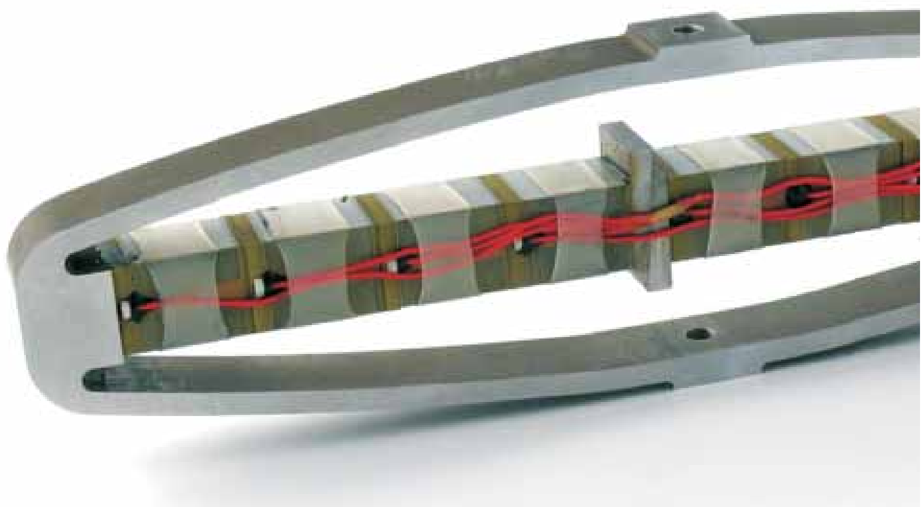
COMPACT
DYNAMIC
PRECISE



CEDRAT TECHNOLOGIES
Innovation in Mechatronics

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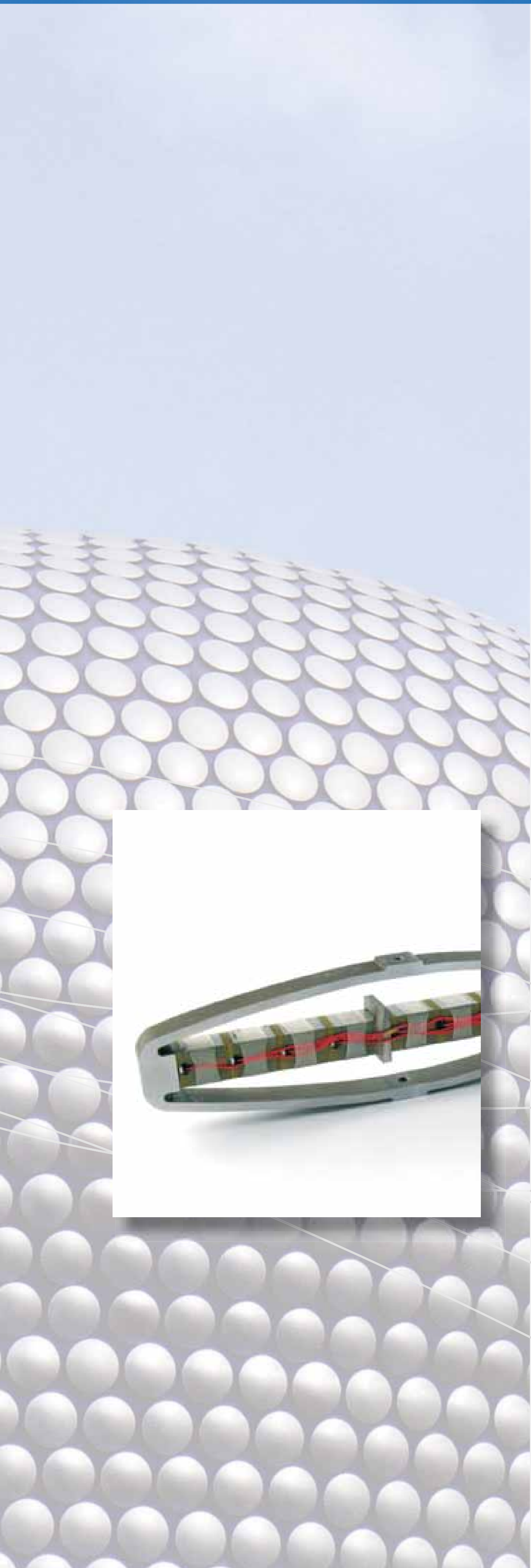


1. CEDRAT TECHNOLOGIES ACTUATOR SOLUTIONS

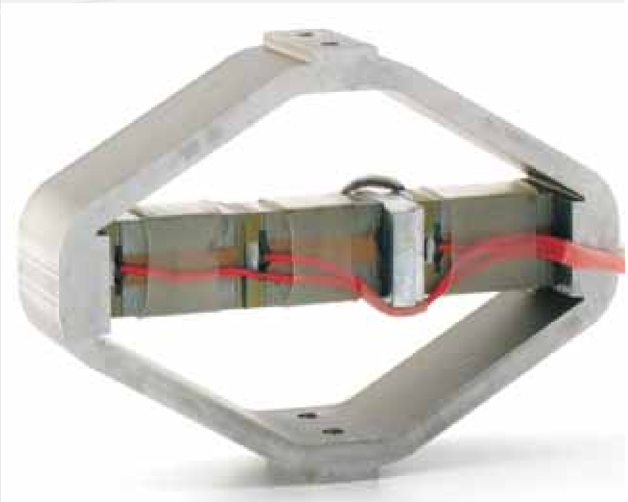
1.1 INTRODUCTION TO PIEZO AND MAGNETIC ACTUATORS FROM CEDRAT TECHNOLOGIES

CEDRAT TECHNOLOGIES has been constantly upgrading and enlarging its range of actuator & related electronic solutions since the middle of the 90s. In order to keep pace with its customers' needs and demands for efficient & robust mechatronic systems, CEDRAT TECHNOLOGIES has been developing Compact, Dynamic and Precise components through several families of products:

- Piezo actuators (APA®, PPA & Mechanisms) working in strain mode,
- Piezo actuators (LSPA, RSPA & LSPS) working in stepping mode,
- Controllable magnetic actuators (MICA),
- Bistable magnetic actuators (BLMM),

These actuators as well as the dedicated drivers, sensors and controllers are presented all along the sections of this catalogue. These actuators coupled with the relevant drive, sensor and controller offer a wide range of standard components and functions to build your own mechatronic systems and applications. In order to satisfy specific requests and demanding environments, CEDRAT TECHNOLOGIES can develop both customised components and mechatronic systems under your technical specifications from the building blocks briefly described here below.

■ Figure 1.1: View of a PPA



■ Figure 1.2: View of APA®

1.1.1 PARALLEL PRE-STRESSED ACTUATORS (PPA)

PPA are solid-state linear Actuators (Figure 1.1). They only use the expansion of the active material, in 33-mode, to produce a useful displacement. This displacement is proportional to the voltage within a 170V range. Typically, the Actuator's deformation is about 0.1% (1μm/mm), so their displacements are limited to about 100μm. However, the forces are naturally high, easily higher than 1kN.

Parallel Pre-stressed Actuators (Figure 1.1) use an external deformable frame to pre-stress the ceramics. The level of pre-stress can be higher. PPA are cheaper, more compact and display a much better dynamic behaviour than conventional Direct Piezo Actuators.

1.1.2 AMPLIFIED PIEZOELECTRIC ACTUATORS (APA®)

APA® are solid-state long-stroke linear Actuators (Figure 1.2). They are based on the expansion of the active material and on a mechanism to amplify the displacement. This amplified displacement is also proportional to the voltage within a 170V range. The advantages of APA® are their relatively large displacements combined with their high forces and compact size along the active axis. It leads to a deformation of 1% (10μm/mm) or more. Therefore, their stroke may achieve up to 1 mm.
Thanks to their compactness, APA® can be stacked in series to reach strokes longer than 1mm.

Since APA® are robust, they can also be used in dynamic applications, including in resonant devices. In this last case, the applicable voltage to get the maximum stroke is very low (about 1 to 10V).

1.1.3 STEPPING PIEZO ACTUATORS (SPA)

Stepping Piezo Actuators are another way to use Amplified Piezoelectric Actuators (APA®). Stepping Piezoelectric Actuators (SPA) are new long-stroke piezoelectric motors for micro/nano positioning applications benefiting from the APA® heritage. They operate by accumulation of small steps. Between each step the actuator is locked in position. When the long stroke is performed, it can also be operated in a deformation mode for a fine adjustment. In this case, the stroke is proportional to the applied voltage, which leads to a nanometre resolution and a high bandwidth.
SPA concept leads to different product families (LSPA, RSPA, LSPS...) which differ by their motion type (Linear or Rotating) and by the possible addition of a guiding (case of the Stages).

1.1.4 MOVING IRON CONTROLLABLE ACTUATOR (MICA)

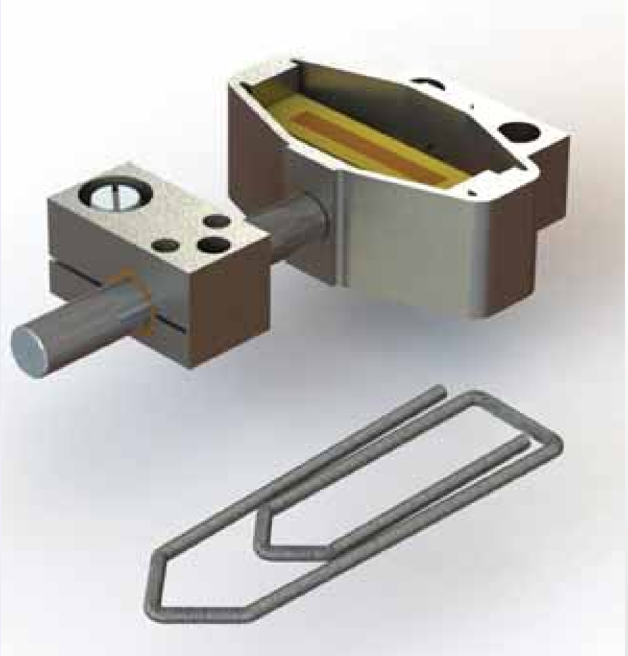
Linear actuators:
For applications where long strokes and highly dynamic actuators are required, CEDRAT TECHNOLOGIES develops dedicated magnetic actuators, the MICA (figure 1.4) and BLMM. With strokes up to 10 mm, forces up to 1500N, MICA are perfectly complementary products to our well-known piezoelectric offer.

MICA are robust, long lasting and powerful controllable actuators, with a force proportional to the current and can be used either for high frequencies or static applications. They come with an embedded position sensor and convenient mechanical interface for an easy integration.

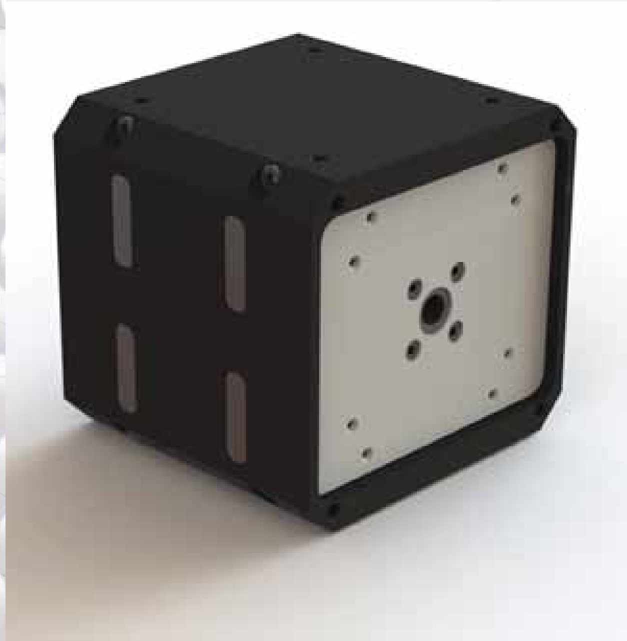
1.1.5 BISTABLE LINEAR MOVING MAGNET (BLMM)

BLMM are miniature bistable actuators offering low power consumption and a fast switching time. They are easy to control in on/off mode.

These products are presented in the chapter 6 dedicated to Magnetic Actuators.



■ Figure 1.3: View of a LSPA



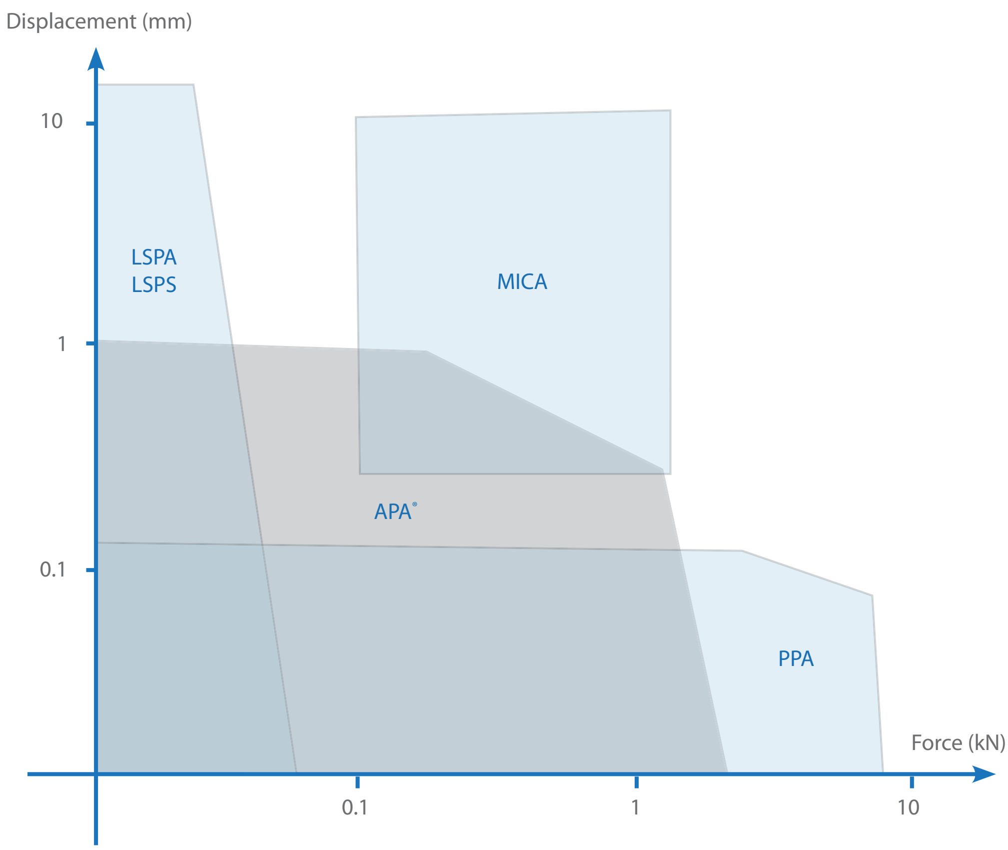
■ Figure 1.4: View of MICA

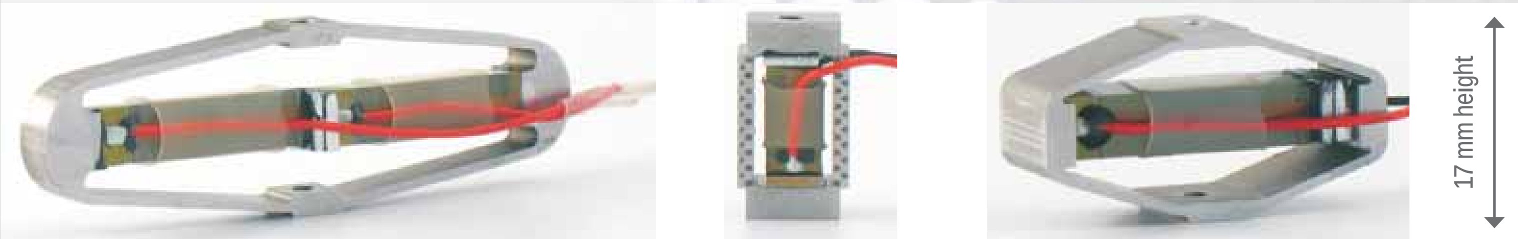
1.2 COMPARISON OF CEDRAT TECHNOLOGIES LINEAR ACTUATORS

CEDRAT TECHNOLOGIES's standard linear actuators cover a range of free displacements from 10 µm to 10 mm (Figure 1.5). They have been designed in order to offer the largest possible stroke while keeping a reasonable size. The choice between these different solutions should be made as a compromise between force and displacement.

For example, considering an active height of about 17mm, one can choose between an APA200M, an APA40SM and a PPA10M, which offer quite different strokes and forces (Figure 1.6).

■ Figure 1.5: Comparison of max displacements and forces of some linear actuators (PPA, APA®, LSPA, LSPS and MICA) from CEDRAT TECHNOLOGIES



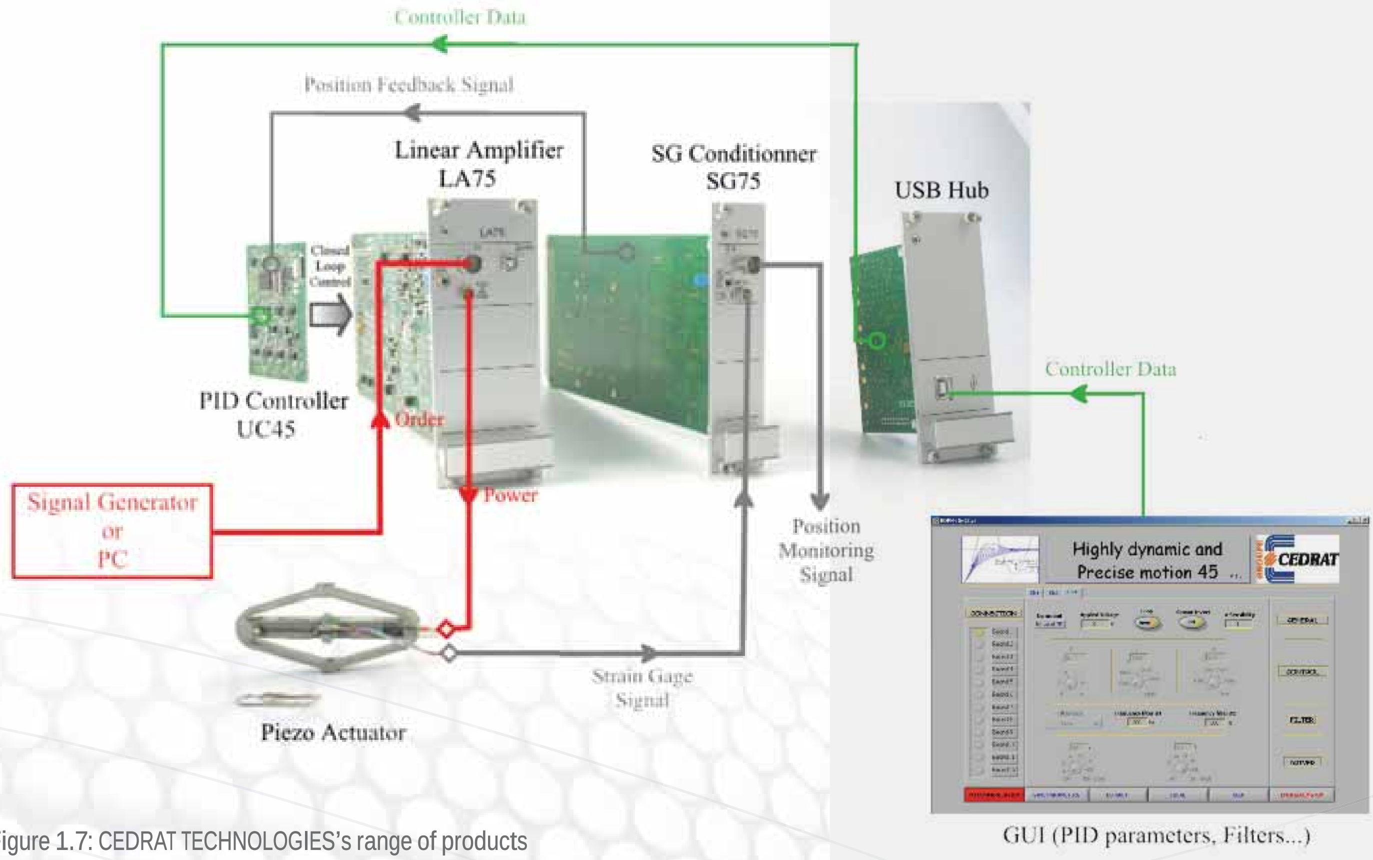


■ Figure 1.6: Comparison of linear Piezo Actuators APA200M,PPA10M & APA40SM of CEDRAT TECHNOLOGIES with comparable size but different free displacements and blocked forces.

1.3 SYNTHESIS OF CEDRAT TECHNOLOGIES OFFER

All the products from CEDRAT TECHNOLOGIES can be assembled to build a complete mechatronic system (Figure 1.7).

Note that mechanisms can produce larger stroke than the elementary actuators. All these electromechanical devices can be driven and controlled with the appropriate electronics.



■ Figure 1.7: CEDRAT TECHNOLOGIES's range of products

Several solutions of piezo actuation exist: the choice depends on the required stroke and force. The advantages are high positioning accuracy, possible non-magnetic operation, fast response time, low power consumption.

2. TUTORIAL FOR PIEZOELECTRIC ACTUATORS

2.1 INTRODUCTION TO PIEZOELECTRIC MATERIALS

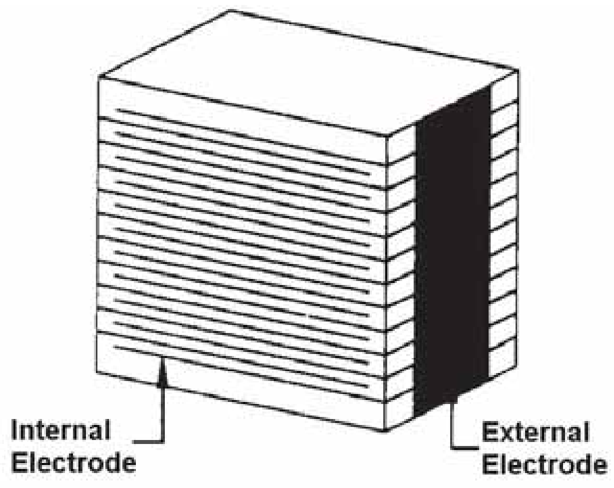
In 1880, the Curie brothers first examined the piezoelectric effect on crystal materials, which has the ability to produce electrical charges in response to externally applied forces. This is called the direct effect. This effect is reciprocal; meaning that the piezoelectric material changes its dimensions under applied electrical charges.

In 1922, Langevin proposed the first Actuator based on crystal materials. To enhance its efficiency, this Actuator was driven at resonance. The discovery of piezoelectricity in PZT (lead zirconate titanate) in the late 1960's increased the number of applications for industrial use. Piezoelectric transducers based on bulk PZT rings have been developed for sonar, ultrasonic welding, ultrasonic cleaning applications, etc. Sensor technology using piezoelectric ceramics (pressure or force sensors, hydrophones, accelero-meters...) has matured since then.

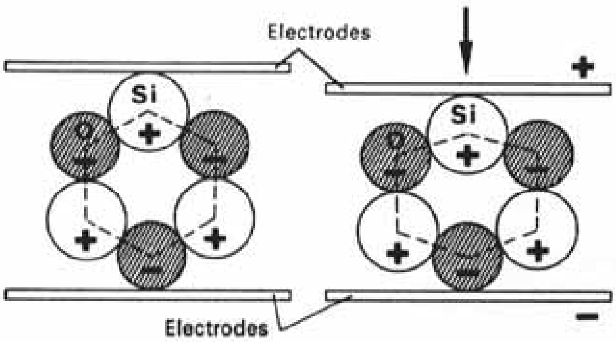
Based on piezoelectric bulk PZT rings, Actuators for positioning purposes have also been studied. However, to obtain the deformation level required for this type of applications, it is necessary to use high input voltages. For instance, 0.5 mm thick PZT rings require an excitation voltage of approximately one thousand volts, which is clearly too high for several practical purposes.

Multilayer Actuators (MLAs), derived from the high capacitor technology, were introduced on the market in 1988 to circumvent the previous limitations (Figure 2.1). Because MLAs are easy to operate, they have been increasingly used in various applications. The required excitation voltage of 150 Volts or less is well adapted to modern electronics.

These new materials are used by CEDRAT TECHNOLOGIES to build high energy density actuators and other devices, which are available either as standard or customised products, and which can be supplied with the dedicated electronics.



■ Figure 2.1: Schematic view of a MLA



■ Figure 2.2: Piezo effect on the crystal structure (example of the quartz)

2.2 CHARACTERISTICS OF PIEZOELECTRIC MATERIALS

Piezoelectric materials are crystalline solids whose asymmetric structures create an electric dipole moment in the crystal lattice, which is sensitive to both the elastic strain and applied electrical field (Figure 2.2).
PZT materials are ferroelectric materials under the Curie temperature: the poling process gives the material its remanent polarization. During the poling operation, the material is subjected to a high electric field at the Curie temperature. If the material is subjected to a greater temperature than its Curie temperature, it is no longer piezoelectric. It can be repoled to be piezoelectric again under certain conditions.

Stresses and Strains are related to each other by the Young's modulus of the ceramic. In addition, a stress generates an electric field through the inverse piezoelectric effect. Since the ceramic is a dielectric medium, the electrical displacement is related to the electric field. These relationships can be combined in several sets of equations.

For example:

$$S_\alpha = s^E_{\alpha\beta} T_\beta + d_{n\alpha} E_n$$

$$D_m = d_{m\beta} T_\beta + \varepsilon^T_{mn} E_n$$

a, b = 1, ..., 6
m, n = 1, 2, 3

S : Strain T : Stress
D : Induction E : Field
s^E : Compliances at constant field
d : Piezoelectric strains per unit of field
ε^T: Permittivity at constant stress

The previous equations can be combined to define the electro-mechanical coupling coefficient, which can be seen as the ratio of the convertible energy to the total energy supplied to the Piezoelectric Actuator. Practical values of the material's coupling coefficient can be higher than 50%, but in Actuators, or in resonant transducers, the effective coupling factors keff are usually lower. The electromechanical coupling coefficient should not be regarded as the Actuator's efficiency. The set of equations shown above does not take any loss into account.
Commercial piezoelectric ceramics can be classified as soft-type or hard-type materials based on the ease or the difficulty of depolarizing them. The Table 1.1 lists some typical properties of active materials (Figure 2.3).

Actuators made from single crystals or Electro-Active Polymer's (EAP's) are still in their infancy, but may lead to new actuators in the future: their strain capabilities up to respectively 3% and 300% are outstanding.

