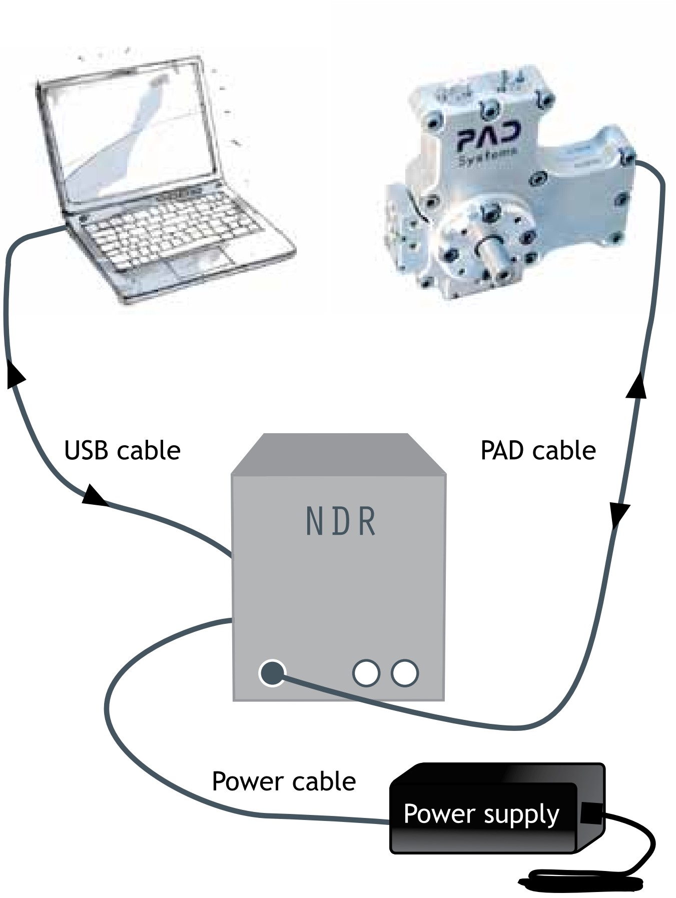


Figure K: Connections between PAD, NDR and computer.

The NDR is easily connected to the user's PC via a standard USB cable. From the PC the user can command and control each parameter separately ranging from rotational speed and direction to more complex matters such as high speed positioning.

All cabling and software is shipped with each individual NDR as a plug-and-play unit.
Inside the NDR is a fused high-voltage power supply, which is tightly controlled by the in-system microcontroller monitoring the actual output signals going to the PAD. From the voltage and phase of the driver output, a live measurement of the torque will be shown through the software supplied with the unit.

The NDR has an easy to use interface with only two buttons, "reset" and "high-voltage enable/disable", which cannot be accessed though the software interface and therefore serve as safety "overrides" in case of computer back-lock.

The NDR is shipped with the following accessories:

- Black Pelican case
- USB stick containing software
- USB cable
- 12 Vdc, power supply
- Output cable to the PAD
- Cable adapted to the country of use (please specify when ordering)

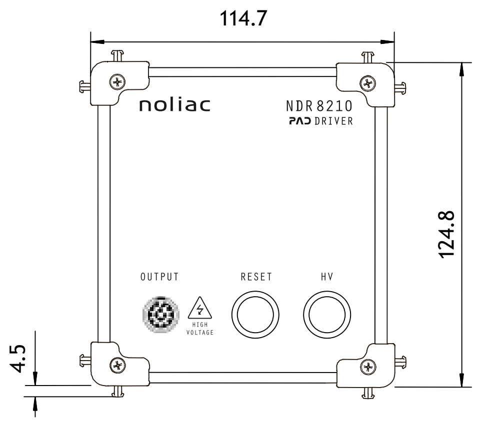
PIEZO ACTUATOR DRIVE

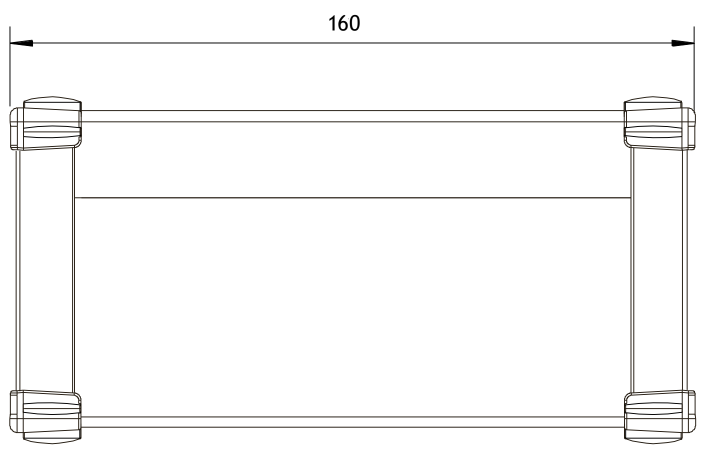
NDR8210 Specifications

Parameter	Unit	NDR8210	Tolerances
Input/ output characteristics			
Supply voltage	Vdc	12	
Supply current	A	3A	Max
Power input connector		P2J Ø2.1*Ø5.5*11	
Logic input connector		USB	
Output connector (LEMO)		EGG.2B.314.CLL	
Electrical parameters (AC adapter)			
Input voltage range	Vac	100 – 240	
Input frequency range	Hz	47 – 63	
Power	W	80	Max
Operational parameters			
Output voltage range	V	-20 – 200	
Frequency range	Hz	0 – 40	
Output noise (7µF load)	mV	5	Max
Points per PAD cycle		1,024	
Environmental parameters			
Temperature range	°C	+5 – +45	
Ingress protection		IP 31	
Mechanical parameters			
Mass	kg	1.8	Max

Table D: NDR8210 specifications.

DIMENSIONS





PIEZO ACTUATOR DRIVE

PAD and NDR combined characteristics

RESOLUTION

The resolution of the system θ_{min} can be calculated based on the characteristics of the PAD and NDR.

$$\theta_{min}[turns] = \frac{\theta_c[turns]}{N_\Theta[-]}$$

JITTER

Thanks to the low noise on the output of the NDR, the PAD exhibits a very low jitter, which can be estimated by this formula:

$$\delta_\Theta[turns] = \frac{\sqrt{2}.\delta_U[V].\theta_c[turns]}{\pi.(U_{max} - U_{min})[V]}$$

SPEED

The speed of a PAD motor N is proportional to the input frequency f and follows the relationship:

$$N\left[\frac{turns}{s}\right] = \theta c[turns].f[Hz]$$

HEAT GENERATION

Piezoelectric ceramics dissipate energy in the form of heat proportional to the dissipation factor (tan δ), the tangent of the loss angle for the material. For a PAD, the dissipated energy is proportional to the operating frequency f (therefore to the speed) and can be calculated according to the formula:

$$P_{heat}[W] = 2\pi.f[Hz].4.C[F].\tan\delta[-].(U_{max} - U_{min})^2[V^2]$$

Performance of PAD7220 combined with NDR8210:

Parameter	Unit	PAD7220 with NDR8210
Load detection sensitivity	Nm	< 0.01
Resolution Θ_{min}	arc sec	< 4

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	Mul ti-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
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