Magnetostrictive materials like Terfenol-D are also studied at CEDRAT TECHNOLOGIES. They expand when subjected to a magnetic field. Despite the losses occurring in the excitation coil, Actuators based on this material may be well suited for very low-voltage or power applications. Customised Actuators and transducers based on this material can be built by CEDRAT TECHNOLOGIES upon request.

Electrostrictive materials, such as PMN-PT also exist in Multilayer. This material displays a low hysteresis (< 2%), but is much more temperature-dependent than PZT material.

■ Figure 2.3: View of piezoactive materials

■ Table1-1: Properties of Piezoactive materials

MATERIALS	"CONTROL FIELD E ELECTRIC H MAGNETIC"	YOUNG'S MODULUS AT CONSTANT FIELD (GPA)	MECHANICAL QUALITY FACTOR QM	ELECTRO-MECHANICAL COUPLING COEFFICIENT K33 (%)	QUASISTATIC MAXIMUM STRAIN (PPM)
BULK PIEZOELECTRICS					
PZT-8	E	74	1000	64	+/- 110
PZT-7	E	72	600	67	
PZT-4	E	66	500	70	+/- 150
PZT-5	E	48	75	75	+/- 300
Single-crystals (PZN-PT)	E	10	-	90	3000
MULTILAYERED PIEZOELECTRICS (MLAs)					
Soft-type	E	45	25 – 50	70	1250
Hard-type	E	62	200 – 500	60	800
ELECTROACTIVE POLYMERS (EAPs)					
PVDF	E	1	20	30	1000
Dielectric Elastomers	E	1	-	-	3.000.000
MAGNETOSTRICTIVES					
Terfenol-D	H	25	10 – 20	70	1600

2.3 INTERESTS AND APPLICATIONS OF PIEZO ACTUATORS

The primary advantages of Piezo Actuators are:

- Their solid-state design with no rolling parts, so that they are not subjected to wear,
- Unlimited resolution, making them ideal for nano-positioning,
- Low power consumption,
- High force / mass ratio, allowing their fast response time,
- Possible non-magnetic actuation,
- Possible operation in ultra high vacuum.

Piezoactive Actuators also display several limitations:

- Limited displacements range (below 1mm) when using only deformation. For higher displacements, the use of a piezo motor such as LSPA is necessary,
- Limited to temperatures below < 100° C (or 150° C in H.T. option), although some progress is being made for automotive applications.

Piezoactive Actuators find applications in various industrial fields:

- Mechanics: Positioning of tools, Pick & Place, Diamond turning, Oval piston machining, Damping, Active control, Generation of ultrasonic or sonic vibrations, NDT, Health monitoring.
- Microelectronics: Positioning of masks, wafers or magnetic heads, Non-magnetic actuation, Micro-relay, Probe testing, wire bonding,
- Fluidics: Proportional valves, Pumps, Measuring, Injections, Ink jet, Droplet generators, Flow mass meter.
- Optics & Vision: Positioning of mirrors or lenses, micro-scanning, Astronomy, Focusing, Laser cavity tuning, Alignment or deformation of fibers, Deformation of FBG, Scanners, Choppers, Interferomoters, PDP glass cutting, Modulators.
- Electronics: Positioning of masks, wafers or magnetic heads, Non-magnetic actuation, Circuit breakers, Chip testing.
- Air & space: Active flaps, Shape control, Active wing.
- Electrical energy: Piezoelectric generator, Energy harvesting, Electric switch.

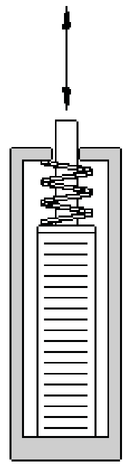
2.4 DIRECT PIEZO ACTUATORS (DPA) AND PARALLEL PRE-STRESSED ACTUATORS (PPA)

Direct Piezo Actuators (DPA) are the most common type of Actuators (Figure 2.4): they consist of a stack of pre-stressed active material. Conventional DPA use a serial pre-stress (Figure 2.5). The level of pre-stress determines the pulling force capability. A more robust technique (widely used at CEDRAT TECHNOLOGIES in power ultrasonic transducers) consists in combining a parallel pre-stress with a bolt-tightened steel rod. However, it requires MLA rings which are less common. A third alternative consists in pre-stressing the MLA stack through an external elastic frame, leading to a Parallel Pre-stressed Actuator PPA (Figure 2.6).

DPA and PPA use the expansion of the active material, in 33-mode, to produce a useful pushing displacement. As most of the energy strain is stored into the active material, the effective coupling factor of this structure is high, generally higher than 50%, as well as the elastic energy per unit of mass. The level of pre-stress can be higher in PPA than in DPA. PPA are more compact and lighter than DPA. Because the pre-stress level is better controlled, they display a better dynamic behaviour than DPA and can be operated at resonance. At last, PPA are cheaper than DPA: that is why CEDRAT TECHNOLOGIES only offers PPA as a standard non amplified preloaded piezo actuator.

The displacement is roughly proportional to the voltage, from -20 to 150V, which can be produced with special power electronics. The relation between the displacement and the voltage is not exactly linear because of the hysteresis of the active material. This effect can be well controlled with the appropriate feedback electronics, which linearize the system's behaviour.

■ Figure 2.4: View of DPA



■ Figure 2.5: Schematic construction for DPA

■ Figure 2.6: View of PPA

As the strain of present piezo materials is limited to 0.12%, the induced displacement is necessarily small, even with very long actuators. That is the reason why there is no direct Piezo Actuator offering 200µm of stroke available on the market.

Due to non active pieces (end parts, prestress mechanism), the deformation of the Actuator is smaller than that of the material itself, leading to values from 0.08% to 0.10% (0.8 to 1µm/mm) in the PPA80L. Thus, a 100mm long PPA can reach about 80 to 100µm. The longest PPA can hardly be longer than 200mm because of the risks of fracture in buckling. That is the reason why there is no direct Piezo Actuator 200µm of stroke available on the market (in this case APA® offer an alternative solution).

DPA and PPA must be used carefully since they cannot bear any twisting or flexural torque. To avoid this problem, elastic flexural hinges must be added. However, these hinges are more difficult to design because they must also be capable of supporting some stiffness. Additionally, standard DPA have been designed for low frequency operation, typically less than 100 Hz. Amplified Piezoelectric Actuators (APA®) are used to circumvent these limitations, since the elastic amplifier can bear transverse and dynamic forces.

2.5 AMPLIFIED PIEZOELECTRIC ACTUATORS (APA®)

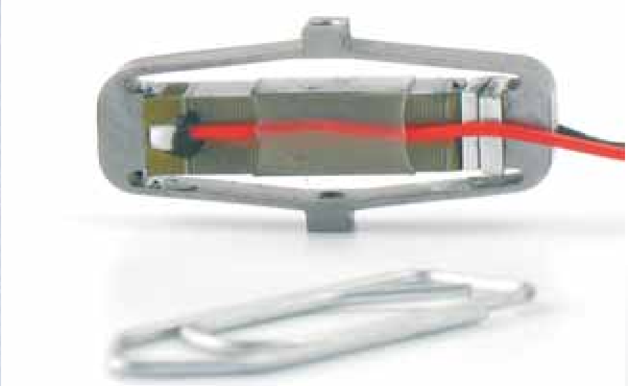
The displacement limitation of DPA and PPA can be overcome thanks to an elastic mechanical amplifier. Various designs, most of them using flexural hinges, have been proposed in the past. Stresses become very high in the hinges during actuation, resulting in fatigue effects.

APA® are based on a shell without any hinges (Figures 2.7 and 2.8). High displacements of APA® combined with high forces show that these Actuators achieve displacement amplifications of 2 to 20 and have a good mechanical efficiency. Thanks to this amplification and to their shape ratio, they can achieve deformations from 1% to 10%. Note that their deformation is a contraction, meaning that APA® are pulling actuators.

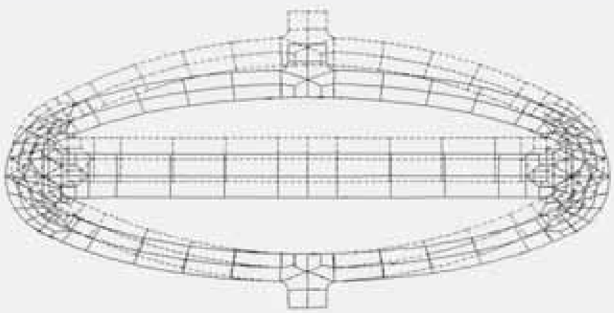
For example, at 150V, the APA400M Actuator produces free displacements up to 400µm and blocked forces up to 38N along its 14.3 mm short axis. It corresponds to a deformation of 2.8% along the short (active) axis. This large deformation can also be found on large APA®: the APA500L produces free displacements up to 500µm and blocked forces up to 570N, along its short axis, which is about 50mm height.

APA® present the following advantages:

- The Actuators are small and compact relative to their stroke,
- The displacement magnification and the stiffness are functions of the excentricity of the shell,
- Mechanical impedance matching and a satisfactory electromechanical coupling are possible,
- It can be operated in a wide range of frequency including the resonance frequency,
- The bending behaviour of the shell under the piezoelectric actuation allows an acceptable distribution of stresses in the amplifier,
- Bending and / or twisting moments can be exerted (to a certain extent) on the shell, which prevents the MLA from breaking. From this specific point of view, APA® are considered to be more robust than DPA & PPA,
- The price of an APA® is much lower than the price of a direct Piezo Actuators producing the same stroke. This is due to the mechanical amplifier which is less expensive than active materials.



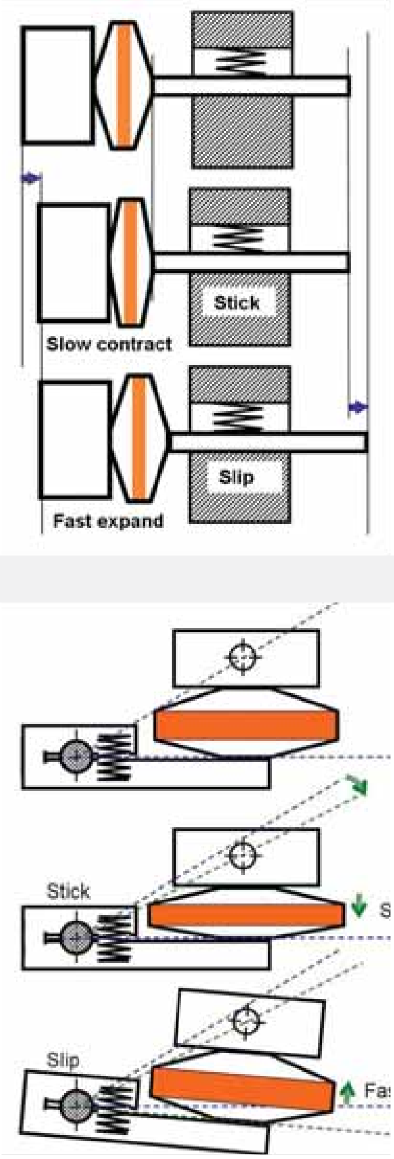
■ Figure 2.7: View of an APA120S



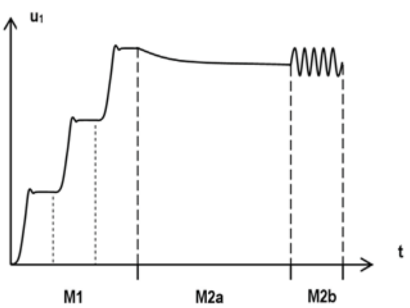
■ **Figure 2.8: Finite element computation of an Amplified** Piezoelectric Actuator APA®; dotted lines = structure at rest; full lines = structure deformed by the piezoelectric effect (ATILA FEM result).

The stroke of an APA® as well with a PPA is proportional to the applied voltage. The resolution is limited by the noise of our driving electronics, which display a signal to noise ratio of about 85 dB. The hysteresis limits the positioning accuracy. A closed loop is necessary to reach an accuracy better than 0.1%. The APA® can be driven up to one third of the resonance frequency for positioning applications. The APA® can be driven at resonance for vibration generation.

2.6 STEPPING PIEZO ACTUATORS (SPA)



■ Figure 2.9: View of LSPA and RSPA



■ Figure 2.10: Example of displacements performed by SPA (M1: long stroke stepping mode, M2a: short stroke quasi-static deformation mode, M2b: dynamic deformation mode)

Stepping Piezoelectric Actuators (SPA) are new long-stroke piezoelectric motors for micro/nano positioning applications benefiting from the APA® heritage. They operate by accumulation of small steps by stick-slip (step mode M1). Between each step the actuator is locked in position (Figure 2.9). When the long stroke is performed, it can also be operated in a deformation mode (M2) for a fine adjutment (Figure 2.10). In this case, the stroke is proportional to the applied voltage, which leads to a nanometre resolution and a high bandwidth.

This actuator can be supplied with CEDRAT TECHNOLOGIES standard Linear Amplifiers. To summarise, SPA offer:

- A stepping mode producing strokes of several mm,
- A blocking at rest in any position (locking without power supply), leading to a high stiffness,
- A nano positioning resolution all along the stroke,
- Non magnetic behaviour.
- The SPA relies on a simple design: an APA®, a front mass, a clamp and a rod.

The SPA can be driven by a one-channel CEDRAT TECHNOLOGIES linear amplifier. Many SPA can be defined starting from the standard range of APA®. SPA find applications as micro positioning, locking mechanisms. They can be non-magnetic and/or vacuum compatible.

The SPA concept leads to different product families:

- LSPA: Linear Stepping Piezo Actuators
- RSPA: Rotating Stepping Piezo Actuators
- LSPS: Linear Stepping Piezo Stages, which are based on a LSPA and an additional linear guiding for removing transverse parasitic motion.

All these products can perform in harsh environment:

- wide temperature range (including cryogeny > : - 200°C to + 70°C
- vacuum
- external vibrations and shocks

2.7 STATIC BEHAVIOUR OF PIEZOACTIVE ACTUATORS

This section gives some guidelines to choose the best PPA or APA® for quasistatic applications.

In most cases, the displacement **ΔU** is the first interest: it depends on both the applied voltage V and the generated force F:

$$\Delta U = (NV - F)/K$$

where N is the force factor of the Actuator and K is the stiffness. The product NV, when the voltage is maximum, is also referred to the blocked force F_0.

$$F_0 = NV_{max}$$

It is clear that the displacement **ΔU** becomes 0, when the generated force F reaches F_0. The Actuator's maximum stroke **ΔU_0** is called the free displacement and then equals:

$$\Delta U_0 = F_0/K$$

The relation between the free displacement and blocked force can be drawn on the Actuator's load characteristic (Figure 2.11).

If a constant load F (i.e. weight) is smaller than the blocked force or the maximal tensile force, the weight does not affect the stroke of the Piezoelectric Actuator, but only results in a shift of the zero voltage position (Figure 2.12) to a distance **ΔL**:

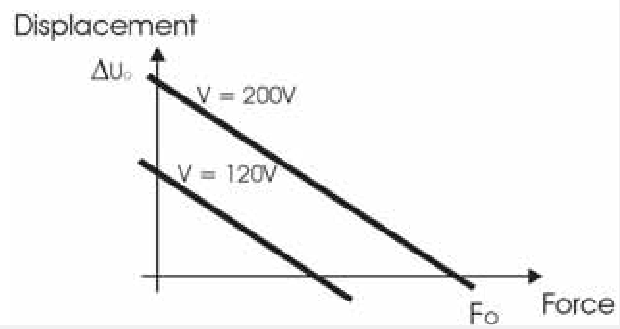
$$\Delta L = F/K$$

A very different situation occurs when the Piezoelectric Actuator acts against a spring with a stiffness Kt. The stroke becomes (Figure 2.13):

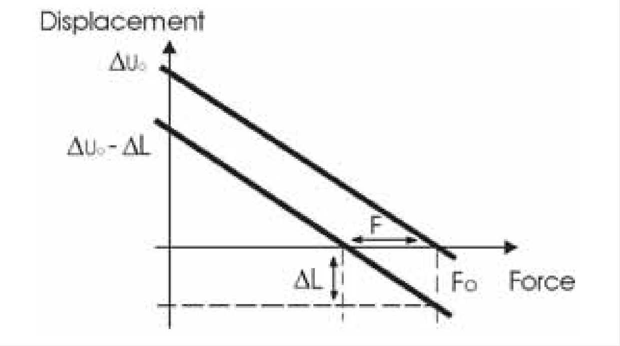
$$\Delta U = (NV - K_t \Delta U)/K$$
$$= \Delta U_0 \,(K/(K+K_t))$$

Since Piezoelectric Actuators are pre-loaded thanks to a spring, the previous relationship explains why the strain of DPA or PPA is smaller than the active material strain itself.

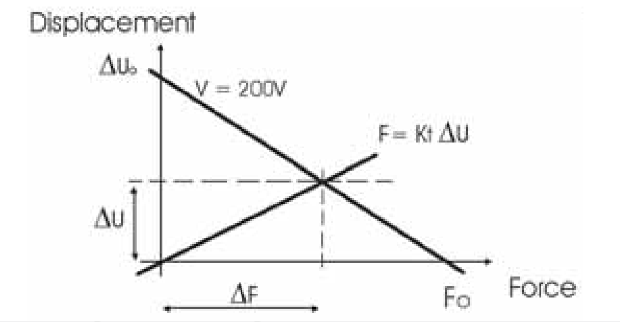
Piezoactive Actuators can be mechanically arranged in series and/or in parallel. In the first case (Figure 2.14.a), displacements are added and the force stays constant, while in the latter, the forces are added and the displacement remains the same (Figure 2.14.b).



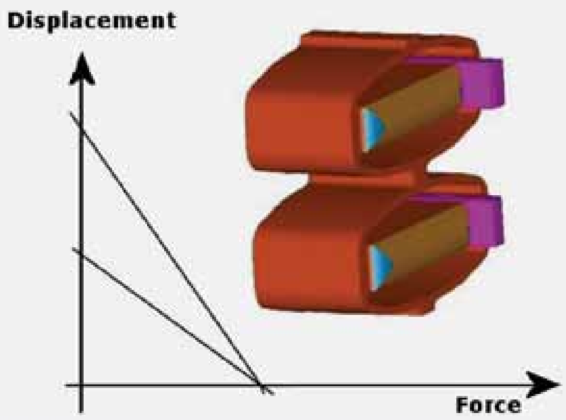
■ Figure 2.11: Load characteristics of a Piezoelectric Actuator

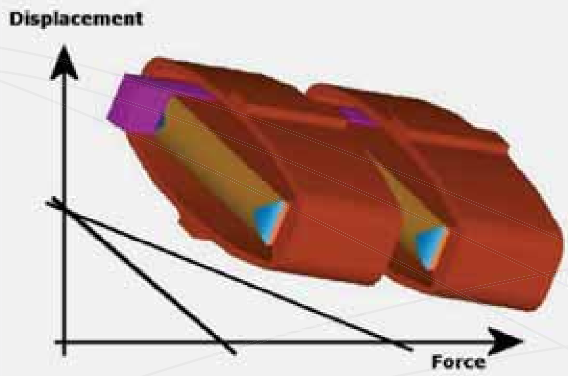


■ Figure 2.12: Position shift and load characteristics of the Actuator under a constant force



■ Figure 2.13: Load characteristics under a spring with a stiffness kt.





■ Figure 2.14: Series (a) and Parallel (b) arrangements of APA®

2.8 DYNAMIC BEHAVIOUR OF ACTUATORS (LOW LEVEL)

This section introduces the effect of electromechanical resonance on actuators. It is written for Piezo Actuators such as PPA and APA®, but it also applies to elastically-guided Magnetic Actuators such as MICA.

If either the applied voltage or the external force varies with the time, the displacement still follows the excitations until dynamic behaviours appear. The previous relationships remain valid in the quasistatic bandwidth, which is limited by about one third of the resonance frequency. If the actuator is unloaded, the resonant frequency is f_{r0}:

$$f_{r0} = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$$

where m is the effective mass of the Piezoelectric Actuator (not equal to the total mass of the Piezoelectric Actuator, see the application notes).

$$m = K / (2\pi f_{r0})^2$$

If the Actuator is loaded with an additional mass M, the resonance frequency fr then becomes:

$$f_r = \frac{1}{2\pi}\sqrt{\frac{K}{m+M}}$$

The resonance frequency is also affected by external masses, spring constants or damping effects.

Dynamic operations are more complex because of the acceleration acting on the Piezoelectric Actuator. Displacements (and consequently stresses) can become very high.

At resonance, considering a constant voltage amplitude, they are magnified (Figure 2.15) by the mechanical quality factor Qm:

$$\Delta U_0 = Q_m.NV/K$$

The vibration speed Δv is often used in dynamic operations and is proportional to the displacement:

$$\Delta v = 2\pi f.\Delta U$$

Speed variation versus frequency (Figure 2.15) also demonstrates the resonance phenomena. The values of the Qm factor depend on many parameters coming both from the Actuator and the load. Typical values are in the range of 20 (high level) to 200 (low level) under free condition. They decrease in case of resistive load (load exhibiting damping or energy radiation).

Due to this amplification and to mechanical limits, the maximum voltage that can be applied at resonance is much lower than under static condition (Figure 2.16). Thus, a full stroke of PPA, APA®, UPAs or UPDs is achieved under free condition with only a few volts (1 to 10V).

The maximum voltage at resonance frequency is roughly the maximum voltage under static condition divided by the Q_m factor:

$$\left(V_{max@f=f_r}\right) = \left(V_{max@f=0}\right) / Q_m$$

The resonance is also responsible for the overshoot and oscillations, which can be seen on the step response of the Actuator (Figure 2.17). This undesirable effect can be controlled with appropriate driving electronics or additional damping or with a closed-loop control (see 2.11).

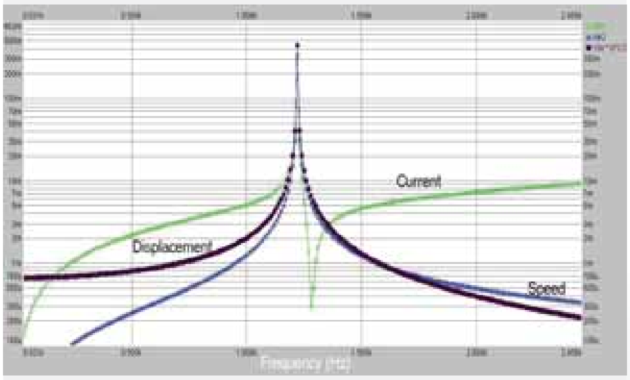
The response time t_r of the Actuator is limited by the resonance frequency f_r:

$$t_r = 1/(2*f_r)$$

In practical situations, the response time of the actuator can be limited by the load time value of the electronics.

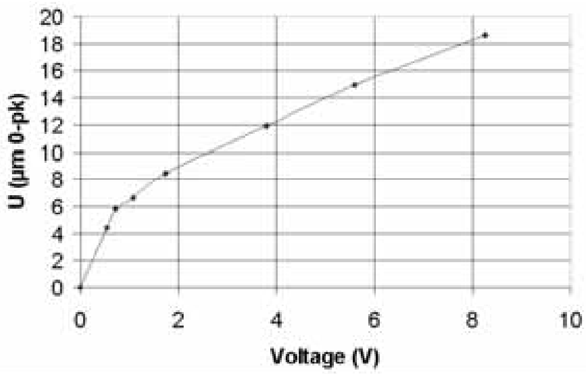
Note that the use of Piezo Actuators under dynamic conditions (either at resonance or under transient conditions) requires a careful design and a lot of experience, because of the mechanical breaking risks.

Please do not hesitate to contact CEDRAT TECHNOLOGIES for design & tests or to use CEDRAT TECHNOLOGIES CADs for preliminary analysis.

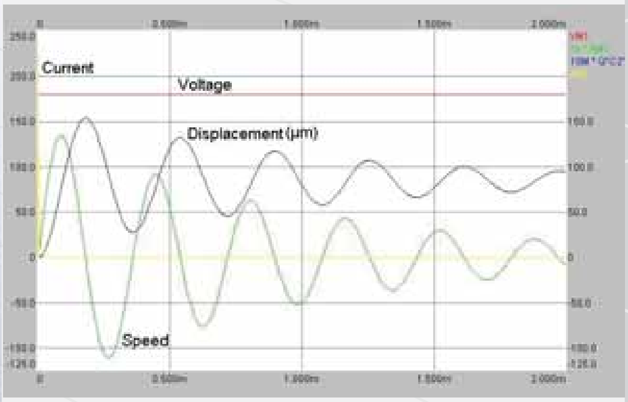


■ Figure 2.15: Current, displacement and speed of the Actuator versus frequency: the resonance effect can either be seen on the Actuator's speed or on the current

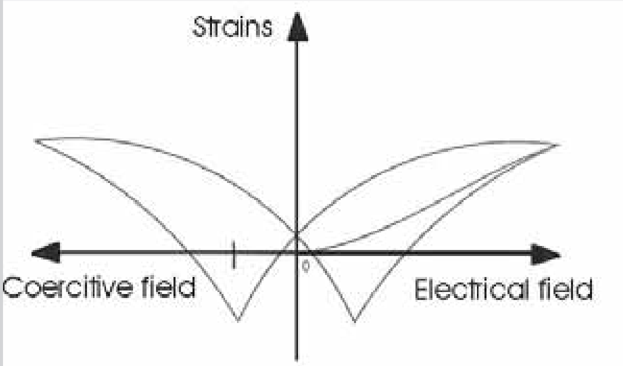
Displacement of the APA® at the resonance in free-free condition



■ Figure 2.16: Relation between the displacement and the voltage for an APA60S at resonance



■ Figure 2.17: Step response of the APA60S Actuator



■ Figure 2.18: Electrical field-strain relation in a piezoelectric material

2.9 LIMITATIONS OF PIEZOELECTRIC ACTUATORS

Piezoelectric Actuators have several limitations that must be taken into account in order to properly design the applications. These limits are electrical, mechanical and thermal. The impact of these limits depends a lot on the frequency region the actuators are used in (see Table 2.2). These frequency regions are governed by the requested function and applications.

2.9.1 ELECTRICAL LIMITS

The maximum applied voltage is limited to 150 V by the insulating layer. Since the thickness of the layer in the MLA is 100 µm, it corresponds to an electrical field of 1.5 kV/mm. The applied voltage cannot be decreased under –20V. Otherwise, the polarization would be reversed (Figure 2.18).

In Static operations (S region), their lifetime is mainly limited by the combination of DC voltage and humidity, which penetrates through the external insulation layer and leads to an increase in current leakage. A larger current leakage can lead to an electrical breakdown.

In Dynamic Strain non-resonant operation (DS region), electrical limits may be encountered. Because of the capacitive nature of piezo actuators, the higher the frequency is, the higher the current is. This current need may reach the power amplifier limits. To solve this problem CEDRAT TECHNOLOGIES develops high power linear and switching amplifiers.

■ Table 2.2: Different methods to use piezoelectric actuators

Ref	Frequency region	Bandwidth Definition
S	Static & quasistatic	From 0 to Fr/3
DS	Dynamic Strain	Between Fr/3 and Resonance region
R	Resonance	3dB-bandwidth around mechanical resonance frequency Fr
DF	Dynamic Force	Frequency above Resonance region
I	Impulse (S + DS + R + DF)	Whole frequency spectrum

2.9.2 MECHANICAL LIMITS

In dynamic operations, especially in resonance region (R), the piezo actuator mechanical stress limits may be encountered.

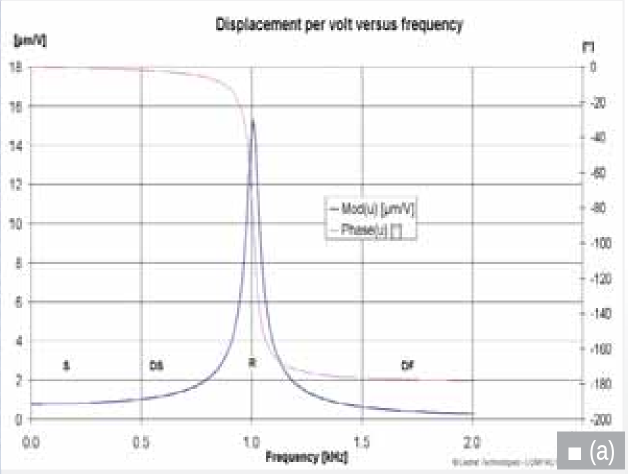
Since multilayer piezo ceramics are laminated and brittle materials, they cannot bear any tensile forces. Bending or twisting moments must be avoided as much as possible, even during the mounting procedure. Tensile forces during dynamic operations or switched operations must also be avoided. To overcome this material limit, a pre-stress (also called preload) should be applied onto the ceramic to maintain it in compression. Therefore a well-defined mechanical pre-stress is applied on all the Piezo Actuators from CEDRAT TECHNOLOGIES.

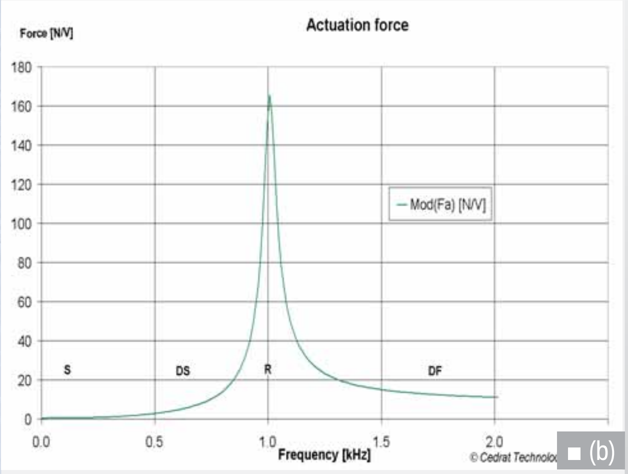
Under dynamic conditions, the level of pre-stress in a piezo actuator is responsible for the limitation of the actuator's stroke (or its vibration amplitude). Mobile masses generate dynamic forces and stresses that can rapidly damage the actuator if tensile stresses are encountered. Therefore a high pre-stress is applied in most of CEDRAT TECHNOLOGIES actuators to maintain the ceramic in compression. This is highly beneficial for dynamic applications as shown in the examples below.

Examples of impacts of electric or mechanical limits on an actuator's capabilities.

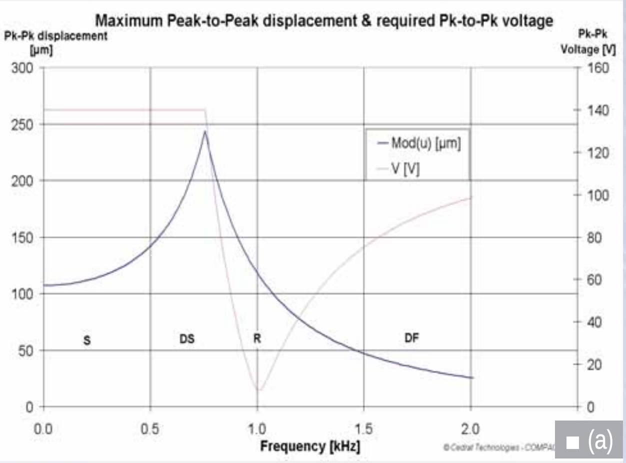
The advantage of a high pre-stress is shown with the APA120ML example under blocked-free conditions, loaded with a 180gr mass. This offers a static stroke of 130µm @ 170V, so 0.76µm/V. Its blocked force is 1400N so 8.2N/V. Its loaded resonance frequency is 1kHz. The graphs of figure 2.19 show the actuator response in harmonic analysis (sine excitation) and the 4 frequency regions. Thanks to the nominal high pre-stress of the APA120ML, the maximal dynamic peak force can reach 700N. Thus the maximal dynamic stroke below resonance (DS region) is higher than its maximal static stroke, while the stroke at resonance (R region) is similar to the static stroke (figure 2.20). It gives a very large bandwidth for displacement generation. Dynamic forces above resonance (DF region) can reach the blocked force. All these dynamic properties are important for non-resonant dynamic applications such as forced vibration generation or active damping, as well as for resonant applications such as vibration generation at resonance.

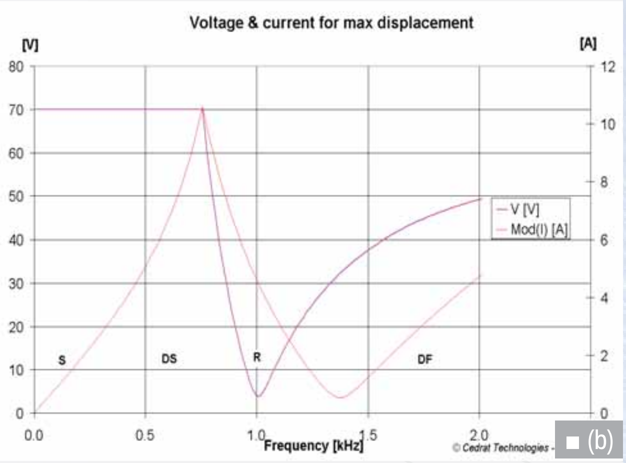
For the same reason, the APA120ML can survive large external vibrations and has successfully passed space qualifications. To improve even more the ability to generate or withstand dynamic strokes in APA®, CEDRAT TECHNOLOGIES proposes solutions such as the Parallel Pre-stress. Note also that below resonance, the displacement can be higher than at resonance, but the needed current is high, which may reach the power limit of the electric amplifier.
If a 10 times lower pre-stress were applied on the APA120 ML,





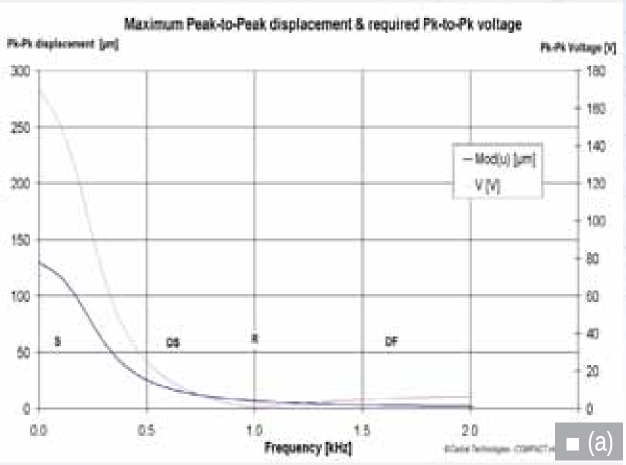
■ Figure 2.19: APA120ML in blocked-free conditions, loaded with a mass of 180gr: Displacement (a) and dynamic force (b) due to inertial forces versus frequency

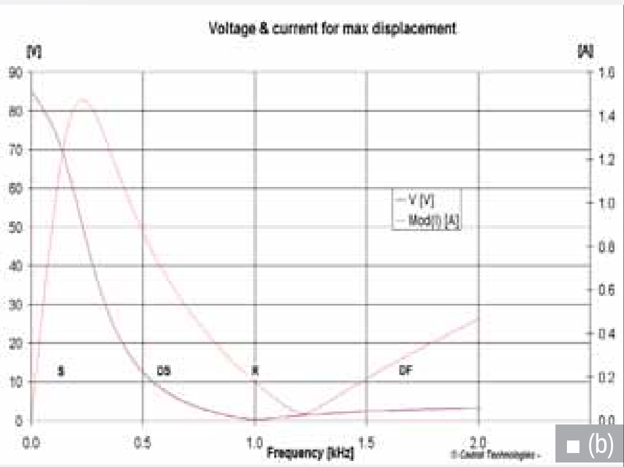




the maximal dynamic peak force (in DS region) could only reach 70N and so the maximal dynamic stroke at resonance (R) and below resonance would be much smaller than its maximal static stroke (figure 2.21).

■ Figure 2.20: (a) Standard APA120ML in blocked-free condition, loaded with a mass of 180gr : Maximal displacement and maximal applicable voltage versus frequency.
(b) Requested peak voltage and peak current to reach the displacement of (a).





■ Figure 2.21: (a) Modified APA120ML with a low pre-stress (90% less than nominal) under blocked-free conditions, loaded with a mass of 180gr: Maximal displacement and maximal applicable voltage versus frequency.
(b) Requested peak voltage and peak current to reach the displacement of (a).

Most of CEDRAT TECHNOLOGIES's APA® and PPA Actuators can be operated under dynamic conditions in a large frequency range or under impulse conditions.

Because of mechanical limits, some piezo actuators can only be operated under static conditions.

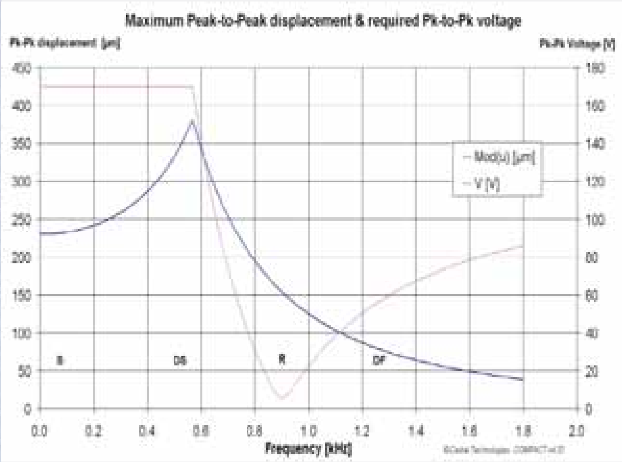
To check if an actuator can be operated in dynamics, one can verify if the resonant stroke is close to the static one, or ask for CEDRAT TECHNOLOGIES's COMPACT tool.

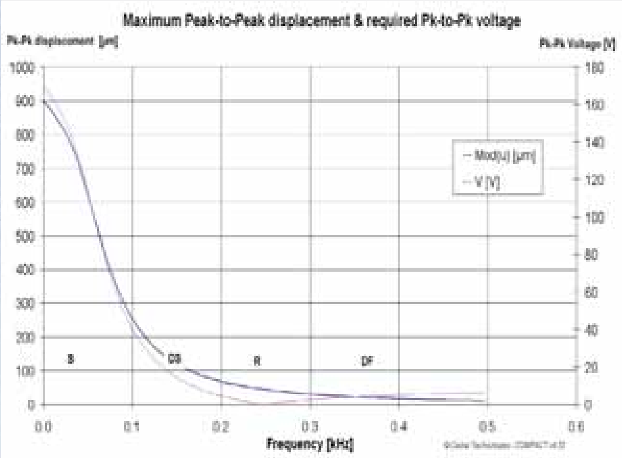
Note also that APA® with large amplification as the APA900M have reduced pre-stress. That is why their maximal dynamic stroke in DS an R region is lower than their static stroke in S region, even much below resonance. It limits their application to quasi-static conditions. Therefore an APA200M can produce more displacement at 500Hz than an APA900M, although its static stroke is smaller (figure 2.22) (Table 2.3).

To verify that an actuator can provide high dynamic capability, just compare the max dynamic stroke at resonance (In CEDRAT TECHNOLOGIES Data sheet, these are given with a 10% security margin) with the max static stroke. If the resonance peak-to-peak stroke is similar to the static stroke, the actuator can be operated with its full stroke up to the resonance frequency, including DS regions. To check this possibility in your application, please ask CEDRAT TECHNOLOGIES for support with COMPACT simulations.

Impulse applications found for example in injectors and shutters are the most complex cases regarding an actuator's limits. In these applications, a step excitation signal is typically used. This causes overshoots which clearly excite resonance and can break the actuator.

Impulse response is due to a transient excitation signal. It can be analysed as a spectrum of frequencies by Fourier Transform. This signal spectrum can be multiplied with the above transfer functions to get the actuator's response. Thus an impulse excitation uses the actuator under dynamic conditions combining resonance and non resonance frequency regions (DS, R, DF), which generates a lot of stresses in the actuator. For this reason, high-pre-stressed actuators are preferable to get a long life time under Impulse strain conditions.

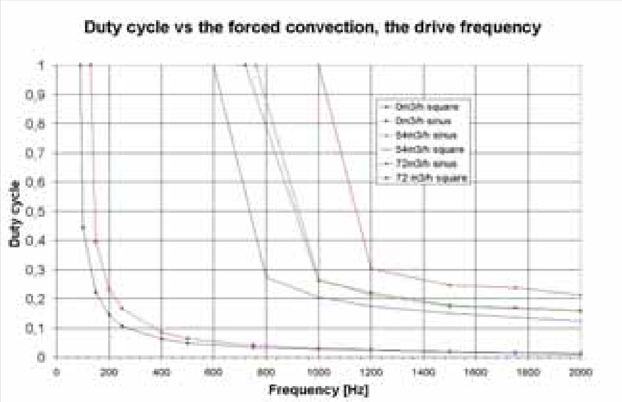




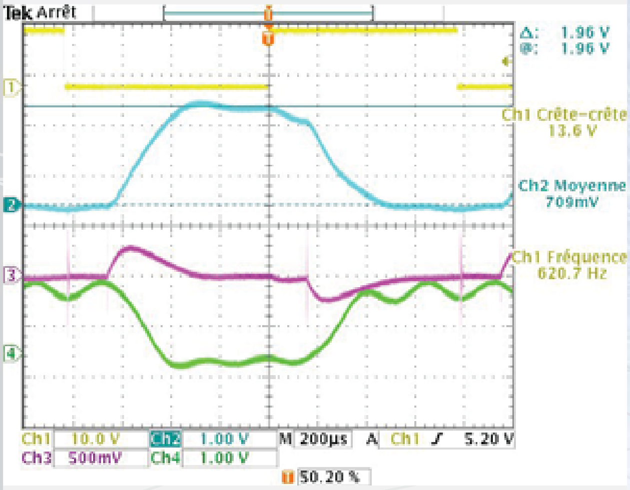
■ Figure 2.22: APA200M and APA900M in blocked-free condition, unloaded: Maximal displacement according to pre-stress and maximal applicable voltage versus frequency.

Model	Static stroke (µm pk to pk)	Resonance stroke (µm pk to pk)	Ability to operate under dynamic conditions DS,R,DF, I conditions
APA-120ML	130	115	Very good
APA-200M	230	150	Good
APA-900M	900	80	No

■ Table 2.3: Summary of the mechanical limits cases for three actuators



■ Figure 2.23: Limitation of the standard APA-60SM due to the self-heating



■ Figure 2.24: Temporal excitation and resolution displacement of the APA® during the lifetime test (from top to bottom: Order, Voltage, Current, Displacement)

2.9.3 THERMAL LIMITS

Due to the dielectric and mechanical losses, the Piezoelectric Actuator warms up under continuous excitation. Losses are mainly non-linear and depend on the excitation frequency, the voltage amplitude and the humidity level. To avoid a depoling effect of the ceramic, the temperature in the Actuator should be monitored to ensure that it stays well below the ceramic's Curie temperature. So the typical temperatures range from -40°C to +80°C.

As a consequence, the duty cycle of a piezoelectric actuator in dynamic operation is limited by its thermal behaviour. For instance, to maintain a constant temperature on the APA60SM actuator, the duty cycle should be reduced or a forced convection should be applied as the driving frequency increases (Figure 2.23).

There are currently a lot of researches on materials that aim at producing MLAs displaying higher working temperatures (up to 140°C). Upon request, CEDRAT TECHNOLOGIES can produce Actuators with these new components.

Similarly, the standard MLAs work at low temperature and have already been tested in liquid nitrogen (77 K, -196°C): at this cryo temperature, their strain is only one third of the one obtained at room temperature. As a consequence, PPA and APA® offer a reduced stroke; LSPA, RSPA, LSPS present a reduced speed.

Provided that self heating and tensile forces are prevented, the Amplified piezoelectric actuators do not show any fatigue effect. For example, a test was carried out during 6 months (without interruption) on the APA200M under full scale pulse (0 – 150 V) with a driving frequency of 600 Hz (Figure 2.24). It showed the ability of the actuator to operate for 10^{10} cycles.

Thermo-mechanics may be an issue in the case of a fine positioning application over a large range of temperature: the PZT in the multilayer technique display various Coefficients of Thermal Expansion CTE (as a function of some construction details). Standard Amplified piezoelectric actuators display fairly large CTE due to some thermal mismatch between the piezo component and the shell material. There are some possibilities to cancel this CTE. Please consult CEDRAT TECHNOLOGIES for your specific need.

2.10 DRIVING OF PIEZOELECTRIC ACTUATORS

A Piezoelectric Actuator is a capacitive device, whose capacitance is often very large (as much as 110 microfarads). Such a device is a difficult load for its driving electronics, since a significant charge transfer rate is necessary to achieve a fast response. In addition the Actuator will produce electrical energy when submitted to a mechanical load.

Linear amplifiers are the most common amplifiers and have high signal to noise ratio. Switched power amplifiers are more efficient under reactive loading in dynamic applications, but are more difficult to control. The general synoptic of the driving system for a piezoelectric system is given Figure 2.25.

With a linear amplifier the voltage applied to the actuator is directly proportional to the input signal. The gain of the power amplifier is set to 20. Therefore, to obtain the whole stroke of a given actuator, one should input a signal varying from –1 V to 7.5 V. The applied voltage on the actuator will then vary from –20 to 150 V.

There is some limitation to the constant gain of the amplifier. Indeed, when the variation speed of the input signal (order) increases, the current limitation I_{lim} of the amplifier limits the slew rate of the output voltage (Figure 2.26). The current provided to a piezo ceramic depends on its capacitance and on the variation speed of the applied voltage.

The current for a capacitive load is given by the following expression:

$$I_{piezo} = C_{piezo} \times \frac{dV}{dt}$$

For a given current limitation I_{im}, the shortest load time is given by:

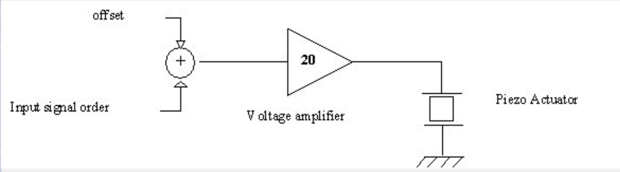
$$t_{load} = \frac{\Delta V \times C_{piezo}}{I_{lim}}$$

Where ΔV is a peak to peak voltage value,

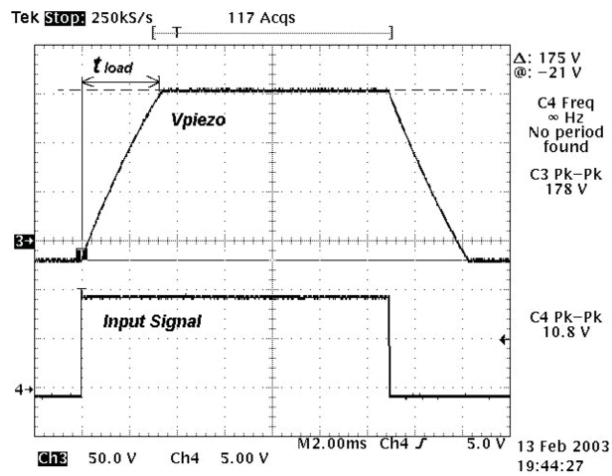
$$\Delta V = 2 \,.\, Vp$$

In dynamic operation, the peak current i flowing into the Actuator linearly increases with the frequency of a sine signal.

$$i \approx 2\pi \,.\, f \,.C_{piezo} \,.V_p$$



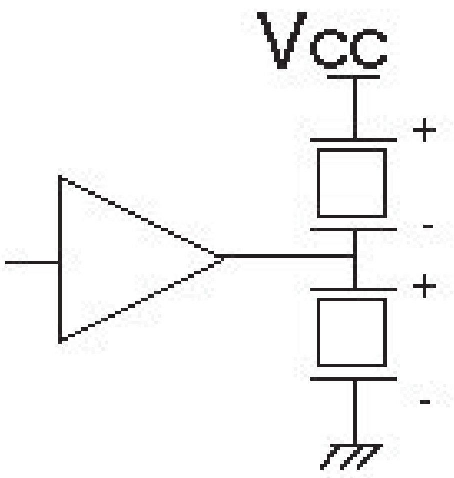
■ Figure 2.25: Synoptic of a driving system



■ Figure 2.26: The current limitation limits the voltage slew rate of the piezo

Several limitations apply to the Piezo Actuators: maximum voltage, tensile stress, thermal limits. They should be taken into account in the application design. Thermo - mechanics may be an issue in the case of positioning application over a large range of temperature.

CEDRAT TECHNOLOGIES has a great experience in designing Piezo Actuators or mechanisms taking into account the environment (thermal, random vibrations, lifetime...).



■ Figure 2.27: Push-pull operation using one electric driver

Two types of driving electronics are available: the linear type offers a good signal to noise ratio, while the switching type is more **efficient.**

If a high accuracy is required, a closed loop including the Actuator, a position sensor & a controller are necessary to remove the hysteresis.

where C_{piezo} is the quasistatic capacitance of the Piezo Actuator, and V_p the peak value of the sine voltage applied to the actuator.

Due to the peak current limitation, the maximal frequency for a sine signal is given by:

$$f_{\sin\max} = \frac{I_{lim}}{\Delta V \times C_{piezo} \times \pi}$$

The max frequency for a triangle signal is given by:

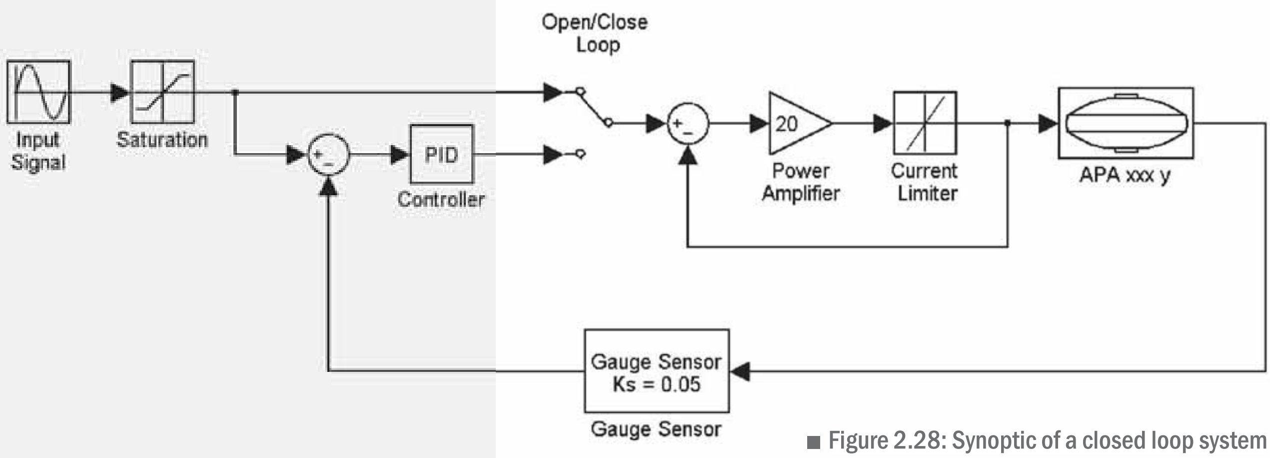
$$f_{triangle\ max} = \frac{I_{lim}}{2 \times \Delta V \times C_{piezo}}$$

The required effective electrical reactive power Q is equal to:

$$Q \approx 4 \,.\, f \,.\, C_{piezo} \,.\, V_p^{\,2}$$

It should be noticed that the capacitance C_{piezo} depends on the applied voltage and on the temperature. This means that a margin should be kept for the increase in the power demand resulting from the actuator's self-heating.

Nota: One option available on the linear driver is the push-pull operation, which can be used to drive tilt devices or electrically centred mechanisms (Figure 2.27).



■ Figure 2.28: Synoptic of a closed loop system

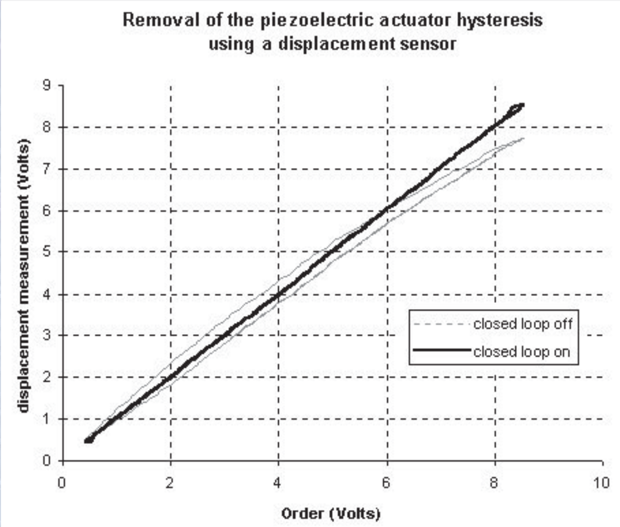
2.11 CONTROL OF PIEZOELECTRIC ACTUATORS

The resolution of a piezoelectric actuator is limited by the electrical noise of the driving system. Typical values of the signal to noise ratio of the driving electronic (below the resonance frequency of the actuator) range from 70 to 85 dB.

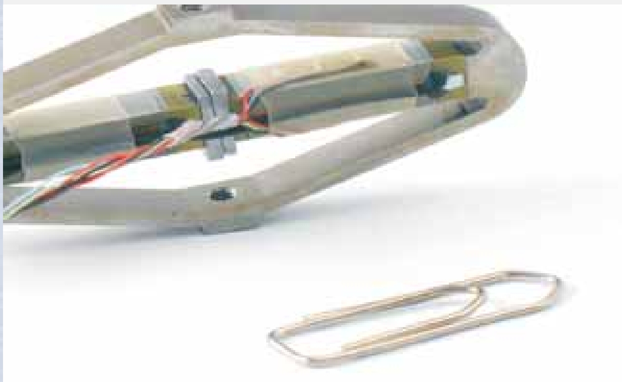
MLAs always display an hysteresis, which limits the positioning accuracy. Other effects, such as drift, also limit the Actuator's linearity. Therefore, displacement sensors are often used to ensure a linear response of the Piezoelectric Actuators through a closed-loop (Figure 2.28).

Among sensors, strain gauges are the most popular ones because of their integrated features (Figures 2.29 and 2.30). An accuracy of 1/700 is usually achieved (SG option). Capacitive displacement sensors or eddy current sensors ECS option can also be used and a precision of 1/1000 can be obtained.

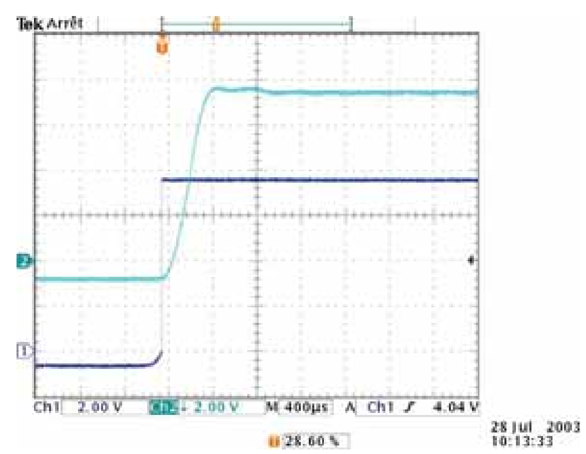
In practical situations, with a piezo actuator in closed loop, one should consider the settling time close to $t_s = 1/f_r$ (Figure 2.31).



■ Figure 2.29: Example of an hysteresis removal using a SG displacement sensor



■ Figure 2.30: Example of an APA150M equipped with Strain Gauges

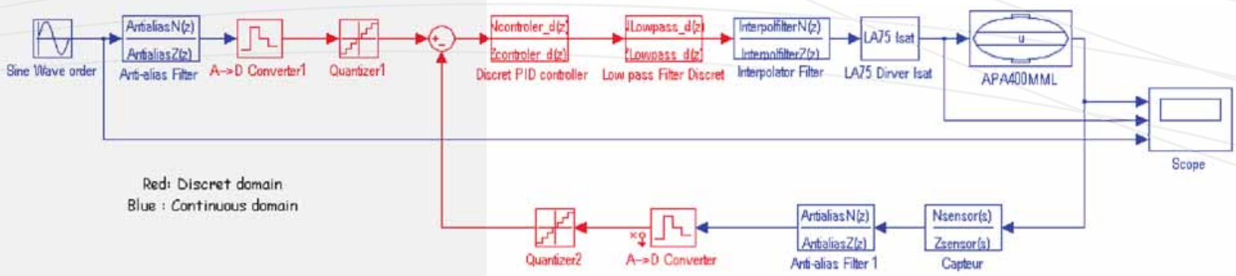


■ Figure 2.31: Mechanical response in closed loop. Channel 2 of a piezo actuator to a step voltage signal (channel 1)

2.12 DIGITAL CONTROL OF PIEZOELECTRIC ACTUATORS

When accuracy or speed is required, additional controllers are implemented in specific control loop to improve the performances of the piezoelectric mechanisms. Coupled with Strain Gauges Sensors (SG75 conditioner Option) or Eddy current sensor (ECS75 conditioner option), the Servo Controller (UC45, UC65 or UC75) is ideally the best solution to control the displacement or to increase the response time of the actuators by regulating the applied command. The digital control can be dealt with similarly to an analogue control (figure 2.32), but also includes an ADC (Analogue-Digital Converter) and a DAC (Digital-Analogue Converter). An ADC includes several functions (Figure 2.33).

The sampling rate is the speed at which the ADC converts the input signal, after the signal has passed through the analogue input path, to digital values that represent the voltage level. This means that the digitizer will sample the signal after application of any attenuation, gain, and/or filtering by the analogue input path, and converts the resulting waveform to a digital representation. The higher the sampling rate, the better the signal will be defined. The sample rate is directly linked to the frequency of the signal to digitalize. The Nyquist theorem states that a signal must be sampled at a rate greater than twice the highest frequency component of the signal to accurately reconstruct the waveform; otherwise, the high-frequency content will alias at a frequency inside the spectrum of interest.



■ Figure 2.32: Schematic of a discrete feedback control loop

■ Figure 2.33: Composition of a Analogue – Digital Converter

In applications, the use of a sampling frequency at least 30 times the crossover frequency of the continuous design is recommended to preserve the behaviour of the continuous system at a reasonable degree.

The other parameter of the ADC and DAC is the quantization parameter. The quantization is defined as the process of converting an analogue signal to a digital representation. After the zero hold, the signal is passed into the ADC for sampling and conversion into a digital signal of a finite word length (16 bits for example) representing the total range of the analogue signal. The signal to noise ratio is in the order of 2^N and the quantization error is 2^{-N} (N being the number of bits). This point can be also applied for the DAC output. Additional information are available in the Application Note Section.

3. APPLICATIONS, SOLUTIONS & DESIGN

This section deals with solutions provided by CEDRAT TECHNOLOGIES for various applications using both standard and customised products.

This section gives the customer many ideas of what Functions and Applications are feasible with CEDRAT TECHNOLOGIES components. These Applications and their Working Conditions are given in section 3.1

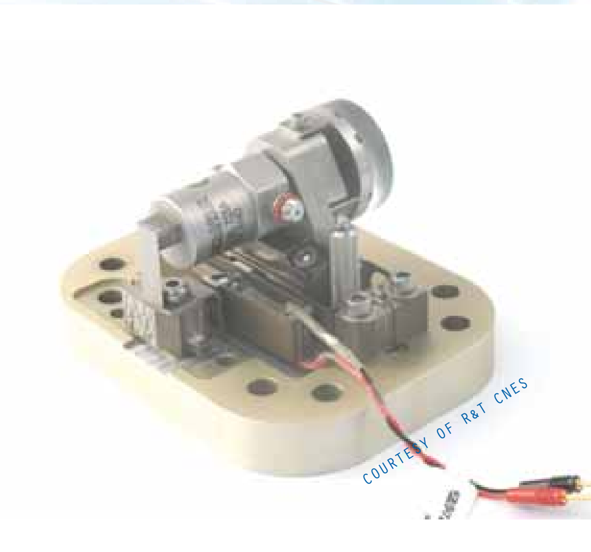
CEDRAT TECHNOLOGIES, as a customer-oriented company, manufactures and sells not only standard products, but also customised solutions, especially for OEM series.

The range of standard Actuators from CEDRAT TECHNOLOGIES is not always sufficient to cover the specifications of a customer's application. Several situations may arise:

- The strokes of standard Actuators are not large enough,
- The standard mechanical interfaces are not well suited to the application,
- The application requests a more complex mechanism than a single Actuator,
- A special feature such as non-magnetism is required.

Solutions to remove these limitations are shown through applications in section 3.1 and are completed with additional technological solutions introduced in section 3.2

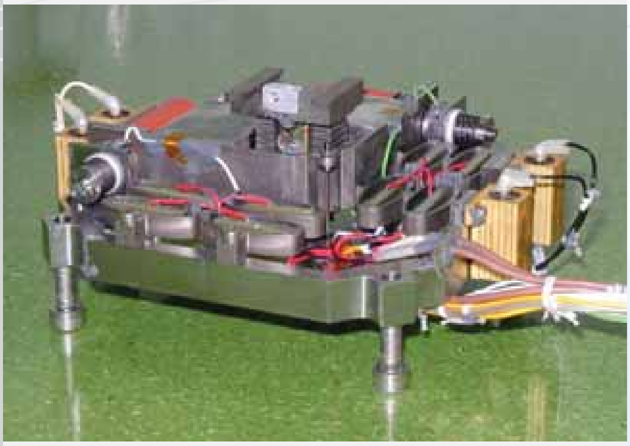
In all these cases, CEDRAT TECHNOLOGIES can provide all the services presented in section 3.3 to help the customer with a fast and costeffective solution combining its existing products, its building blocks, its experience and its development facilities.



At CEDRAT TECHNOLOGIES, service does not end with the delivery of your products. Service and support is our most important commitment, and we ensure it with our network of representatives around the world. Our engineering, manufacturing and quality expert teams are ready to serve you from concept, through development, to technical assistance during your implementation process.

Working conditions	Inertial forces	Electric Power	Functions / used as	Applications/used for
Static	negligible	negligible	• Micropositioner • Slow actuator • Force Generator	• Micro & Nano positioning • Flow control • Material Stress testing
Dynamic Strain non resonant	not negligible	can be very high (Electric current need can be limiting)	• Wide bandwidth Vibration generator • Vibration damper • Fast actuator	• High frequency Shaker • Forced Vibration Assistance • Active damping, Isolation • Shutter, XY Scanning • Fast positioning • Material stress cycling
Dynamic Strain at resonance	high	not negligible (Applied voltage should be monitored)	• High-amplitude Vibration generator • Sonic transducer • Ultrasonic transducers	• Resonance Vibration Assistance to process • Ultrasonic welding, micro-injection moulding ... • Fluid degassing, cleaning
Dynamic Force	high	high	• Proof-mass vibration / force generator • Proof-mass vibration damper	• SHM structure exciters • Hammer • Active damping of structures
Impulse Strain (Dynamic)	can be high	can be very high (Electric current need can be limiting)	• On-off fast actuators • Impactors • Long-stroke actuation (SPA Motors)	• Shutter • Fluid injection • Circuit breaker • Fast positioning • Long-stroke positioning
Dynamic Sensing	can be high (due to external vibrations)	negligible (Generated voltage should be monitored)	• Electric generator • Force sensor	• Energy Harvesting • Igniters • Force Sensing

■ Table 3.1: Applications, Functions & Working Conditions



■ Figure 3.1: Midas Space Instrument (courtesy of ESA)

3.1 APPLICATIONS, FUNCTIONS AND WORKING CONDITIONS

The following table establishes the relation between Applications, requested Functions and associated Working Conditions.

The Working Conditions are the kinematic conditions so that the inertia and dynamic force impacts on the piezo actuator are taken into account. The working conditions are split into several kinematic conditions: Static, Dynamic non resonant, Resonant…

The Function is the type of physical action or operation (Force, motion, vibration,…) that the piezo actuator generates on the user system. The function is the answer to the following question: How is the actuator used inside the system?

The Application is the result of the actuator's function inside the system. The application is the answer to the question: What is the actuator's operation/function used for?

The Working Conditions can be more or less demanding for the actuator and the electronics. They are associated to different frequency regions, introduced in previous section. Most of CEDRAT TECHNOLOGIES actuators can really operate under dynamic conditions thanks to their pre-stress level, which opens them to a wide range of applications and markets. To select an actuator for a given application, it is useful to know its function and working conditions (Table 3.1).

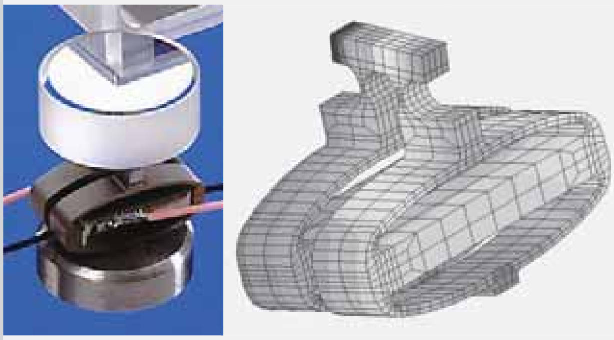
3.1.1 APPLICATIONS OPERATED UNDER STATIC CONDITIONS

XY & XYZ MICRO POSITIONING MECHANISMS

Several XY stages have been designed at CEDRAT TECHNOLOGIES for various needs.

The customized XYZ mechanism for the MIDAS instrument of ROSETTA space mission was developed under an ESA/ESTEC contract, starting from standard APA50S and PPA10M. The function of this mechanism is to ensure the nano-resolution scanning motion of an Atomic Force Microscope (AFM) under a severe environment (Figure 3.1). Although operated under static conditions, the ability of CEDRAT TECHNOLOGIES actuators to withstand large vibrations thanks to their pre-stress allowed the mechanism to pass vibration tests. It has been launched in 2004 and successfully tested after launching.

■ Figure 3.2: XYZ200M-SG stage for IR Spectroscopy (courtesy of GES Lab / Montpellier University)



■ Figure 3.3: Tilt-translator TT50S (based on 2 APA50S Actuators) and producing an angular displacement of +/- 0.5° and a resonance frequency of 1800 Hz, a) Actuator; b) corresponding FEM modelling

■ Figure 3.4: DTT35XS, based on 4 APA35XS (courtesy of EADS SODERN)

■ Figure 3.5: Miniature Tilt-translator TT40uXS (courtesy of ETHZ)

Another example of XYZ mechanism developed for an optical application is given with Figure 3.2. This mechanism is able to perform any stroke in the volume [-100,+100µm] x [-100,+100µm] x [0,200µm]. It is entirely based on standard components. It combines a standard XY200M stage based on 4 APA200M for centred XY displacements (scanning function) with a set of 3 APA 200M for Z displacements (focussing function).

TILT TRANSLATOR MECHANISMS

As APA® are rather flat, they can be arranged in parallel. It is interesting either to increase the force or for tilting applications. In this last case the flat structure of APA® allows to place their actuation axes close together to get a relatively large tilt angle. This is shown with a first Tip-translator TT50S based on 2 APA50S Actuators and producing an angular displacement of +/- 0.5° and a resonance frequency of 1800 Hz. In this mechanism, the Finite Element Method can be used to design flexural hinges (Figure 3.3).

Using this possibility, standard products including a tilt translator named TT60SM and a double tilt translator named DTT35XS have been designed for optical deflection (Chapter 6). The TT60SM and DTT35XS are respectively based on 2 APA60SM and 4 APA35XS mounted with flexural hinges.
Customized tilt mechanisms can also be easily derived from other standard actuators. For instance, a space version of the DTT35XS has been developed for EADS within the PHARAO project (Figure 3.4). This mechanism has to withstand external vibrations and benefits from the APA® properties.
Another configuration to build tilts has been designed for actuation functions in Micro Aerial Vehicles for ETZH (Figure 3.5). The complete mechanism is monolithic and uses two APA® in a push-pull configuration. This allows deflection of up to 10°, with only 0.35gr.

TRIPODS, HEXAPODS

CEDRAT TECHNOLOGIES's actuators have also been used to build complex nano-positioning mechanisms such as tripod, hexapods, 5 d-o-f mechanisms in the fields of astronomy and space optics.

For example, CSEM and NTE had to develop a tripod mechanism for nano-positioning and stabilization of the M5 mirror in the Extremely Large Telescop (ELT) of ESO. The mirror mass is more than 600kg. This induces that a static load but also dynamic loads (due to possible earthquakes) have to be added to the functional dynamic load. After a trade-off analysis, CSEM and NTE have selected the APA® technology. Therefore CEDRAT TECHNOLOGIES has developed 3 customized extremely-large actuators APA500XXL meeting these severe requirements (Figure 3.6).

Other examples of piezo actuators applications in mechanisms are given in:

http://www.cedrat-technologies.com/en/technologies/actuators/piezo-mechanisms.html

3.1.2 APPLICATIONS OPERATED UNDER DYNAMIC NON-RESONANT CONDITIONS

FAST XY STAGES FOR SCANNING, STABILISATION...

Several OEM XY stages for fast micro-scanning and stabilisation are produced in series by CEDRAT TECHNOLOGIES.

Figure 3.7.a XY25XS stage uses parallel piezo actuation, which is also used in XY200M products. This configuration is optimal for fast motion and renders feasible new optical functions. For example fast micro-scanning is highly beneficial in military Infra Red cameras to improve the camera resolution. In this application the short response time of the actuators is used to perform a complex pattern to allow image reconstruction from several pictures at a rate of 100Hz. Therefore the actuators are used under almost Impulse Strain conditions. In addition, the XY stage should operate in spite of external vibrations, the camera being embedded in military vehicles. Therefore CEDRAT TECHNOLOGIES actuators' performances in dynamics are suited to this class of application.

Parallel magnetic actuation is another option when even larger strokes are needed. Figure 3.7.b is a XY stage based on small MICA actuators offering 2mm x 2mm stroke, designed for optical stabilization.

SERVO PIEZO TOOLS

The Servo Piezo Tools (SPT) developed by CEDRAT TECHNOLOGIES and available as OEM products are dedicated to both fast and precise machining: Applications vary from oval piston machining to aspherical lens machining.
For example, the SPT400MML uses the Amplified piezoelectric actuator APA400MML to obtain a large and fast motion of the diamond tool (400µm at more than 100Hz). The SPT400MML is arranged in a casing and dry air is used to expel dust from the casing. It includes an Eddy Current proximity Sensor for position control.
The SPT400MML (Figure 3.8) is driven by a standard LA75C drive. The closed loop is performed by a real time platform (Dspace, Delta Tau PMAC, ...) or by the UC75 board and carries out the following tasks:

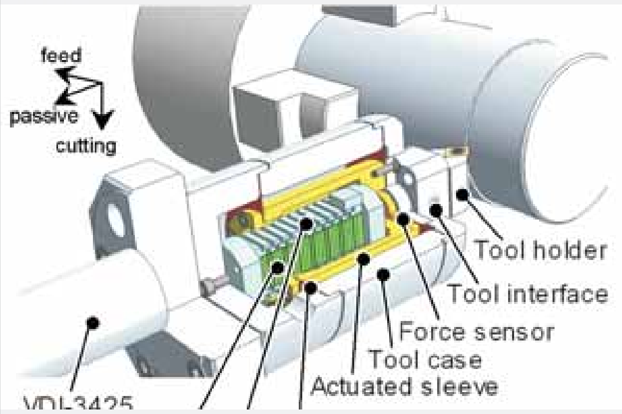
- Closed loop between the SPT and the Eddy Current proximity Sensor,
- Synchronization of the loop with the master axis of the lathe.

■ Figure 3.6: APA500XXL for ELT M5 mechanism (courtesy of CSEM, NTE and ESO)

■ Figure 3.7a: XY stage based on APA25XS used for micro-scanning

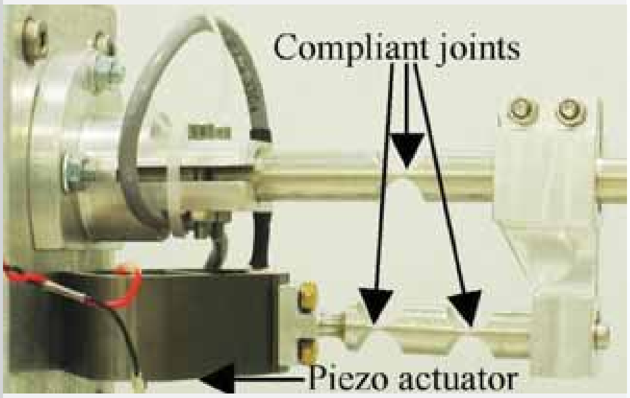
■ Figure 3.7b: XY stage based on MICAS used for stabilisation

■ Figure 3.8: Servo Piezo Tool SPT400MML



■ Figure 3.9: Smart Tool based on PPA60L (courtesy of IFW)

■ Figure 3.10a: ACV with APA® on ski (courtesy of Rossignol and ESA)



■ Figure 3.10-b: ACV with APA® on Cardiolock medical robot (courtesy of IRCAD)

ACTIVE VIBRATION DAMPERS

When coupled to well suited driving and control electronics, piezo actuators are deemed candidate to actively damp the vibrations on a mechanical structure. CEDRAT TECHNOLOGIES has already developed and set up several OEM solutions based on APA® & PPA for Active Control of Vibrations (ACV) on machine tools (Figure 3.9), truss and ski (Figure 3.10) and contributed in new ACV applications for example in the CARDIOLOCK medical robot.

Actuators or systems for vibrations damping are also available upon request. Other examples of applications of active damping are given in:
http://www.cedrat-technologies.com/en/technologies/mechatronic-systems/vibration-control.html

VIBRATION GENERATOR OPERATING IN FORCED VIBRATION MODE

Amplified piezoelectric actuators (APA®) and Parallel Prestress Actuators (PPA) found several applications for vibration generation in forced vibration mode (below resonance): They can provide as much stroke as at resonance, which is not the case with Langevin transducers. Their frequency range can reach ultrasonic frequencies (> 20kHz). In forced vibration mode, their stroke is not as sensitive to the load as in resonance mode. That is why APA® and PPA are progressively replacing Langevin transducers in sonic and ultrasonic transducers applications.

To supply the actuator in forced mode, high power electronics are required. For such forced vibration mode, high power amplifiers are required. For piezo actuators, the linear amplifier LA75C is still an option but switching amplifiers SA75D offering up to 3kVA (30A, 170V) are more appropriate. For magnetic actuators such as MICA, CEDRAT TECHNOLOGIES has qualified several amplifiers available on the market up to 10kV. Please contact us for such a selection.

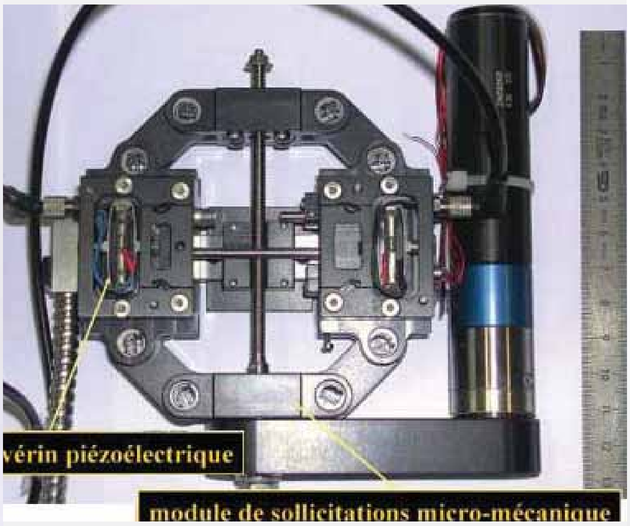
APA® and PPA used in forced vibration mode are typically used in machines for material mechanical testing, such as the lifetime test of Semicon silicon parts or films by stress cycling, (Figure 3.11) or machines for vibration testing such as piezoelectric shakers (Figure 3.12).

MICA is a new alternative for vibration testing. It offers more strokes (up to 10mm) such as electrodynamic shakers while being much more compact.

Another range of industrial applications of this mode is the vibration assistance to processes. Forced vibrations provide a useful assistance in many processes such as food cutting, glass cutting, engraving, machining (milling, drilling ...), extruding etc. Typically vibration assistance improves the process speed and/or surface quality.

An example in the field of Vibration Assisted Machining (VAM) or Modulation Assisted Machining (MAM) results from the AVIBUS project coordinated by CEDRAT TECHNOLOGIES. From tests of ARTS and CETIM, the Vibration Assisted Drilling (VAD) tool holder of Figure 3.11.b allows to reduce the drilling time by a factor of 3.
Another example is Automated Food Cutting. In this case, because of the large compliance of the product to cut, millimetric vibrations are required. This is achieved using customised MICA magnetic actuators (Figure 3.11.c) putting the knife in oscillation.

Other examples of applications of forced vibrations using CEDRAT TECHNOLOGIES' products are given in:
http://www.cedrat-technologies.com/en/technologies/actuators/sonic-ultrasonic-generators.html



■ Figure 3.11a: Cycling Stress Machine (courtesy of 3S Lab, UJF)

3.1.3 APPLICATIONS OPERATED UNDER DYNAMIC RESONANT CONDITIONS

PIEZO VIBRATORS OPERATING AT RESONANCE

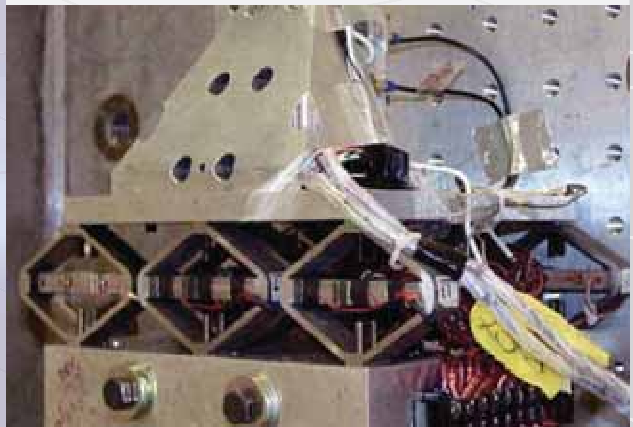
CEDRAT TECHNOLOGIES PPA and APA® are also successfully used in resonant mode for vibration generation at a fixed frequency.

In some cases, special interfaces are useful, for example the Ultrasonic Piezo Actuators (UPAs) deriving from the APA® have been developed to offer a more compact solution than Langevin transducers for the generation of ultrasonic vibrations. UPA structures are the same as APA® structures, but they are maintained on the side of the long axis in order to decouple the support from the vibration generation (Figure 3.13).
Ultrasonic Piezo Drives (UPDs) are ultrasonic vibration generators looking like the UPA. They are designed to produce 2 orthogonal components of vibrations that can be combined to get an elliptical vibration.
UPAs and UPDs are customised products finding applications in machining (for example ultrasonic engraving) or in ultrasonic piezo motors.

■ Figure 3.11.b: AVIBUS VAD tool holder

■ Figure 3.11.c: Vibrating Food Cutter using MICA

Compared to Langevin transducers (the most common structure for ultrasonic generation, which is also mastered by CEDRAT TECHNOLOGIES - Please ask for a separate documentation.), UPA and UPD offer several significant advantages:
- Much smaller size and weight, for the same frequency and displacement amplitude,
- Much higher deformations due to the above advantages,
- Much lower voltage (1 to 10V instead of 200 to 1000V).



■ Figure 3.12: Piezoelectric shaker (courtesy of Sandia Lab)

■ Figure 3.13: View of an Ultrasonic Piezo Actuator (UPA)

■ Figure 3.14a: PM900M Proof Mass Actuator

■ Figure 3.14b: Customized MICA200L used in proof mass for anti-vibration

3.1.4 APPLICATIONS OPERATEDUNDER DYNAMIC FORCE CONDITIONS

PROOF-MASS ACTUATOR

A Proof-Mass Actuator (PMA) aims at generating dynamic forces into a structure to either excite vibrations in the structure (proof-mass shaker) or to damp vibrations of the structure (proof-mass dampers).

CEDRAT TECHNOLOGIES piezoelectric PMAs are made of an APA®, a back mass fixed on one side of the actuator, and optionally some guiding functions (Figure 3.14). The second side of the actuator is fixed on the structure. By reaction, because of mass inertia, dynamic forces can be produced in the structure at the resonance frequency and above resonance. On this condition, the PMA may provide dynamic forces up to the APA® blocked force.

PMAs based on APA® are compact and can operate at relatively low frequency. The PMA900M is based on an APA900M and a mass of 0.23kg. Its resonant frequency is 60Hz. It may generate a dynamic force of 10N peak from 50Hz to 500Hz. This actuator has been developed to reduce noise in an aircraft cabin for ALENIA within the MESEMA FP6 Eu R&D project.

Customized MICA magnetic actuators (fig 3.14b) have been also successfully used in a proof-mass configuration for anti-vibration. This actuator is able to generate vibrations larger than 1mm and forces of 200N on a bandwidth up to 500Hz. In the proof mass mode, the operational frequency was 50Hz – 500Hz.

3.1.5 APPLICATIONS OPERATED UNDER IMPULSE CONDITIONS

FAST PIEZO VALVES

The well-known advantages (rapid response and precise positioning) of APA® have been used in valve designs to obtain both rapid and precise-flow proportional valves.

A first gas valve (Figure 3.15) was manufactured using a small amplified piezo actuator (APA100S) and was further driven with a switched amplifier to get a high frequency modulation. A frequency bandwidth higher than 400 Hz with a stroke of 100 µm has been measured. These properties can also be used for gasoline injectors.
CEDRAT TECHNOLOGIES has already designed and developed hydraulic piezo valves within the European project MESEMA and space piezo valves under ESA contracts for the propulsion of micro satellites.

For specific designs of piezo valves, please contact CEDRAT TECHNOLOGIES or visit:
http://www.cedrat-technologies.com/en/technologies/actuators/electro-fluidic-devices.html

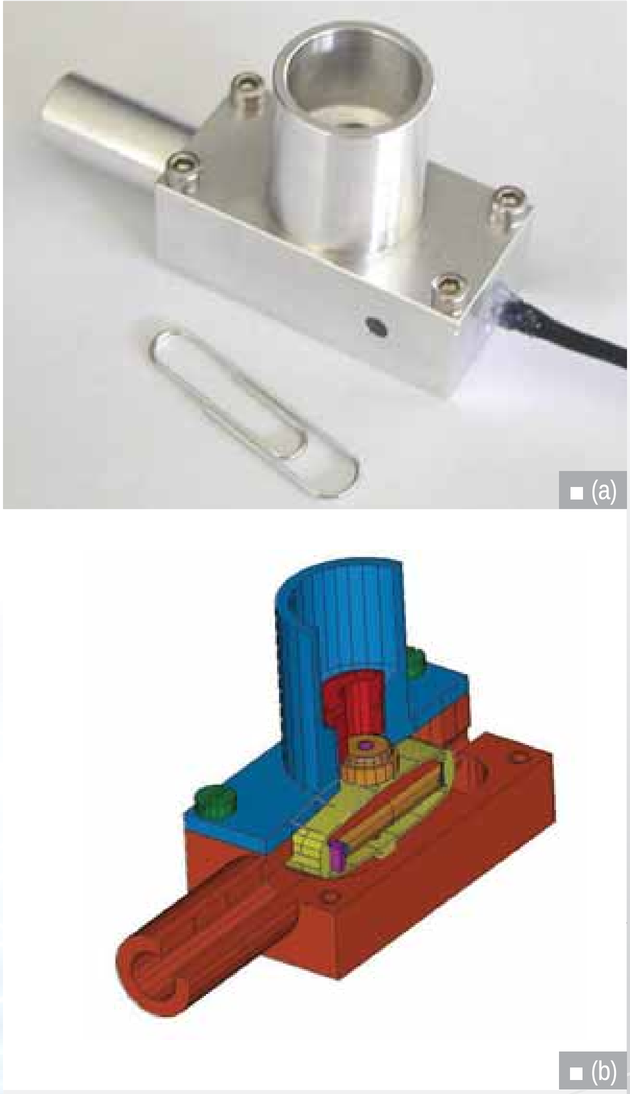
LONG-STROKE ACTUATION WITH SPA PIEZO MOTOR

Stepping Piezoelectic Actuators (SPA) are new piezo motors for long stroke actuation whose principle and product characteristics are introduced in section 2.6: An SPA is basically an APA® exploiting both slow and fast strains to get stick slip effects. Thus the SPA uses the APA® under Impulse strain conditions.

As a first consequence, the SPA takes advantage of the APA® pre-stress to demonstrate the following performances: Fast time response, ability to withstand external vibrations, robust structure (no dismounting during operation), good resistance to transverse forces... As a second consequence, all APA® offering good dynamic capabilities can be used to make new SPA. Therefore new customised SPA can easily be developed upon request from the large range of standard APA®.

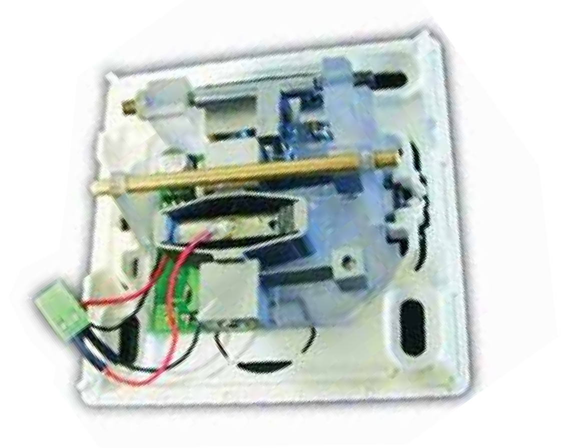
The LSPA30uXS (Figure 3.16) is an example of customised miniature piezo-motor developed for a MRI-compatible medical implant. It is based on the SPA motor concept and the APA30uXS micro actuator. This motor is fully-non magnetic, passing MRI tests. Its mass is less than 1gr. It performs stroke of 3mm with a controllable speed from 0 to 70mm/s. The Blocking force at rest is higher than 0.5N while the actuation force is higher than 0.2N.

The SPA technology has received a Golden Micron award at MICRONORA 2008 micro technology fair because of its relevance for precision and miniaturisation positioning functions.
Examples of CEDRAT TECHNOLOGIES piezo motors and applications are given in:
http://www.cedrat-technologies.com/en/technologies/actuators/piezo-motors-electronics.html

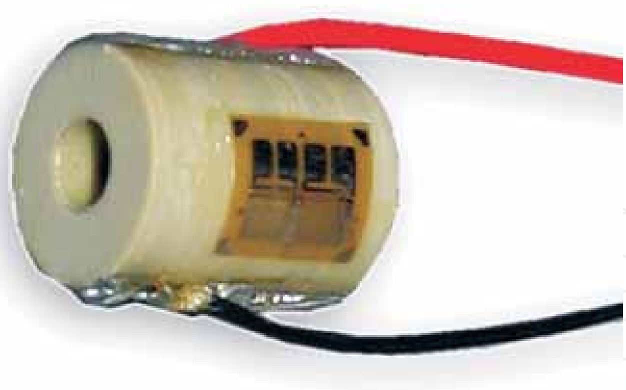


■ Figure 3.15: Pneumatic piezo valve (a) hardware view (b) CAD view

■ Figure 3.16: LSPA30uXS piezo motor (a) and MICRONORA golden micron award (b)



■ Figure 3.17: Piezo generator based on APA60SM, for converting mechanical shocks into electrical power generation (courtesy of LEGRAND)



■ Figure 3.18: Annular MLA stacks with a SG option

■ Figure 3.19: HPPA for the first European space Lidar, Aladin/Aeolus (courtesy of Galileo Avionica)

3.1.6 APPLICATIONS OPERATED UNDER DYNAMIC SENSING CONDITIONS

PIEZO GENERATORS & ENERGY HARVESTING

Piezo actuators can also be used as electric generators. When subjected to an external source of vibration or to a shock, a piezo actuator produces electrical energy.

Among different actuators, APA® are good candidates to perform such a function with reliability and efficiency because they are pre-stressed and because their shell contributes to a favourable dynamic stress distribution.
It has been demonstrated for example that a small APA® subjected to a shock produces enough energy to supply an RF emitter with enough power for a range of 10m (Figure 3.17).

CEDRAT TECHNOLOGIES can develop customised piezo generators using its range of standard piezo actuators. Examples of other piezo harvesting applications are given in:
http://www.cedrat-technologies.com/en/technologies/mechatronic-systems/energy-harvesting.html

3.2 ADDITIONAL TECHNOLOGICAL SOLUTIONS

This section presents technological solutions that can be proposed in addition to technological solutions introduced in 3.1 or to standard products described in chapters 4 to 7.

3.2.1 PIEZOELECTRIC CERAMIC STACKS

Multilayer Piezoelectric material (MLA) could be delivered in various shapes and dimensions (Figure 3.18). CEDRAT TECHNOLOGIES can help you finding the best MLA adapted to your needs. For example, annular MLA stacks can be delivered with a length up to 60 mm (external diameter 6 mm) and equipped with strain gauge sensor.

CEDRAT TECHNOLOGIES has also delivered some annular MLA stacks pre-stressed (preloaded) by an external elastic frame (Figure 3.19). This structure called Hollow Parallel Prestressed Actuator (HPPA) allows to increase the life time and reliability of the piezo rings under severe environment (high level of vibrations) and in dynamic applications. Several HPPA, including Flight Models, have been delivered for various space missions.

3.2.2 SUPER AMPLIFIED PIEZOELECTRIC ACTUATORS APA®

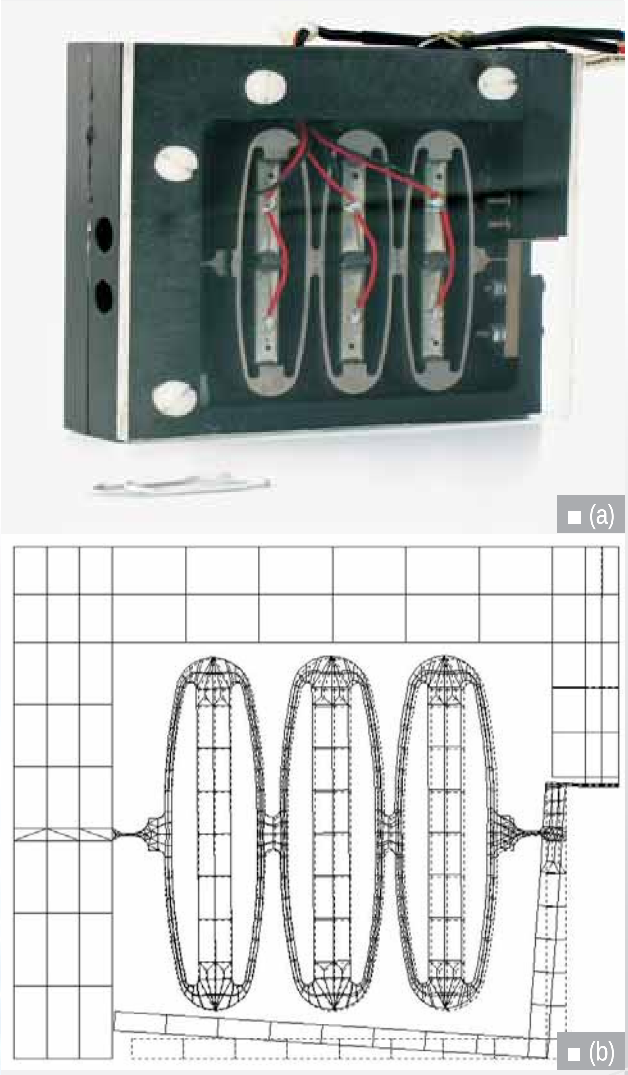
Since APA® are compact and centred, they can be stacked in series to get a larger stroke. This has been used in a mechanism for Magnetic Resonance Imaging (MRI) biomedical need for INSERM (French Institute for Medical Research). 3 APA200M-NMs are stacked to get more than 600µm. A second lever-arm increases the stroke up to 3mm at 150V (Figure 3.20.a), with a sub-micron resolution. The Figure 3.20.b allows a comparison between the ATILA FEM model and the measured deformation. The parts including the APA® have been made Non-Magnetic to fulfil MRI needs. Because of planar design, the APA® shells and the lever arm can be manufactured in a single piece to reduce mass and cost.

3.2.3 MECHANICALLY-DAMPED AMPLIFIED PIEZOELECTRIC ACTUATORS APA®

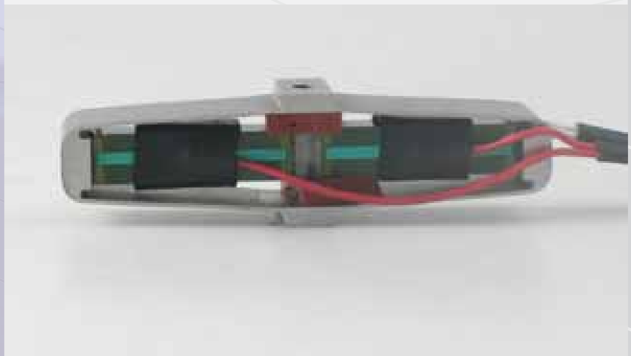
In some applications (operations under external vibrations, impulse response), it is interesting to use an actuator that displays a low mechanical Quality factor. A low Q factor reduces the amplification at resonance and the stress levels.

The large range of Amplified Piezoelectric Actuators APA® can be mechanically damped by adding some elastomer parts in the actuator (Figure 3.21). A Q factor below 5 is achievable.

Please contact CEDRAT TECHNOLOGIES to customise Mechanically Damped APA® (MD option) as a function of your environmental parameters (temperature, vibration level...).



■ **Figure 3.20: Super Amplified Piezoelectric Actuators** APA® producing 3 mm of stroke and having a resonance frequency of 100 Hz: (a) Actuator ; (b) corresponding FEM modelling



■ Figure 3.21: View of an APA400M-MD

■ Figure 3.22: View of a Voice Coil Actuator usable in Vacuum (3 mm of stroke)

■ Figure 3.23: MICA200 Moving Iron Controllable Actuator

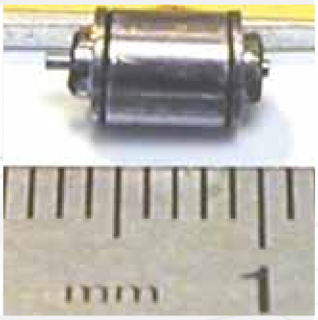
3.2.4 OTHER INNOVATIVE ACTUATORS

CEDRAT TECHNOLOGIES has also developed many different types of innovative actuators and associated electronics, which include:

- Piezo polymers (PVDF) Actuators
- Electro Active Elastomer Actuators
- Moving Coil Actuators (Figure 3.22)
- Magnetostrictive Actuators (Figure 3.24)
- Limited Angle Torque Actuators (Figure 3.26)
- Brushless DC Motors
- Magneto rheological fluid Actuators (Figure 3.27)
- ...

These actuators might be interesting alternative to standard piezo or magnetic actuators from CEDRAT TECHNOLOGIES to address the following applications such as active damping of vibration, shock absorbers, micro actuation, etc.
As a customer oriented company, CEDRAT TECHNOLOGIES can advise customers to perform trade-off analysis and comparison between piezo or magnetic solutions based on the customer specifications.

■ Figure 3.24: AMA Amplified Magnetostrictive Actuator



■ Figure 3.25: BLMM Bi-stable Linear Moving Magnet actuator

■ Figure 3.26: LAT Limited Angle Torque Actuator (Courtesy of ESA)

■ Figure 3.27: Magneto Rheological Fluid Actuator

3.3 DESIGN, MANUFACTURING & TESTING SOLUTIONS

This section presents services that can be proposed in assistance to the use or customisation of standard products described in chapters 4 to 8.

3.3.1 PIEZO AND MAGNETIC DEVICES

Piezo devices can be designed with numerical tools, what is currently done at CEDRAT TECHNOLOGIES:

- ATILA® Finite Element software is used to model the Actuator's behaviours including piezoelectric coupling, 3D structure, dynamic aspects and losses,
- Flux® software is used to design magnetic actuators, motors and sensors,
- SolidWorks® software is used to develop mechanisms using several Piezoelectric Actuators.

Some examples of applications of these CADs are given in the previous sections.

Specialised test equipments available at CEDRAT TECHNOLOGIES are also recommended to test active devices:

- HP Impedance analyser used for the measurement of admittance curve, resonance and equivalent circuits,
- Polytec interferometers and autocollimator used to measure the actuator's main displacement & speed as well as parasitic displacement with high precision (Figure 3.28.a),
- Climatic and Thermal Vacuum chambers allow the analysis of thermal behaviour and/or of the effects of primary or ultra vacuum (such as Paschen effect) (Figures 3.28.b, Figure 3.28.c).

Thanks to its facilities (Figures 3.28 a,b,c,d,e,f) CEDRAT TECHNOLOGIES can easily accommodate contracts from the development phase to full-scale production. We encourage facility tours.

3.3.2 PRODUCTION CAPABILITY

CEDRAT TECHNOLOGIES has a network of experienced sub-contractors in precision mechanics and electronics and performs the integration and measurement of all the mechatronic products. We can apply several quality standards (ECSS, MIL-STD, ANSI/IPC3).

CEDRAT TECHNOLOGIES routinely integrates batches up to

■ Figure 3.28a: View of CEDRAT TECHNOLOGIES labs, laser interferometer test bench

■ Figure 3.28b: View of CEDRAT TECHNOLOGIES labs, thermal Vacuum chamber

■ Figure 3.28c: View of CEDRAT TECHNOLOGIES labs, climatic test chamber

■ Figure 3.28d: View of CEDRAT TECHNOLOGIES labs, electronic integration

■ Figure 3.28e: View of CEDRAT TECHNOLOGIES labs, metrology

■ Figure 3.28f: View of CEDRAT TECHNOLOGIES labs, clean assembly hood

several hundreds of actuators or mechanisms (Figures 3.29a and 3.29b), using an adapted surface of 400m² and an ISO4 clean room.

3.3.3 ENGINEERING, R&D PROJECTS, TRAINING & TECHNICAL ASSISTANCE

Different kinds of technical assistance are provided by CEDRAT TECHNOLOGIES:

- Modeling, designing, prototyping or testing according to the customer's needs
- Industrial projects leading to a turn-key solution
- R&D collaborative Projects funded by the European Commission (FP7 projects) or other frameworks (Eureka, national projects)
- Manufacturing for the account of customers under QA (ECSS, MIL-STD, ANSI/IPC3)
- Technology transfers (Licensing)
- Training courses on Magnetic and Piezo Actuators or on more than 20 other mechatronic items.

As presented in the former chapters, CEDRAT TECHNOLOGIES' know-how, facilities and experience allows its team to efficiently develop new actuators, sensors, mechanisms or high level mechatronic system.

CEDRAT TECHNOLOGIES performs step-by-step developments in partnership with its customers. Expertise, optimisation, design, prototyping, testing, manufacturing, any of these phases can be addressed to help our customers reaching their demanding application targets.

Several new mechatronic technologies are being developed or are being improved: please do not hesitate to take a look at our web site for any updated information.

In terms of service through a project, CEDRAT TECHNOLOGIES can also adapt an existing product or technology to new environmental conditions: thermal range, resistance to particular vibration spectrum, lifetime... as found in aerospace, medical, oil industries ...

For more information about CEDRAT TECHNOLOGIES services, please visit:
http://www.cedrat-technologies.com/en/services.html

■ Figure 3.29a: Integration of a batch of piezoelectric mechanisms

■ Figure 3.29b: BRUCE electromagnetically controlled low shock locking device (courtesy CNES)

TRAINING

CEDRAT TECHNOLOGIES provides training courses dedicated to engineer and technician who wish to discover, improve or recover their knowledge in electrical engineering.

CEDRAT TECHNOLOGIES has a partnership with CETIM to promote mechatronic training courses.

More information are available in our dedicated training course catalogue that can be downloaded on our website:

www.cedrat-technologies.com/en/services/training.html

MODEL SERIES	UNITY	APA uXS - XXS
Note		
Blocking force	(N)	2 - 6
No-load stroke	(µm)	30-150
S.G. option		
N.M. option		
H.T. option		
T.C. option		
Mechanical Interface option		FI-H-SI
Electrical Interface option		Single Cu wire
Note		Smallest actuator

4. SELECTION GUIDE FOR PIEZO ACTUATORS

4.1 SELECTION GUIDE

4.1.1 INTRODUCTION

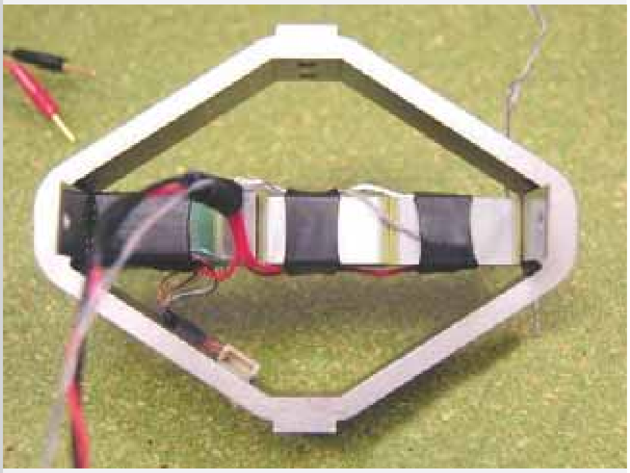
CEDRAT TECHNOLOGIES offers a wide range of standard Actuators: Conventional Multilayer Actuators (MLAs), Parallel Pre-Stressed Actuators (PPA) and Amplified piezoelectric actuators (APA®). Several options are available and most of the Actuator's functional properties, mechanical or electrical interfaces can be modified to meet the customer's needs. Please do not hesitate to contact CEDRAT TECHNOLOGIES for more information about an actuator's additional features.

APA XS	APA S	APA SM	APA M	APA MML	APA ML	APA L	APA XL
18	40 - 100	100 - 200	110-800	190-250	1400 - 1900	600 - 1300	700 - 1100
50-80	60 - 120	40 - 80	16 - 184	280-360	90 - 120	250 - 500	500 - 1000
* (except 50XS)	*	*	*	*	*	*	*
*	*		* (except 400M 900M)			*	
	*	*	*	*	*	*	*
	*			*			
FI - H - TH - SI	FI - H - TH - SI	FI - H - TH - SI	FI - H - TH - SI	FI - H - TH - SI	FI - H - SI	FI - H - TH - FF - SI	FI - H - TH - SI
Two wires AWG32	Two wires AWG30	Two wires AWG30	Two wires AWG30	Two wires AWG30	Two wires AWG26	Two wires AWG26	Two wires AWG26
		Stiff serie		Medium serie	Stiff serie		Larger actuator

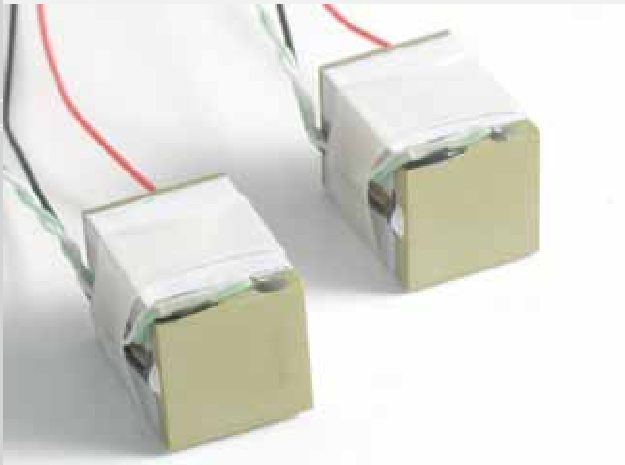
■ Table 4.1a: Selection guide of Amplified Piezoelectric Actuators

MODEL SERIES	UNITY	PPA M	PPA L	PPA XL
Note				
Blocking force	(N)	800	3500	7000
No-load stroke	(µm)	10 - 40	40 - 80	40 - 120
S.G. option		*	*	*
N.M. option		*		
H.T. option		*	*	*
T.C. option				
Mechanical Interface option		TH	TH	TH
Electrical Interface option		Two wires AWG30	Two wires AWG26	Two wires AWG26
Note				Larger actuator

■ Table 4.1b: Selection guide of Parallel Pre-stressed Actuators



■ Figure 4.1a: View of an APA® in free – free configuration: APA95ML-FF



■ Figure 4.1b: Thermocouple sensor on the piezo ceramic

4.1.2 OPTIONS

S.G. OPTION

The S.G. (Strain Gauges) option refers to a Piezo Actuator equipped with Strain Gauges. The Strain Gauges signal should be monitored with a SG75 electronic board to get a calibrated sensor for control purposes.

N.M. OPTION

With this option the actuator is made from non-magnetic (NM) material from non-magnetic material: it does not disturb the magnetic field and/or is thus completely insensitive to an external applied magnetic field. Some properties (e.g. thermo-mechanical behaviour, mass, width) may differ from the standard Actuator's features.

VAC (VACUUM) OPTION

The Vacuum (VAC) option refers to an actuator offering low outgassing in vacuum and the ability to bear Ultra High Vacuum environment.

H.T. OPTION

The High Temperature (HT) option refers to special piezo material and processes (bonding) that can be used to build High Temperature piezoelectric actuators.

T.C. OPTION

The Thermo-compensated (TC) option is a special construction which allows the improvement of the behaviour within a wide temperature range, especially at the liquid nitrogen temperature (77° K).

note: N.M. and T.C. options are not compatible.

C.R.F.P. OPTION (PRELIMINARY)

The CRFP option relates to the use of a Carbon Fiber Reinforced Polymer (CRFP) composite for making the APA® shell instead of metal. This change leads to several advantages: Significant mass reduction, higher bandwidth, lower Q-factor, much lower thermal expansion. This option results of a collaboration with ONERA considering helicopter flap applications.

M.D. OPTION (PRELIMINARY)

The Mechanical Damping (MD) option consists in added elastomeric parts inside the APA®. This option provides damping and lowers the Q-factor at resonance (see 3.2.3). This also reduces overshot in on-off applications and improves resistance to external vibration. This option results of R&T works for CNES.

S.V. OPTION

In some cases, the change of mechanical interfaces or the piezo components on the shell materials leads to a modification of the functional properties. In that case, the Specific Version of an existing standard actuator is called the S.V. option. For any question regarding mechanical integration, please contact CEDRAT TECHNOLOGIES.

THERMOCOUPLE OPTION

For certain dynamic application, it may be necessary to follow up the self heating of the piezo ceramic in order to avoid overheating and damages.
For such application case, we developed a dedicated option where we bond a thermocouple sensor on the piezo ceramic (Figure 4.1b) in order to monitor its inner temperature.
The thermocouple sensor can be either type K (most popular) or type T (for non magnetic requirement).

4.1.3 MECHANICAL INTERFACE OPTIONS

F.I. OPTION

The Amplified piezoelectric actuator has two identical flat interfaces that can be bonded.

H. OPTION

The Amplified piezoelectric actuator has two identical mechanical interfaces: a flat interface with a non threaded hole.

T.H. OPTION

The Amplified piezoelectric actuator has two identical mechanical interfaces: a flat interface with a centered threaded hole.

F.F. OPTION

The "free-free" interface means that the actuator is held in a way that enables symmetric movements (Figure 4.1). The free-free configuration gives a noticeably higher bandwidth, but only one half of the stroke. However, the piezo stacks can be subjected to higher transverse forces in this case. Please contact CEDRAT TECHNOLOGIES to discuss your application.

GUIDING OPTION

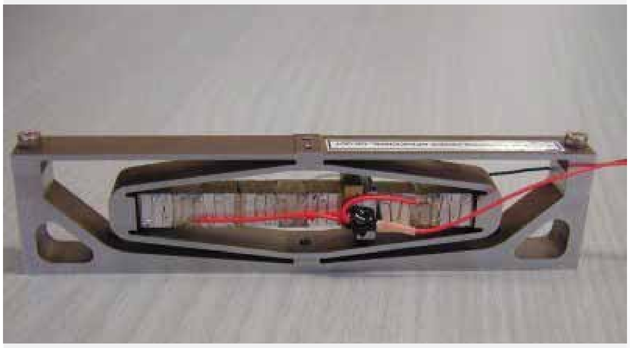
To obtain a better dynamic movement, it is possible to add a flexible guiding to the actuator's shell. This can be added at the application integration level or designed monolithically with the shell (Figure 4.2). Please contact CEDRAT TECHNOLOGIES to discuss your application.

TW TWIN OPTION

The twin option consists in two Actuator monolithically staked in serie for some redundancies (Figure 4.3). Please contact CEDRAT TECHNOLOGIES to discuss your application.

S.I. OPTION

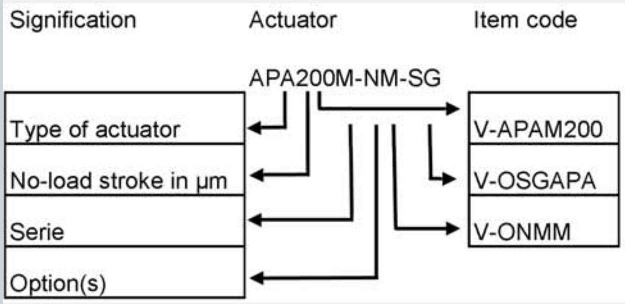
In order to make the mechanical integration of its actuators easier as OEM products, CEDRAT TECHNOLOGIES can design and machine a Specific Interface on top of its actuators to meet the customer's needs. For any question regarding mechanical integration, please contact CEDRAT TECHNOLOGIES.



■ Figure 4.2a : Single blade guided Amplified Piezoelectric Actuator APA®

■ Figure 4.2b : Double blades guided Amplified Piezoelectric Actuator APA®

■ Figure 4.3 : Twin Amplified Piezoelectric Actuator APA®



■ Table 4.2: Signification of items code

To offer you the “state of the art” of Piezo Actuators, some new Actuators are given with “preliminary data”, which means that the Actuator has been designed but has not been tested as much as requested by CEDRAT TECHNOLOGIES quality standards at the time the catalogue is printed.

4.1.4 ADDITIONAL DATA

Some of these Actuators are space-qualified: this means that the Actuator underwent several tests providing a large heritage:

- Random vibration & shocks,
- Thermal vacuum,
- Radiations,
- AC&DC life-time test.

Please contact CEDRAT TECHNOLOGIES for more information about an actuator’s additional features.

4.1.5 CODE DESCRIPTION

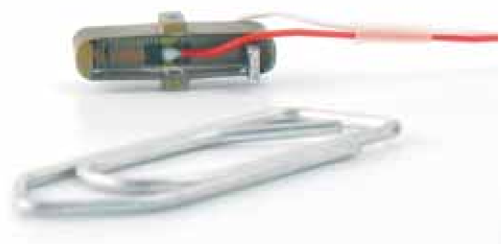
Items are referenced thanks to the item code mentioned on the characteristics table (Table 4.2). Codes for optional item have to be added.
Please do not hesitate to take a look at our web site, where you can download:

- The technical data sheet,
- The mechanical interface drawing,
- The 3D edrawings file.

4.2 AMPLIFIED PIEZOELECTRIC ACTUATORS APA® uXS & XXS SERIES

Some applications of APA® uXS and XXS are:

- Earing implants
- Actuation in Micro Aerial Vehicle
- Energy harvester for pacemaker
- Micro electro optical systems
- Piezo motors LSPA30uXS and RSPA30uXS



■ Figure 4.4: View of the APA150XXS actuator

REFERENCES	UNIT	APA30uXS	APA150XXS
Item Code		V-APAXS30	V-APAXXS150
Notes		-	-
Displacement	(µm)	42,0	122,0
Blocked force	(N)	3,3	0,5
Stiffness	(N/µm)	0,08	0,004
Resonance frequency (free-free)	(Hz)	24500	2441
Response time (free-free)	(ms)	0,02	0,20
Resonance frequency (blocked-free)	(Hz)	4770	456
Response time (blocked-free)	(ms)	0,10	1,10
Force limit (0-pk)	(N)	1,65	0,13
Max. displacement at resonance (pk-pk)	(µm)	38	55
Voltage range	(V)	-20 ... 150	-20 ... 150
Capacitance	(µF)	0,05	0,15
Resolution	(nm)	0,42	1,22
Thermo-mechanical behaviour	(µm/°K)	0,39	1,40
Height H (in actuation direction)	(mm)	3,9	4,5
Length	(mm)	8,6	13,1
Width (incl. edges, wires)	(mm)	5,0	9,0
Mass	(g)	0,15	1,3
Standard mechanical interface		2 flat surfaces 1*2.5 mm² with a Ø 0.8 mm hole	2 flat surfaces 1.5*3 mm² with a Ø 0.8 mm hole
Standard electrical interface		2 single Cu wires 80 mm long with Ø 1 banana plug	2 PFTE insulated AWG32 wires 80 mm long with Ø 1 banana plug

■ Table 4.3: Characteristics of the APA® uXS & XXS Actuators (see chapter 10 - Applications note)

Available option(s) + performances:
VAC, NM (except APA150XXS)
Available interface option(s):
FI, SI, H

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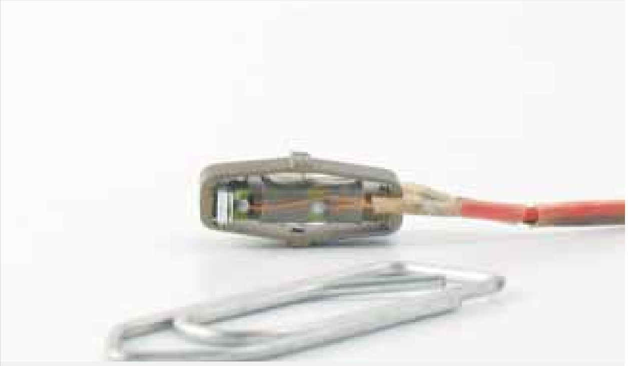
4.3 AMPLIFIED PIEZOELECTRIC ACTUATORS APA® XS SERIES



■ Figure 4.5: View of the APA35XS actuator

Some applications with APA® XS are:

- micro optical mechanisms such embedded XY pixel shift scanners for IR cameras, cryogenic stages for telescopes
- Micro controllable dynamic valves
- Space qualified micro tip tilts
- Miniature brakes

REFERENCES	UNIT	APA35XS	APA50XS
Item Code		V-APAXS35	V-APAXS50
Notes		-	-
Displacement	(µm)	55,0	78,0
Blocked force	(N)	27,0	18,0
Stiffness	(N/µm)	0,49	0,23
Resonance frequency (free-free)	(Hz)	18600	11420
Response time (free-free)	(ms)	0,03	0,04
Resonance frequency (blocked-free)	(Hz)	3883	2700
Response time (blocked-free)	(ms)	0,13	0,19
Force limit (0-pk)	(N)	13,50	4,50
Max. displacement at resonance (pk-pk)	(µm)	50	35
Voltage range	(V)	-20...150	-20...150
Capacitance	(µF)	0,25	0,25
Resolution	(nm)	0,55	0,78
Thermo-mechanical behaviour	(µm/°K)	0,67	0,91
Height H (in actuation direction)	(mm)	5,5	4,7
Length	(mm)	13,3	12,8
Width (incl. edges, wires)	(mm)	9,0	9,0
Mass	(g)	2,0	2,0
Standard mechanical interface [TH]		2 flat surfaces 1.25*5 mm^2 with M1 threaded hole	2 flat surfaces 1.5*5 mm^2 with M1 threaded hole
Standard electrical interface		2 PTFE insulated AWG32 wires 80 mm long with Ø 1 banana plug	2 PFTE insulated AWG32 wires 80 mm long with Ø 1 banana plug

■ Table 4.4: Characteristics of the APA® XS Actuators

Available option(s) + performances:

SG (except 50XS), NM, VAC

Available interface option(s):

FI, H, TH, SI

4.4 AMPLIFIED PIEZOELECTRIC ACTUATORS APA® S SERIES

Some applications with APA® S are:

- Shaking powder for X-ray diffraction
- Optical stabilization for embedded cameras
- Space qualified optical stages
- Nano-indentation

■ Figure 4.6: View of the APA60S actuator

REFERENCES	UNIT	APA60S	APA120S
Item Code		V-APAS60	V-APAS120
Notes		-	-
Displacement	(µm)	74	132
Blocked force	(N)	66	29,0
Stiffness	(N/µm)	0,90	0,22
Resonance frequency (free-free)	(Hz)	9744	6681
Response time (free-free)	(ms)	0,05	0,07
Resonance frequency (blocked-free)	(Hz)	2079	1098
Response time (blocked-free)	(ms)	0,24	0,46
Force limit (0-pk)	(N)	33	7,25
Max. displacement at resonance (pk-pk)	(µm)	66	59
Voltage range	(V)	-20 ... 150	-20 ... 150
Capacitance	(µF)	1,55	1,55
Resolution	(nm)	0,7	1,3
Thermo-mechanical behaviour	(µm/°K)	0,97	1,60
Height H (in actuation direction)	(mm)	15,0	13,0
Length	(mm)	29,2	28,7
Width (incl. edges, wires)	(mm)	9,0	9,0
Mass	(g)	8,5	7,2
Standard mechanical interface [TH]		2 flat surfaces 2.5*5 mm² with M2 threaded hole	2 flat surfaces 2.5*5 mm² with M2 threaded hole
Standard electrical interface		2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug

■ Table 4.5: Characteristics of the APA® S Actuators

Available option(s) + performances:
SG, NM, VAC, HT, TC
Available interface option(s):
FI, H, TH, SI

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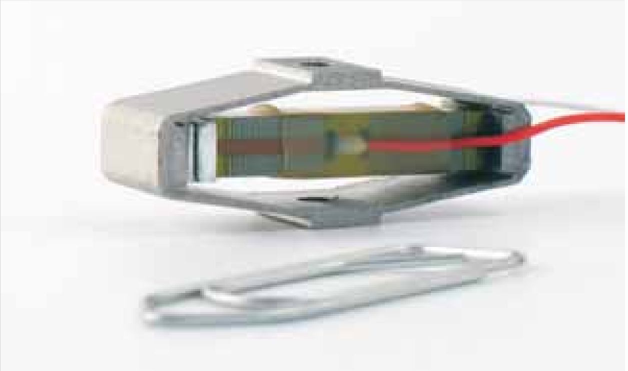
4.5 AMPLIFIED PIEZOELECTRIC ACTUATORS APA® SM SERIES



■ Figure 4.7: View of the APA60SM actuator

Some applications with APA® SM are:

- Shock energy harvester in wireless switches
- Material Stress cycling
- Injectors

REFERENCES	UNIT	APA40SM	APA60SM
Item Code		V-APASM40	V-APASM60
Notes		-	-
Displacement	(µm)	52	72
Blocked force	(N)	194	105
Stiffness	(N/µm)	3,73	1,45
Resonance frequency (free-free)	(Hz)	16000	9252
Response time (free-free)	(ms)	0,03	0,05
Resonance frequency (blocked-free)	(Hz)	4100	2802
Response time (blocked-free)	(ms)	0,12	0,18
Force limit (0-pk)	(N)	97	53
Max. displacement at resonance (pk-pk)	(µm)	47	65
Voltage range	(V)	-20 ... 150	-20 ... 150
Capacitance	(µF)	1,55	1,55
Resolution	(nm)	0,5	0,7
Thermo-mechanical behaviour	(µm/°K)	0,73	0,93
Height H (in actuation direction)	(mm)	15,0	13,0
Length	(mm)	27,2	26,9
Width (incl. edges, wires)	(mm)	11,5	11,5
Mass	(g)	11,0	10,0
Standard mechanical interface [TH]		2 flat surfaces 5*10 mm² with M2.5 threaded hole	2 flat surfaces 5*10 mm² with M2.5 threaded hole
Standard electrical interface		2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug

■ Table 4.6: Characteristics of the APA® SM Actuators

Available option(s) + performances:

SG, VAC, HT

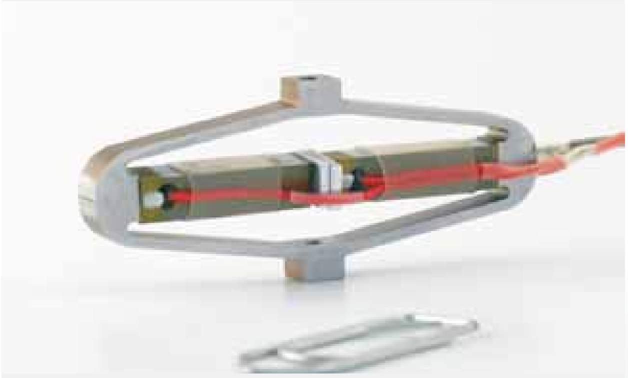
Available interface option(s):

FI, H, TH, SI

4.6 AMPLIFIED PIEZOELECTRIC ACTUATORS APA® M SERIES

Some applications with APA® M are:

- Fast X-Ray vacuum compatible shutters
- Dynamic valves
- Laser cavity tuning
- Miniature Active flaps for aero vehicles



■ Figure 4.8: View of the APA150M actuator

REFERENCES	UNIT	APA100M	APA150M	APA200M
Item Code		V-APAM100	V-APAM150	V-APAM200
Notes		-	-	-
Displacement	(µm)	110	180	230
Blocked force	(N)	184	88	73
Stiffness	(N/µm)	1,7	0,49	0,32
Resonance frequency (free-free)	(Hz)	7600	4563	4600
Response time (free-free)	(ms)	0,07	0,11	0,11
Resonance frequency (blocked-free)	(Hz)	1900	1103	900
Response time (blocked-free)	(ms)	0,26	0,45	0,56
Force limit (0-pk)	(N)	92	44	27
Max. displacement at resonance (pk-pk)	(µm)	99	162	155
Voltage range	(V)	-20 ... 150	-20 ... 150	-20 ... 150
Capacitance	(µF)	3,2	3,2	3,2
Resolution	(nm)	1,1	1,8	2,3
Thermo-mechanical behaviour	(µm/°K)	1,47	2,22	2,72
Height H (in actuation direction)	(mm)	25,0	22,0	17,0
Length	(mm)	55,1	55,1	55,0
Width (incl. edges, wires)	(mm)	9,0	9,0	9,0
Mass	(g)	19,5	17,4	15,7
Standard mechanical interface [TH]		2 flat surfaces 5*5 mm² with M2.5 threaded hole	2 flat surfaces 5*5 mm² with M2.5 threaded hole	2 flat surfaces 5*5 mm² with M2.5 threaded hole
Standard electrical interface		2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug

■ Table 4.7: Characteristics of the APA® M Actuators

Available option(s) + performances:
SG, NM, VAC, HT, MD
Available interface option(s):
FI, H, TH, FF, SI

The technical information on this leaflet is not contractual and can be changed without prior notice.

■ Figure 4.9: View of the APA400M actuator

4.7 SUPER AMPLIFIED PIEZOELECTRIC ACTUATORS APA® M SERIES

Some applications with super amplified APA® M are:

- Clamping in wire feeding system
- Inverted microscope positionner
- Haptic technology feedback for display panels
- Energy harvesters

REFERENCES	UNIT	APA400M	APA900M
Item Code		V-APAM400	V-APAM900
Notes		-	Use limited to static operation
Displacement	(µm)	465	710
Blocked force	(N)	26	5
Stiffness	(N/µm)	0,06	0,01
Resonance frequency (free-free)	(Hz)	1824	865
Response time (free-free)	(ms)	0,27	0,58
Resonance frequency (blocked-free)	(Hz)	373	156
Response time (blocked-free)	(ms)	1,34	3,21
Force limit (0-pk)	(N)	6,50	0,25
Max. displacement at resonance (pk-pk)	(µm)	209	64
Voltage range	(V)	-20...150	-20...150
Capacitance	(µF)	3,15	3,15
Resolution	(nm)	4,7	7,1
Thermo-mechanical behaviour	(µm/°K)	5,29	7,98
Height H (in actuation direction)	(mm)	13,0	10,0
Length	(mm)	48,4	49,0
Width (incl. edges, wires)	(mm)	11,5	11,5
Mass	(g)	19,0	18,0
Standard mechanical interface [TH]		2 flat surfaces 5*10 mm² with M2.5 threaded hole	2 flat surfaces 5*10 mm² with M2.5 threaded hole
Standard electrical interface		2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug

■ Table 4.8: Characteristics of the Super APA® M Actuators

Available option(s) + performances:
SG, VAC, MD
Available interface option(s):
FI, H, TH, FF, SI

The technical information on this leaflet is not contractual and can be changed without prior notice.

4.8 AMPLIFIED PIEZOELECTRIC ACTUATORS APA® MML SERIES

Some applications with APA® MML are:

- active stabilisation of a watt balance
- High frequency shakers
- Elasto IRM
- Long range cavity modulation in interferometers

Figure 4.10: View of the APA400MML actuator

REFERENCES	UNIT	APA100MML	APA400MML	APA600MML
Item Code		V-APAMML100	V-APAMML400	V-APAMML600
Notes		-	-	-
Displacement	(µm)	100	344	706
Blocked force	(N)	855	189	44
Stiffness	(N/µm)	8,6	0,5	0,1
Resonance frequency (free-free)	(Hz)	5800	2738	1482
Response time (free-free)	(ms)	0,09	0,18	0,34
Resonance frequency (blocked-free)	(Hz)	1730	634	254
Response time (blocked-free)	(ms)	0,29	0,79	1,97
Force limit (0-pk)	(N)	428	95	11
Max. displacement at resonance (pk-pk)	(µm)	90	310	318
Voltage range	(V)	-20... 150	-20...150	-20...150
Capacitance	(µF)	10,0	10,0	10,0
Resolution	(nm)	1,0	3,4	7,1
Thermo-mechanical behaviour	(µm/°K)	1,51	3,38	6,70
Height H (in actuation direction)	(mm)	58,0	20,0	17,0
Length	(mm)	78,0	78,0	78,0
Width (incl. edges, wires)	(mm)	11,5	11,5	11,5
Mass	(g)	50,0	47,5	47,5
Standard mechanical interface [H]		2 flat surfaces 6*10 mm² with M3 threaded hole	2 flat surfaces 6*10 mm² with M3 threaded hole	2 flat surfaces 6*10 mm² with M3 threaded hole
Standard electrical interface		2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug

Table 4.9: Characteristics of the APA® MML Actuators

Available option(s) + performances:

SG, VAC, HT

Available interface option(s):

FI, H, TH, FF, SI

4.9 AMPLIFIED PIEZOELECTRIC ACTUATORS APA® ML SERIES

■ Figure 4.11: View of the APA120ML actuator

Some applications with APA® ML are:

- Active control of vibration on medical robots
- High frequency shakers
- Fretting fatigue testing
- Hammers
- Space qualified positionner

REFERENCES	UNIT	APA95ML	APA120ML
Item Code		V-APAML95	V-APAML120
Notes		-	-
Displacement	(µm)	94	130
Blocked force	(N)	1900	1400
Stiffness	(N/µm)	20,2	10,8
Resonance frequency (free-free)	(Hz)	7000	6450
Response time (free-free)	(ms)	0,07	0,08
Resonance frequency (blocked-free)	(Hz)	2000	1750
Response time (blocked-free)	(ms)	0,25	0,29
Force limit (0-pk)	(N)	950	700
Max. displacement at resonance (pk-pk)	(µm)	85	117
Voltage range	(V)	-20 ... 150	-20 ... 150
Capacitance	(µF)	20,0	20,0
Resolution	(nm)	0,9	1,3
Thermo-mechanical behaviour	(µm/°K)	1,48	1,66
Height H (in actuation direction)	(mm)	60,0	45,0
Length	(mm)	80,1	78,9
Width (incl. edges, wires)	(mm)	22,5	22,5
Mass	(g)	164,0	160,0
Standard mechanical interface [H]		2 flat surfaces 9*20 mm² with 2 Ø 3.2 mm holes, centred at 5 mm from the side	2 flat surfaces 9*20 mm² with 2 Ø 3.2 mm holes, centred at 5 mm from the side
Standard electrical interface		2 PTFE insulated AWG26 wires 300 mm long with Ø 1 banana plug	2 PTFE insulated AWG26 wires 300 mm long with Ø 1 banana plug

■ Table 4.10: Characteristics of the APA® ML Actuators

Available option(s) + performances:

SG, VAC, HT

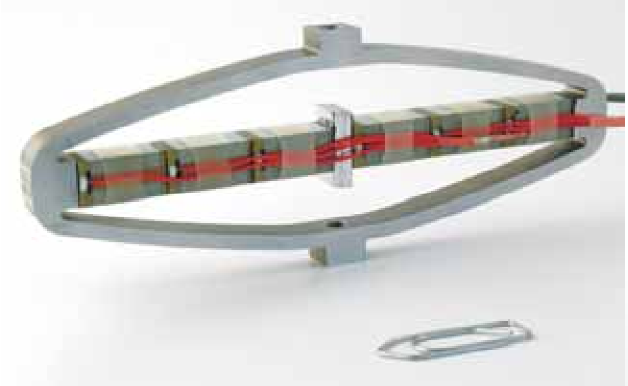
Available interface option(s):

FI, H, TH, FF, SI

4.10 AMPLIFIED PIEZOELECTRIC ACTUATORS APA® L SERIES

Some applications with APA® L are:

- Helicopter flaps
- High frequency shakers
- Material stress cycling
- Mirror positioning in telescopes & instruments



■ Figure 4.12: View of the APA500L actuator

REFERENCES	UNIT	APA230L	APA500L	APA1000L
Item Code		V-APAL230	V-APAL500	V-APAL1000
Notes		-	-	-
Displacement	(µm)	236	500	912
Blocked force	(N)	1350	570	280
Stiffness	(N/µm)	5,7	1,1	0,3
Resonance frequency (free-free)	(Hz)	3000	1900	1302
Response time (free-free)	(ms)	0,17	0,26	0,38
Resonance frequency (blocked-free)	(Hz)	850	460	254
Response time (blocked-free)	(ms)	0,59	1,09	1,97
Force limit (0-pk)	(N)	675	285	70
Max. displacement at resonance (pk-pk)	(µm)	212	450	410
Voltage range	(V)	-20 ... 150	-20 ... 150	-20 ... 150
Capacitance	(µF)	40,0	40,0	40,0
Resolution	(nm)	2,4	5,0	9,1
Thermo-mechanical behaviour	(µm/°K)	3,5	6,1	10,5
Height H (in actuation direction)	(mm)	85,0	55,0	35,0
Length	(mm)	145,3	145,0	145,0
Width (incl. edges, wires)	(mm)	16,0	16,0	16,0
Mass	(g)	275,0	200,0	190,0
Standard mechanical interface [TH]		2 flat surfaces 10*10 mm² with M5 threaded hole	2 flat surfaces 10*10 mm² with M5 threaded hole	2 flat surfaces 10*10 mm² with M5 threaded hole
Standard electrical interface		2 PTFE insulated AWG26 wires 300 mm long with Ø 1 banana plug	2 PTFE insulated AWG26 wires 300 mm long with Ø 1 banana plug	2 PTFE insulated AWG26 wires 300 mm long with Ø 1 banana plug

■ Table 4.11: Characteristics of the APA® L Actuators

Available option(s) + performances:
SG, VAC, HT, NM, CRFP, MD
Available interface option(s):
FI, H, TH, FF, SI

The technical information on this leaflet is not contractual and can be changed without prior notice.

■ Figure 4.13: View of the APA1000XL actuator

4.11 AMPLIFIED PIEZOELECTRIC ACTUATORS APA® XL SERIES

Some applications with APA® XL are:

- High frequency shakers
- Fretting Fatigue testing
- Helicopter flaps
- Positioning of heavy loads
- Force Testing

REFERENCES	UNIT	APA500XL	APA1000XL
Item Code		V-APAXL500	V-APAXL1000
Notes		-	-
Displacement	(µm)	600	1050
Blocked force	(N)	1100	745
Stiffness	(N/µm)	1,83	0,71
Resonance frequency (free-free)	(Hz)	1470	980
Response time (free-free)	(ms)	0,34	0,51
Resonance frequency (blocked-free)	(Hz)	345	210
Response time (blocked-free)	(ms)	1,45	2,38
Force limit (0-pk)	(N)	633	428
Max. displacement at resonance (pk-pk)	(µm)	540	945
Voltage range	(V)	-20 ... 150	-20 ... 150
Capacitance	(µF)	110,00	110,00
Resolution	(nm)	6,0	10,5
Thermo-mechanical behaviour	(µm/°K)	7,49	12,23
Height H (in actuation direction)	(mm)	82,0	57,0
Length	(mm)	214,3	214,3
Width (incl. edges, wires)	(mm)	24,5	24,5
Mass	(g)	650,0	600,0
Standard mechanical interface [TH]		2 flat surfaces 15*15 mm² with M5 threaded hole	2 flat surfaces 15*15 mm² with M5 threaded hole
Standard electrical interface		2 PTFE insulated AWG26 wires 300 mm long with Ø 1 banana plug	2 PTFE insulated AWG26 wires 300 mm long with Ø 1 banana plug

■ Table 4.12: Characteristics of the APA® XL Actuators.

Available option(s) + performances:

SG, VAC, MD

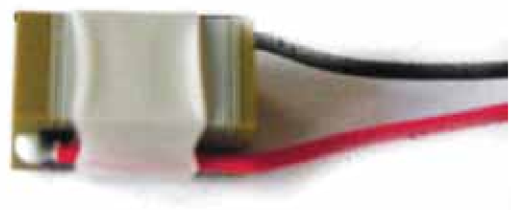
Available interface option(s):

FI, H, TH, FF, SI

The technical information on this leaflet is not contractual and can be changed without prior notice.

4.12 MULTILAYER ACTUATORS MLA SERIES

The Multi Layer Actuators (MLA) are non pre-stressed low voltage piezo ceramics. As a consequence, they are not suited to high level dynamic operations.
Strain Gauges (SG) can be added on MLA upon request.
Wired connections are secured through a tube shrink.
MLA can be driven by CEDRAT TECHNOLOGIES linear amplifiers.
Expertise of CEDRAT TECHNOLOGIES on MLA results from several space evaluation programs performed for CNES and ESA on different types of MLA.



■ Figure 4.14: View of the MLA 5*5*10 actuator

REFERENCES	UNIT	MLA_2*5*10	MLA_5*5*10	MLA_5*5*20	MLA_10*10*20
Item Code		V-MLA2510	V-MLA5510	V-MLA5520	V-MLA101020
Notes		-	-	-	-
Displacement	(µm)	10,0	10,0	20,0	20,0
Blocked force	(N)	240,0	1000,0	1000,0	4000,0
Stiffness	(N/µm)	24,0	100,0	50,0	200,0
Resonance frequency (free-free)	(Hz)	130000	130000	60000	60000
Response time (free-free)	(ms)	0,004	0,004	0,008	0,008
Voltage range	(V)	-20 ...150	-20 ...150	-20 ...150	-20 ...150
Capacitance	(µF)	0,22	0,55	1,20	4,40
Resolution	(nm)	0,10	0,10	0,20	0,20
Thermo-mechanical behaviour	(µm/°K)	-0,01	-0,01	-0,01	-0,01
Height H (in actuation direction)	(mm)	10,0	10,0	20,0	20,0
Length	(mm)	2,0	5,0	5,0	10,0
Width (incl. wires)	(mm)	9,0	9,0	9,0	16,0
Mass	(g)	0,8	1,9	3,8	15,0
Mechanical interface		2 flat surfaces 2*5 mm²	2 flat surfaces 5*5 mm²	2 flat surfaces 5*5 mm²	2 flat surfaces 10*10 mm²
Standard electrical interface		2 PTFE insulated AWG32 wires 80 mm long	2 PTFE insulated AWG30 wires 80 mm long	2 PTFE insulated AWG30 wires 80 mm long	2 PTFE insulated AWG30 wires 80 mm long

■ Table 4.13: Characteristics of the MLAs

Available option(s) + performances:
SG, VAC

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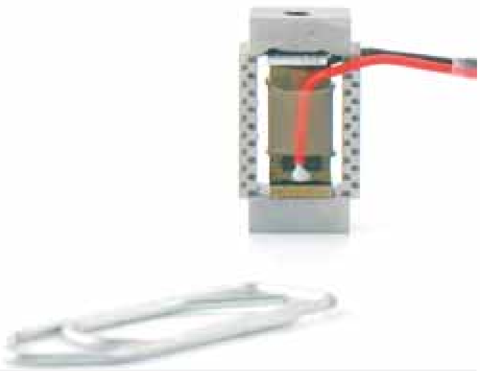


■ Figure 4.15: View of the PPA10M actuator

4.13 PARALLEL PRE-STRESSED ACTUATORS PPA M SERIES

Some applications with PPAM are:

- Vibration assistance to glass cutting
- Ultrasonic injector for plane engines
- Needle vibrator in a space Atomic Force Microscope
- Active deformation of mirror in telescopes
- Ultrasonic injection

REFERENCES	UNIT	PPA10M	PPA20M	PPA40M
Item Code		V-PPAM10	V-PPAM20	V-PPAM40
Notes		-	-	-
Displacement	(µm)	9	20	36
Blocked force	(N)	800	800	800
Stiffness	(N/µm)	90	40	22
Resonance frequency (free-free)	(Hz)	60800	38500	23400
Response time (free-free)	(ms)	0,01	0,01	0,02
Resonance frequency (blocked-free)	(Hz)	30400	19250	11700
Response time (blocked-free)	(ms)	0,02	0,03	0,04
Force limit (0-pk)	(N)	400	400	400
Max. displacement at resonance (pk-pk)	(µm)	8	18	33
Voltage range	(V)	-20 ... 150	-20 ... 150	-20 ... 150
Capacitance	(µF)	0,7	1,4	2,7
Resolution	(nm)	0,1	0,2	0,4
Thermo-mechanical behaviour	(µm/°K)	0,07	0,06	0,04
Height (in actuation direction)	(mm)	18,0	28,0	48,0
Base depth	(mm)	10,0	10,0	10,0
Base width (incl. wedge & wires)	(mm)	9,0	9,0	9,0
Mass	(g)	6,0	12,0	25,0
Standard mechanical interface - Top		1 centered M2.5 threaded hole 2.5 mm deep	1 centered M2.5 threaded hole 2.5 mm deep	1 centered M2.5 threaded hole 2.5 mm deep
Standard mechanical interface - Base		1 centered M2.5 threaded hole 2.5 mm deep	1 centered M2.5 threaded hole 2.5 mm deep	1 centered M2.5 threaded hole 2.5 mm deep
Standard electrical interface		2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 100 mm long with Ø 1 banana plug

■ Table 4.14: Characteristics of the PPA M Actuators

Available option(s) + performances:

SG, NM, VAC, HT

Available interface option(s):

TH, SI

4.14 PARALLEL PRE-STRESSED ACTUATORS PPA L SERIES

Some applications with PPAL are:

- Active control of vibration in a turning lathe
- Oval piston machining
- Heavy load positioning

■ Figure 4.16: View of the PPA80L actuator

REFERENCES	UNIT	PPA40L	PPA60L	PPA80L
Item Code		V-PPAL40	V-PPAL60	V-PPAL80
Notes		-	-	-
Displacement	(µm)	45	70	94
Blocked force	(N)	3500	3500	3500
Stiffness	(N/µm)	77,6	49,8	37,2
Resonance frequency (free-free)	(Hz)	14300	10900	8840
Response time (free-free)	(ms)	0,03	0,05	0,06
Resonance frequency (blocked-free)	(Hz)	7150	5450	4420
Response time (blocked-free)	(ms)	0,07	0,09	0,11
Force limit (0-pk)	(N)	1200	1200	1200
Max. displacement at resonance (pk-pk)	(µm)	28	43	58
Voltage range	(V)	-20 ... 150	-20 ... 150	-20 ... 150
Capacitance	(µF)	13,3	20,0	26,6
Resolution	(nm)	0,5	0,7	0,9
Thermo-mechanical behaviour	(µm/°K)	0,13	0,11	0,09
Height (in actuation direction)	(mm)	57,0	77,0	97,0
Base length	(mm)	23,5	23,5	23,5
Base width	(mm)	18,0	18,0	18,0
Mass	(g)	92,0	117,0	142,0
Standard mechanical interface - Top		1 centered M3 threaded hole 5 mm deep & 4 M2.5 threaded holes on Ø 15 mm 4 mm deep	1 centered M3 threaded hole 5 mm deep & 4 M2.5 threaded holes on Ø 15 mm 4 mm deep	1 centered M3 threaded hole 5 mm deep & 4 M2.5 threaded holes on Ø 15 mm 4 mm deep
Standard mechanical interface - Base		1 centered M3 threaded hole 5 mm deep & 4 M2.5 threaded holes on Ø 15 mm 4 mm deep	1 centered M3 threaded hole 5 mm deep & 4 M2.5 threaded holes on Ø 15 mm 4 mm deep	1 centered M3 threaded hole 5 mm deep & 4 M2.5 threaded holes on Ø 15 mm 4 mm deep
Standard electrical interface		2 PTFE insulated AWG26 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG26 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG26 wires 100 mm long with Ø 1 banana plug

■ Table 4.15: Characteristics of the PPA L Actuators

Available option(s) + performances:

SG, VAC, HT

Available interface option(s):

TH, SI

The technical information on this leaflet is not contractual and can be changed without prior notice.

4.15 PARALLEL PRE-STRESSED ACTUATORS PPA XL SERIES

■ Figure 4.17 : View of the PPA80XL Actuator

Some applications with PPAXL are:

- Stabilisation of heavy loads in precision machine tool
- Fretting Fatigue testing
- High Frequency Shakers

REFERENCES	UNIT	PPA40XL	PPA80XL	PPA120XL
Item Code		V-PPAXL40	V-PPAXL80	V-PPAXL120
Notes		-	-	-
Displacement	(µm)	44	91	128
Blocked force	(N)	7000	7000	7000
Stiffness	(N/µm)	159,5	77,3	54,7
Resonance frequency (free-free)	(Hz)	13600	8500	6180
Response time (free-free)	(ms)	0,04	0,06	0,08
Resonance frequency (blocked-free)	(Hz)	6800	4250	3090
Response time (blocked-free)	(ms)	0,07	0,12	0,16
Force limit (0-pk)	(N)	2400	2400	2400
Max. displacement at resonance (pk-pk)	(µm)	27	56	79
Voltage range	(V)	-20 ... 150	-20 ... 150	-20 ... 150
Capacitance	(µF)	24,0	48,0	72,0
Resolution	(nm)	0,4	0,9	1,3
Thermo-mechanical behaviour	(µm/°K)	0,16	0,12	0,08
Height (in actuation direction)	(mm)	60,0	100,0	140,0
Base length	(mm)	30,0	30,0	30,0
Base width	(mm)	30,0	30,0	30,0
Mass	(g)	254,0	319,0	384,0
Standard mechanical interface - Top		1 centered M5 threaded hole 6 mm deep & 4 M3 threaded holes on Ø 20 mm 6 mm deep	1 centered M5 threaded hole 6 mm deep & 4 M3 threaded holes on Ø 20 mm 6 mm deep	1 centered M5 threaded hole 6 mm deep & 4 M3 threaded holes on Ø 20 mm 6 mm deep
Standard mechanical interface - Base		1 centered M5 threaded hole 6 mm deep & 4 M3 threaded holes on Ø 20 mm 6 mm deep	1 centered M5 threaded hole 6 mm deep & 4 M3 threaded holes on Ø 20 mm 6 mm deep	1 centered M5 threaded hole 6 mm deep & 4 M3 threaded holes on Ø 20 mm 6 mm deep
Standard electrical interface		2 PTFE insulated AWG26 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG26 wires 100 mm long with Ø 1 banana plug	2 PTFE insulated AWG26 wires 100 mm long with Ø 1 banana plug

■ Table 4.16: Characteristics of the PPA XL Actuators

Available option(s) + performances:

SG, VAC

Available interface option(s):

TH, SI

5. SELECTION GUIDE FOR PIEZO MECHANISMS

5.1 SELECTION GUIDE

Starting from standard Piezo Actuators, several mechanisms can be designed in order to control several degrees of freedom. Basically, all the APA® series can be used to build mechanisms providing several degrees of freedom. These mechanisms can integrate position sensors (Strain Gauges and Eddy Current Sensors) for closed loop control. The long travel mechanisms use an incremental magnetic sensor (MAG) based on the Hall effect.

- X: X guided stage with reduced out-of-plane Y and Z displacements,
- XY: XY stage with reduced out-of-plane Z displacement,
- XYZ: Scanner including three translations,
- OPP: Objective piezo positioner,
- FPS: Fast Piezo Shutter,
- RSPA/LSPA/LSPS: Rotary & Linear Stepping Piezo Actuator & Stage.

Please do not hesitate to take a look at our web site, where you can download:

- The technical data sheet,
- The mechanical interface drawing,
- The 3D edrawings file.

■ Table 5.1: Selection possibilities of piezo mechanisms ▶

ACTUATOR SERIE	MECHANISM
APA XS	XY, TT, DTT, SPA, SPS
APA S	XY, TT
APA SM	X, OPP, SPA
APA M	TT, XY, XYZ, FPS
APA ML	XY

MECHANISM	SENSOR OPTION
X	SG, ECS
XY	SG, ECS
XYZ	SG, ECS (SG for Z axis)
TT	SG, ECS
DTT	SG, ECS
OPP	SG, ECS
FPS	SG
SPA, SPS	MAG

■ Figure 5.1: View of two stacked X120S stages

5.2 X PIEZOELECTRIC STAGES

The piezoelectric stages X60S / X120S are single axis linear guided stage that can be equipped with Strain Gauges for a very fine positioning mode. Parasitic rotations (along X and Y axis) are very limited. The moving frame can be custom designed (attachment points, holes...) and 2 stages can be stacked for XY motion. Two X60S and X120S stages can be stacked to get a 2 degree-of-freedom (XY) mechanism.

REFERENCES	UNIT	X60S	X120S
Item Code		V-XS60	V-XS120
Notes		Preliminary data	Preliminary data
Sensors option		SG	SG
Active axis		TX	TX
Max. No-load displacement [Tx]	µm	55	115
Max. out of plane Z displacement	µm	0,50	0,50
Max. parasitic Z rotation	µrad	-	-
Max. parasitic X Y rotations	µrad	3	3
Voltage range	V	-20 ... 150	-20 ... 150
Stiffness	N/µm	1,82	0,33
Heigth (Z axis)	mm	12	12
Dimensions (X & Y axis)	mm	30*30	30*30
Resolution	nm	0,6	1,2
Mass	g	70	70
Unloaded resonance frequency (in the actuation's direction)	Hz	600	1200
Response time	ms	0,83	0,42
Capacitance (per electrical port)	µF	1,55	1,55
Mechanical interfaces (payload)		4 M3 threaded holes on [] 17*17	4 M3 threaded holes on [] 17*17
Mechanical interfaces (frame)		4 Ø 3.5 mm holes on [] 17*17	4 Ø 3.5 mm holes on [] 17*17
Electrical interfaces		2 PTFE insulated AWG30 wires 100 mm long with Ø1 banana plug	2 PTFE insulated AWG30 wires 100 mm long with Ø1 banana plug

■ Table 5.2: Characteristics of the X60S & 120S stages

Other stages based on APA® from the XS, SM, M and ML series can be **defined.**

5.3 XY PIEZOELECTRIC STAGES

The piezoelectric stage XY200M has a large stroke along the X and Y axis and is able to bear load up to 3 kg. Applications include Atomic Force or Scanning Tunneling Microscopes and mask positioning. This stage is based on APA200M and display a high stiffness. The stage can be equipped with Strain Gauges (SG) or Eddy Current Sensors (ECS option) for a very fine positioning mode. Parasitic rotations (along X, Y and Z rotation) are very limited. The moving frame can be custom designed (attachment points, holes...). The compact XY25XS stage is well suited to integrated devices for fiber, lens or detector positioning, micro scanning, pixel shift, dithering...

■ Figure 5.2: View of the XY25XS stage

REFERENCES	UNIT	XY25XS	XY200M
Item Code		V-XYXS25	V-XYM200
Notes		-	-
Sensors option		SG, ECS	SG, ECS
Active axis		TX, TY	TX, TY
Max. No-load displacement [Tx, Ty]	µm	25	200
Max. out of plane Z displacement	µm	0,50	1,00
Max. parasitic Z rotation	µrad	50	240
Max. parasitic X Y rotations	µrad	10	50
Voltage range	V	-20 ... 150	-20 ... 150
Stiffness	N/µm	2,50	0,59
Heigth (Z axis)	mm	20,0	22,0
Dimensions (X & Y axis)	mm	50*50	100 *100
Resolution	nm	2,5	2,0
Mass	g	80	180
Unloaded resonance frequency (in the actuation's direction)	Hz	3000	580
Response time	ms	0,17	0,86
Capacitance (per electrical port)	µF	0,50	6,30
Mechanical interfaces (payload)		1 Ø 17 mm hole + 4 Ø1.8mm on Ø 20 mm	3 Ø 2.7 mm holes on [] 38
Mechanical interfaces (frame)		4 Ø 2.8 mm holes on [] 45	4 Ø 4.5 mm holes on [] 84
Electrical interfaces		2 RG178B/U coaxial cables with Harwin connectors	2 RG178B/U coaxial cables with Harwin connectors

■ Table 5.3: Characteristics of the XY stages

Other stages based on APA® from the XS,S, SM, ML and L series can be defined.

The technical information on this leaflet is not contractual and can be changed without prior notice.

■ Figure 5.3: View of the XYZ200M stage

5.4 XYZ PIEZOELECTRIC STAGES

The piezoelectric stage XYZ200M has a large stroke along the X, Y and Z axis and is able to bear load up to 3 kg. Applications include Confocal microscopy, mask positioning and inspection. This stage is based on APA200M and display a high stiffness. The stage can be equipped with Strain Gauges or Eddy Current sensors (ECS option) for a very fine positioning mode. Parasitic rotations (along X, Y and Z rotation) are very limited. The moving frame can be custom designed (attachment points, holes...). This mechanism requires the Push-pull option on the first two channels of the driver.

REFERENCES	UNIT	XYZ200M
Item Code		V-XYZM200
Notes		-
Sensors option		SG, ECS
Active axis		TX, TY, TZ
Max. No-load displacement [Tx, Ty]	µm	200
Max. Z displacement [Tz]	µm	200
Max. parasitic Z rotation	µrad	240
Max. parasitic X Y rotations	µrad	50
Voltage range	V	-20 ... 150
Stiffness	N/µm	0,59
Heigth (Z axis)	mm	49,0
Dimensions (X & Y axis)	mm	100*100
Resolution	nm	2,0
Mass	g	540
Unloaded resonance frequency (in the actuation's direction)	Hz	380
Response time	ms	1,32
Capacitance (per electrical port)	µF	6,30
Mechanical interfaces (payload)		objective interface max 4/55*1.36 (to be specified)
Mechanical interfaces (frame)		4 Ø 4.5 mm holes on [] 84
Electrical interfaces		2 RG178B/U coaxial cables with Harwin connectors

■ Table 5.4: Characteristics of the XYZ stage

Other stages based on APA® from the XS, S, SM, ML and L series can be **defined.**

5.5 TILT TRANSLATORS TT FOR ΘX-Z MOTION

The tilt translator TT is a Tilt stage based on 2 APA®. With the TT60SM, two types of motion can be generated:

- a Piston Z motion (translation) when the two actuators are simultaneously actuated,
- a Tilt ΘX motion when the two actuators are actuated in opposite phase.

The tilt translator mechanism TT60SM can be equipped with Strain Gauges or Eddy Current Sensors for closed loop operation. If only the tilt motion is required, then only one channel is necessary. The TT60SM mechanism requires the Push-pull option on the driver.

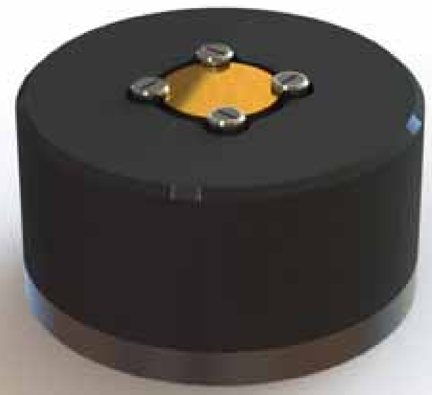
■ Figure 5.4: View of the Tilt Translator TT60SM

REFERENCES	UNIT	TT60SM
Item Code		V-TTSM60
Notes		Preliminary Data
Sensors option		SG, ECS
Active axis		TZ, RX
Max. No-load displacement [Tz]	µm	50,0
Angular displacement [Rx]	mrad (+/-)	11,30
Voltage range	V	-20 ... 150
Stiffness	N/µm	2,00
Height (Z axis)	mm	35,0
Diameter	mm	Ø55mm
Vertical Resolution [Tz]	nm	0,5
Angular resolution [Rx]	µrad	0,1
Mass	g	141
Unloaded resonance frequency (in the actuation's direction)	Hz	400
Response time	ms	1,25
Capacitance (per electrical port)	µF	1,55
Mechanical interfaces (payload)		Flat surface Ø25.4mm (1")
Mechanical interfaces (frame)		4 M3 threaded holes on Ø48mm
Electrical interfaces		Actuators connection: 1.5m wire with Lémo FGG.00.303.CLAD22 connector -SG option: 1.5m wire with Lémo FGG.00.304.CLAD22 connector -ECS option: 1m wire with Radiall R113081000W connector

■ Table 5.5: Characteristics of the tilt translator systems

Other double tilt system based on APA® from the XS, S, SM, M, ML and L series can be defined.

5.6 DOUBLE TILT TRANSLATOR DTT FOR Z-ΘX-ΘY MOTION



■ Figure 5.5: View of the Double Tilt Translator DTT35XS

The double tilt translator DTT is based on 2 pairs of APA35XS. Three types of motion can be generated:

- A vertical Z motion (translation) when the two pairs of APA35XS are simultaneously actuated,
- A Tip & Tilt ΘX and/or ΘY motion up to +/- 2 mrad, when the two actuators of a pair are actuated in opposite phase.

The double tilt translator mechanism can be equipped with strain gauges or Eddy Current sensors to operate in closed loop. For driving the two tilts (Tip Tilt) motion, only two channels are necessary (with the Push-pull mode from the 75 family of drivers).

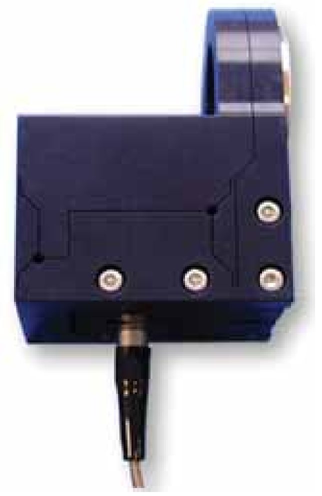
REFERENCES	UNIT	DTT35XS
Item Code		V-DTTXS35
Notes		Preliminary Data
Sensors option		SG, ECS
Active axis		RX, RY, TZ
Max. No-load displacement [Tz]	µm	35,0
Max. Angular displacement [Rx, Ry]	mrad (+/-)	2,80
Voltage range	V	-20 ... 150
Stiffness	N/µm	2,00
Heigth (Z axis)	mm	24,0
Diameter	mm	Ø45mm
Vertical Resolution [Tz]	nm	0,4
Angular resolution [Rx, Ry]	µrad	0,03
Mass	g	53,0
Unloaded resonance frequency (in the tilt direction)	Hz	2800
Response time	ms	0,2
Capacitance (per electrical port)	µF	0,50
Mechanical interfaces (payload)		Flat surface Ø 12.7mm (1/2")
Mechanical interfaces (frame)		Cylinder Ø 43mm or 4 M3 threaded holes on Ø30
Electrical interfaces		Actuators connection: 1.5m wire with Lémo FGG.00.303.CLAD22 connector -SG option: 1.5m wire with Lémo FGG.00.304.CLAD22 connector -ECS option: 1m wire with Radiall R113081000W connector

■ Table 5.6: Characteristics of the DTT35XS

Other double tilt system based on APA® from the XS, S, SM, M, ML and L series can be defined.

5.7 OBJECTIVE PIEZO POSITIONNER OPP120SM

The objective piezo positionner OPP120SM uses the amplified piezo actuators from CEDRAT TECHNOLOGIES's standard range of actuators and an additional guiding for a vertical and accurate movement of the objective. The APA® achieves the trade-off between stroke and stiffness and is therefore well suited to rapid confocal microscopy. The interface with the objective can be customised. The piezo mechanism can integrate an eddy current proximity sensor (ECS option).



■ Figure 5.6: View of the OPP120SM

REFERENCES	UNIT	OPP120SM
Item Code		V-OPPSM120
Notes		-
Sensors option		SG, ECS
Active axis		TZ
Max. No-load displacement [Tz]	µm	140
Max. parasitic rotations [Rx, Ry]	µrad	25
Voltage range	V	-20 ... 150
Resolution	nm	14
Stiffness	N/µm	0,71
Heigth (Z axis)	mm	50,0
Dimensions	mm	65 * 40
Mass	g	180
Unloaded resonance frequency (in the actuation's direction)	Hz	600
Response time	ms	0,83
Loaded resonance frequency (in the actuation's direction) load = 50 g	Hz	440
Loaded response time	ms	1,14
Capacitance (per electrical port)	µF	3,15
Mechanical interfaces (payload)		objective interface max M25*0.75 (to be specified)
Mechanical interfaces (frame)		microscope interface (max M25*0.75) to be specified
Electrical interfaces		1 RG178B/U coaxial cable

■ Table 5.7: Characteristics of the OPP120SM

Other mechanisms based on APA® from the SM, M and L series can be defined.

The technical information on this leaflet is not contractual and can be changed without prior notice.

■ Figure 5.7: View of the FPS200M (courtesy of EMBL)

5.8 FAST PIEZO SHUTTERS FPS200M, FPS400M & FPS900M

The Fast Piezo Shutters (FPS) are mechanisms moving a jaw that open and close a slit. Width of slits up to 1.1 mm can be opened and closed in less than 10ms. Other features include high repeatability, low jitter, long life time...

Design of FPS series is based on APA200M, APA400M and APA900M actuators. The moving jaw is made of tungsten to offer very high X-Ray stop. FPS has been qualified by EMBL at ESRF Grenoble. FPS shutters are used by synchrotron facilities all around the word.

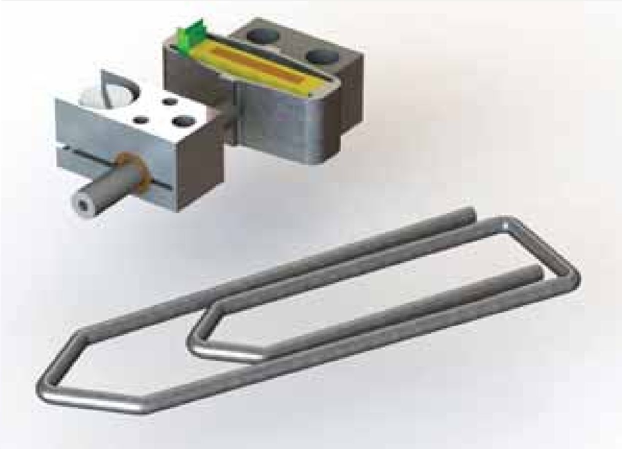
REFERENCES	UNIT	FPS200M	FPS400M	FPS900M
Item Code		V-FPSM200	V-FPSM400	V-FPSM900
Notes		-	-	-
Sensors option		SG	SG	SG
Active axis		TX	TX	TX
Max. No-load displacement (Tx)	µm	400	800	1600
Max. beam diameter	mm	0,3	0,7	1,1
Voltage range	V	-20 ... 150	-20 ... 150	-20 ... 150
Stiffness	N/µm	3,17	0,10	0,02
Heigth (Z axis)	mm	21,0	21,0	23,0
Dimensions (X & Y axis)	mm	60 * 44	60 * 44	60 * 44
Mass	g	150	150	150
Unloaded resonance frequency (in the actuation's direction)	Hz	850	430	248
Aperture & closing time	ms	2,00	4,00	10,00
Capacitance (per electrical port)	µF	3,15	3,15	3,15
Mechanical interfaces (payload)		4 slits (width 0.6 mm)	4 slits (width 0.6 mm)	4 slits (width 0.6 mm)
Mechanical interfaces (frame)		4 holes Ø 2.7mm on [] 24*38 mm	4 holes Ø 2.7mm on [] 24*38 mm	4 holes Ø 2.7mm on [] 24*38 mm
Electrical interfaces		2 RG178B/U coaxial cables	2 RG178B/U coaxial cables	2 RG178B/U coaxial cables

■ Table 5.8: Characteristics of the FPS

Other mechanisms based on APA® from the SM, M and L series can be defined.

5.9 LINEAR STEPPING PIEZO ACTUATOR LSPA

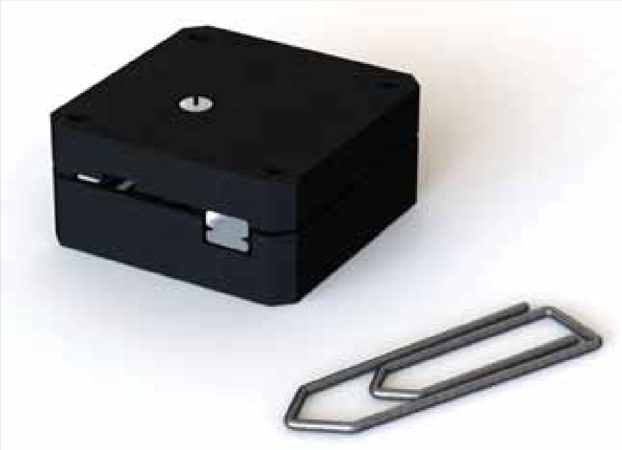
Linear Stepping Piezoelectric Actuators (LSPA) are linear piezoelectric motors for micro/ nano positioning applications benefiting from the APA® heritage. They operate by accumulation of small steps (see 2.6). Between each step, the motor is locked into position and does not need to be powered.
When the long stroke is performed, it can also be operated in a deformation mode for a fine adjustment. In this case, the stroke is proportional to the applied voltage, which leads to a nanometre resolution and a high bandwidth. This LSPA can be supplied with CEDRAT TECHNOLOGIES's standard compact driver SPC45 or with standard Linear Amplifiers CA45 or LA75.
Other Custom Linear Stepping Piezo Actuators can be designed based on various APA®.



■ Figure 5.8: View of the LSPA35XS

REFERENCES	UNIT	LSPA30UXS	LSPA35XS	LSPA40SM
Item Code		V-LSPAUXS30	V-LSPAXS35	V-LSPASM40
Notes		-	Preliminary data	Preliminary data
Base		APA30uXS	APA35XS	APA40SM
Mastered motions		TX	TX	TX
Max. No-load displacement	mm	6	10	20
Holding force without cunsomption	N	0,8	3	15
Max speed	mm/s	70	30	20
Max step size	µm	44	14	6
Max driving force	N	0,3	1	5
Typical max loading	gr	15	30	200
Typical working frequency	Hz	1600	2100	3100
Typical stepping mode resolution	µm	1	1	1
Deformation stroke	µm	30	55	52
Linear resolution	nm	0,3	0,55	0,5
Stiffness	N/µm	0,11	0,49	3,73
Capacitance	µF	0,05	0,25	1,55
Voltage range	V	-20 ... 150	-20 ... 150	-20 ... 150
Typical Lifetime	cycles	1000000	1000000	1000000
Heigth	mm	5,6	12	14
Width	mm	8,8	16	32
Length	mm	19,15	30	45
Mass	g	1,9	5	18
Unloaded resonance frequency (in the actuation's direction)	Hz	2200	2800	4100
Mechanical interfaces (payload)		1 x M2 dep. 3	"M2 dep. 3 + 2x diam1.05 dep. 1"	"M3 dep. 5 + 2x diam2.05 dep. 1"
Mechanical interfaces (frame)		2 x diam 1.8 holes	2 x diam 2.4 holes	2 x diam 3.4 holes
Electrical interfaces		2 PTFE insulated AWG30 wires 50mm long with Ø 1 bananaplug	2 PTFE insulated AWG30 wires 50mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 50mm long with Ø 1 banana plug

■ Table 5.9: Characteristics of the Linear Stepping Piezo Actuators



■ Figure 5.9: View of the LSPS35XS stage

5.10 LINEAR STEPPING PIEZO STAGE LSPS

The Linear Stepping Piezo Stages LSPS are based on the Linear Stepping Piezo Actuator's (SPA) principle (see 2.6). It provides with:

- A long stroke, high speed & blocking at rest
- A micro/nano positioning resolution
- A guided motion & Robustness
- Compactness & Easy Interfaces

LSPS stages can be driven with SPC45 driver or a linear amplifier from the LA75 family. Open and closed loop versions are available.
Custom Stages can be designed with smaller or bigger APA®.

REFERENCES	UNIT	LSPS35XS	LSPS40SM
Item Code		V-LSPSXS35	V-LSPSSM40
Notes		Preliminary data	Preliminary data
Base		APA35XS	APA40SM
Mastered motions		TX	TX
Max. No-load displacement	mm	10	20
Holding force without cunsomption	N	3	20
Max speed	mm/s	30	10
Max step size	µm	37,5	20
Max driving force	N	1	10
Typical max loading	gr	70	400
Typical working frequency	Hz	800	500
Typical stepping mode resolution	µm	1	1
Deformation stroke	µm	55	52
Linear resolution	nm	0,55	0,52
Stiffness	N/µm	0,49	3,73
Capacitance	µF	0,25	1,55
Voltage range	V	-20 ... 150	-20 ... 150
Out of plane	µm	6	10
Z rotation	µrad	0,3	0,5
X Y rotation	µrad	0,3	0,5
Typical Lifetime	cycles	1000000	1000000
Sensors option		MAG	MAG
Heigth	mm	15	20
Width	mm	30	50
Length	mm	30	50
Mass	g	30	90
Unloaded resonance frequency (in the actuation's direction)	Hz	900	1330
Mechanical interfaces (payload)		4 x M2 deep. 6	"4 x M2 deep. 4 + 4 x M3 deep. 4"
Mechanical interfaces (frame)		4 x diam 2.4 holes	4 x diam 3.4 holes
Electrical interfaces		8 pins ERNI connector	8 pins ERNI connector

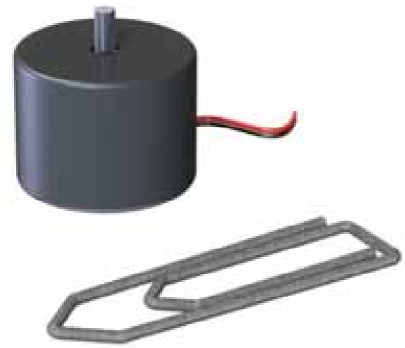
■ Table 5.10: Characteristics of the Linear Stepping Piezo Stage LSPS

5.11 ROTARY STEPPING PIEZO ACTUATORS RSPA

Rotary Stepping Piezoelectric Actuators (RSPA) are rotary piezoelectric motors with 360° revolutions. They operate by accumulation of small steps (see 2.6).
This motor technology provides:

- Extreme Compactness
- High rotational speed & blocking at rest
- Nano resolution
- More than 1 million cycles

The motor is locked in position when it is not powered.
RSPA can be supplied with CEDRAT TECHNOLOGIES's standard compact drivers SPC45 or with standard Linear Amplifiers CA45 or LA75. Custom Stepping Piezo Actuators can be designed based on various APA®.



■ Figure 5.10: View of the RSPA30XS

REFERENCES	UNIT	RSPA30UXS	RSPA35XS
Item Code		V-RSPAUXS30	V-RSPAXS35
Notes		Preliminary data	Preliminary data
Base		APA30uXS	APA35XS
Mastered motions		RZ	RZ
Max. No-load displacement	rad	∞	∞
Holding torque without cunsomption	Nmm	4	30
Max speed	rpm	65	20
Max step size	mrad	6,8	3,5
Max driving torque	Nmm	1,3	10,0
Typical max loading	gr	15	30
Typical working frequency	Hz	1000	600
Typical stepping mode resolution	mrad	0,1	0,1
Capacitance	µF	0,05	0,25
Voltage range	V	-20 ... 150	-20 ... 150
Typical Lifetime	cycles	1000000	1000000
Heigth	mm	10	18
Diameter	mm	12	20
Mass	g	3	8
Unloaded resonance frequency (in the actuation's direction)	Hz	1363	835
Mechanical interfaces (payload)		2mm diameter x 4mm long with 1mm width flatted shaft	3mm diameter x 4mm long with 1mm width flatted shaft
Mechanical interfaces (frame)		4 diam 1.8 holes	4 diam 2.2 holes
Electrical interfaces		2 PTFE insulated AWG30 wires 50mm long with Ø 1 banana plug	2 PTFE insulated AWG30 wires 50mm long with Ø 1 banana plug

■ Table 5.11: Characteristics of Rotatory Stepping Piezo Actuators RSPA

6. MAGNETIC ACTUATORS

CEDRAT TECHNOLOGIES has a long heritage in magnetic actuators and sensors. It has been designing optimizing and manufacturing electro-magnetic actuators for its customers for more than 15 years.

The MICA and BLMM actuators enter as standard products. They come from a series of magnetic building blocks. Like other products developed by CEDRAT TECHNOLOGIES, MICA and BLMM Magnetic are compact and dynamic actuators dedicated for demanding applications.

In case these standard actuators do not meet your requirements, CEDRAT TECHNOLOGIES can develop actuators upon request. A broad range of actuator type is possible, such as electro magnets, solenoid, moving magnets, voice coils, and much more. Some examples of customised actuators are presented. Feel free to call us with your specification.

CEDRAT TECHNOLOGIES also offers a complete range of engineering services, optimisation, feasibility, design, prototyping, test, qualification, manufacturing and training presented at the end of this chapter.

■ Figure 6.1: MICA actuator

6.1 MICA

Moving Iron Controllable Actuator (MICA) actuators are patented magnetic actuators from CEDRAT TECHNOLOGIES. They provide a controllable force on several millimetres of stroke. The optimised design offers a very high energy density, several times better than with voice coils.

With strokes that reach 10mm for the MICA L family and 5 mm for MICA M family, these actuators perfectly complete our well known APA® actuators. MICA actuators are controllable, high force, highly dynamic actuators.

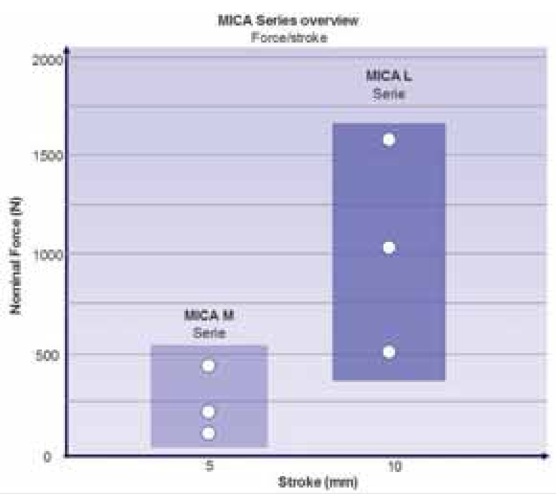
MICA actuators offer:

- Large force in a compact design
- High dynamics (i.e. high acceleration)
- Robust guiding
- Integrated position sensor
- High reliability
- Easy cooling

6.2 MICA L AND M SERIES OVERVIEW

The MICA M actuators have a stroke of 5 mm, and nominal forces range from 110N up to 440 N.
The MICA L actuators have a stroke of 10 mm and nominal forces range from 530 up to 1600N.

All these magnetic actuators could be driven with off the shelf power amplifier existing on the market. Please do contact us for any information on that matter.



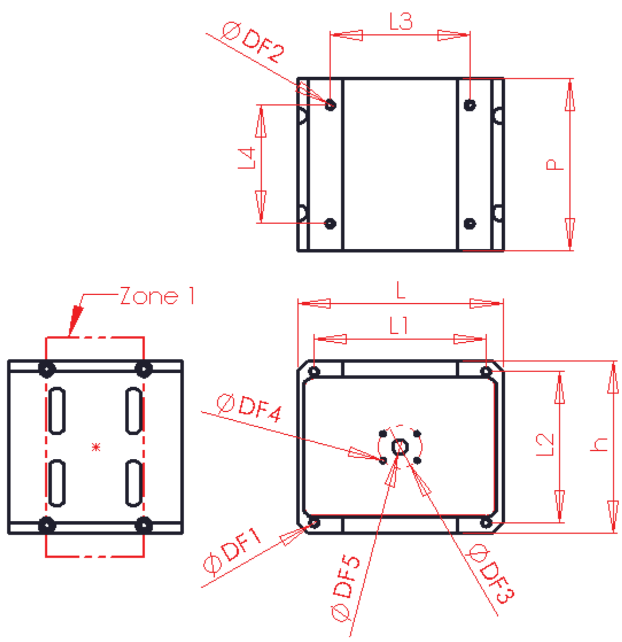
■ Figure 6.2: MICA nominal forcesv versus strokes

On request MICA are available for **specific application. Force, current,** sensor resolution and so one can be adapted. Feel free to call us.

Commercial Name / ID		MICA100M	MICA200M	MICA400M	MICA500L	MICA1000L	MICA1500L
Note	Unit	Preliminary	Preliminary	Preliminary	Preliminary	Preliminary	Preliminary
Stroke	mm	5	5	5	10	10	10
Nominal Force [(1)]	N	110	219	437	535	1063	1594
Nominal Current	A	10	10	10	20	20	20
DC Resistance	ohm	0.87	1.14	1.68	0.57	0.79	1.02
Inductance	mH	12.1	23.9	47.8	24.5	62.4	93.7
Nominal Voltage@20Hz[(1)]	V	17	32	62	63	158	236
Copper Losses[(1)]	W	87	114	168	228	316	408
Connector Electrical interface		SUB-D Combo 17W2	SUB-D Combo 17W2	SUB-D Combo 17W2	SUB-D Combo 17W2	SUB-D Combo 17W2	SUB-D Combo 17W2
Position Sensor		Incremental	Incremental	Incremental	Incremental	Incremental	Incremental
Sensor Resolution	µm	15	15	15	15	15	15
Maximal coil Temperature	°C	150	150	150	150	150	150
Temperature Sensor		PT100	PT100	PT100	PT100	PT100	PT100
Moving mass	g	---	---	---	1562	1925	2291
Total mass	g	---	---	---	8500	13000	17000
Lenght actuator	mm	---	---	---	140	195	245
Height actuator	mm	---	---	---	160	160	160
Depth actuator	mm	---	---	---	160	160	160

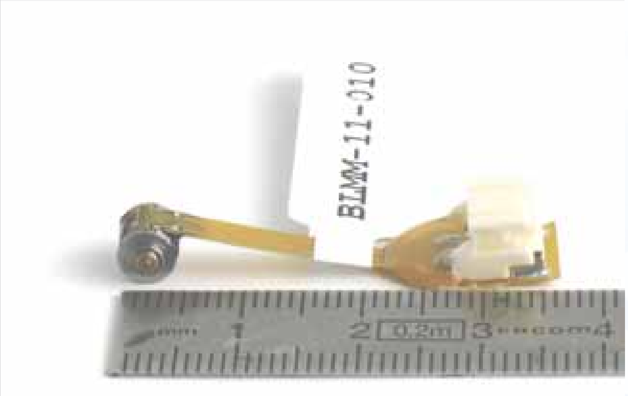
(1): For nominal current.

■ Table 6.1: Characteristics of MICA actuators

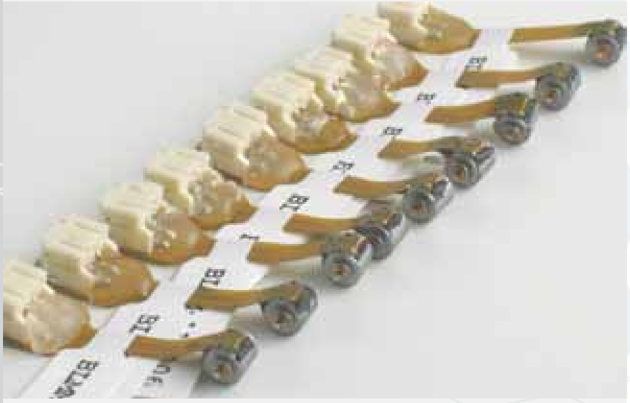


MICA	500L	1000L	1500L
L	140	191	244
P	160	160	160
h	150	150	150
L1	107	160	213
L2	140	140	140
L3	77	130	183
L4	110	110	110
DF1	M8	M8	M8
DF2	M8	M8	M8
DF3	40	40	40
DF4	M5	M5	M5

■ Table 6.2: MICA dimension (mm)



■ Figure 6.3a: BLMM actuator



■ Figure 6.3b: A batch of BLMM actuators

BLMM actuators can be easily driven thanks to our LA24 power supply.
See chapter "Driver" for more details.

6.3 BLMM

BLMM stands for Bistable Linear Moving Magnet (Figures 6.3a & 6.3b).They are based on a permanent magnet moving between two opposite electromagnets.
BLMM are miniature actuators, especially relevant where small size actuator is needed.
The main BLMM characteristic is its holding force without dissipation. This makes BLMM perfect for applications such as latches devices, locking devices, miniature electro valves, contactors, etc...
In addition to the actuators presented in the table 6.3, CEDRAT TECHNOLOGIES has also designed specific BLMM for space valve applications, medical pumps, medical implants, ...

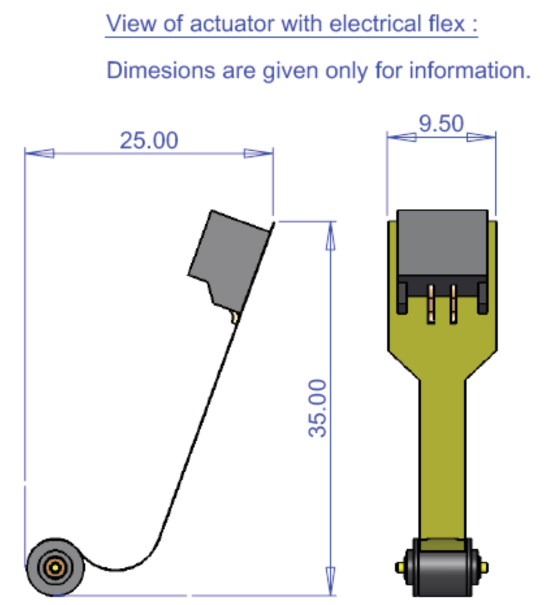
References	Unit	BLMM-1	BLMM-2
Notes			Preliminary
Stroke	mm	> 0,5	3
Holding force at rest (Fh)	N	0,08	50
Actuation force at start stroke (Fs) for Inpc	N	0,06	10
Actuation force at end stroke (Fe) for Inpc	N	0,25	>100
Commutation time	ms	< 1,7	<10
Nominal pulse current Inpc	A	+/- 1,2	
Pulse width	ms	1,7	10
Connector Electrical interface (2 wires)	JST - S2B - PH - SM4 - TB		
Winding resistance	ohm	4,25	
Winding inductance	µH	56,8	
Instantaneous Dissipated power	W	6,2	
Electric Time constant	µs	13	
Temperature rise for 1 switch	°C	0,012	
Temperature in steady state for 15 switch/s	°C	< 130	
Moving Mass	g	0,076	15
Total Mass	g	1,1	50
Actuator diameter size (PCB included)	mm	< 6	25
Height actuator (without shaft)	mm	6,8	20
Type of shaft	All through shaft		
Free Length for shaft fastening	mm	0,3	
Diameter Mobile shaft	mm	0,8	

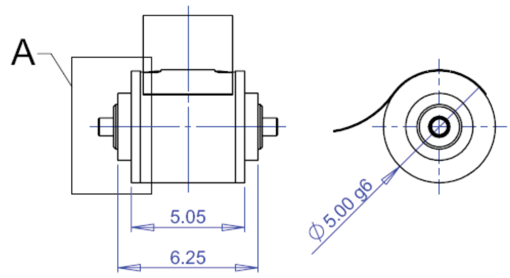
■ Table 6.3: Characteristics of BLMM actuator

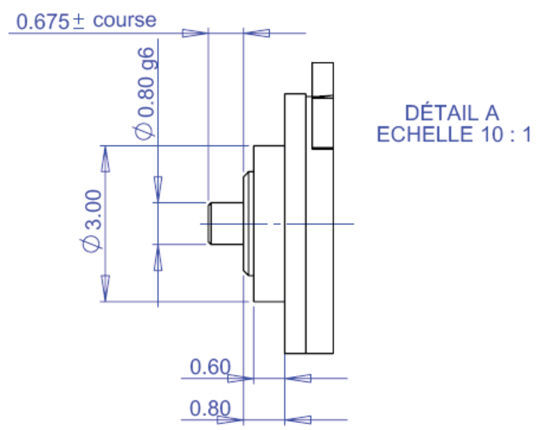
BLMM actuators can be classified into 2 categories, locking actuators and lifting actuators. For a locking actuator, the specific design allows to magnify the holding force. These BLMM are used in locking devices, contactor, positioning systems.
When designing a lifting actuator, the force during the motion and the holding forces are almost balanced. These BLMM are used in electro valves, vibration systems or miniature pumps for example.

BLMM Advantages:

- Small size
- Low power consumption
- Fast
- Easy control







■ Figure 6.4: Mechanical configurations

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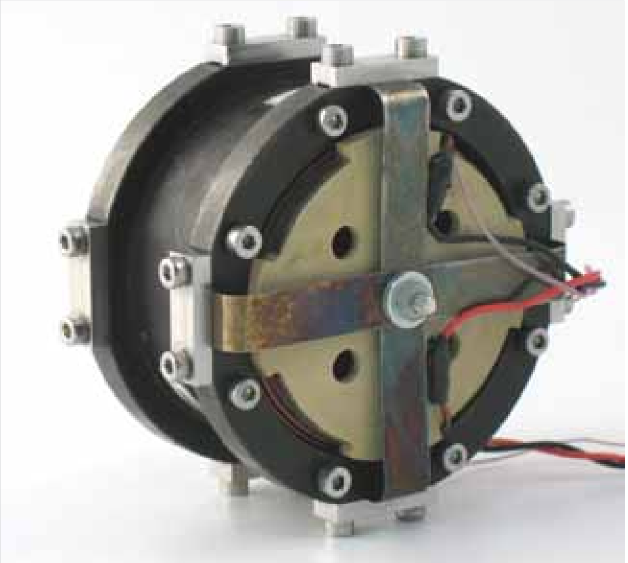
6.4 SPECIFIC MAGNETIC ACTUATORS

CEDRAT TECHNOLOGIES has been developing specific actuators or sensors for more than 15 years. Moving coils, moving magnets, electromagnets... , the actuator technology is selected to fit the customer needs. Some examples are presented here :

SPACE VOICE COIL

This actuator is dedicated to a space application. It is vacuum compatible, with linear guiding made of flexural blades for ultra long life (more than 10 billion of cycles - Figure 6.5)



■ Figure 6.5: Space voice coil

ELECTROMAGNET FOR MEMS AUTOMATIC TESTING MACHINE

Its size and electrical characteristics are adapted to allow the integration in the customer's system (Figure 6.6).

■ Figure 6.6: Electromagnet for MEMS automatic testing machine

DEDICATED MICA CONTROLLABLE ELECTROMAGNET

This actuator replaces a rotating motor plus crankshaft on an oscillating system. The result is a size and mass reduction, lower noise and vibration, longer life time. The specific titanium guiding is tuned to offer a high radial stiffness and an adapted axial stiffness (Figure 6.7).

■ Figure 6.7: Dedicated MICA controllable electromagnet

SMALL LOCKING DEVICES

Actuator that works in 80°C environment.

In case you didn't find the actuator that meets your expectation in this catalogue, CEDRAT TECHNOLOGIES proposes to make on request actuators. For any information regarding Cedrat Technologies engineering capabilities and services offer, please go to Chapter 3.3 (p48) or visit our website: ***www.cedrat-technologies.com***

		PIEZO DRIVER IN 19" CABINET			
Model serie	Unit	LC75x	LA75x-y-z	SP75x-y	SC75x
Note	-	x: Power level: A, B, C	x: Power level: A, B, C y: Nbr of channel: 1 ..3 z: PushPull	x: Power level: A, B, C y: Nbr of channel: 1..2	x: Power level:D
Function	-	Bipolar AC/DC linear converter for piezo actuators	Linear amplifier for piezo actuators	Switching 2 states power driver for piezo actuators	Unipolar AC/DC Switching converter for piezo actuators
Rack compatibility	-	RK42F,3H, RK42F, 4H RK84F,4H	RK42F,3H, RK42F, 4H RK84F,4H	RK42F,3H RK84F,4H	RK42F,4H RK84F,4H
Main or supply voltage	V	110 - 263	-36 / 165	-20 / 150	110 - 263
Output actuator voltage	V	-	-20 / 150	-20 / 150	-
Max output current	mA	up to 2400	up to 2400	up to 360	up to 30000
Resolution	-	-	☺☺	☑	-
Accuracy	-	-	☺☺	-	-
Bandwidth vs power	-	-	☺	-	-

■ Figure 7.1: View of Standard racks

	MAGNETIC DRIVER IN 19" CABINET	
SA75x	LC24x	LA24x-y
x: Power level:D	x: Power level: A	x: Power level: A y: Nbr of channel: 1 ..3
Switching power amplifier for piezo actuators	Bipolar AC/DC linear converter for magnetic actuators	Linear amplifier for magnetic actuators
RK42F,4H RK84F,4H	RK42F, 3H RK84F, 4H	RK42F, 3H RK84F, 4H
0 / 240	110 - 263	-65 / 65
-20 / 150	-	-46 / 46
up to 30000	up to 1400	up to 1400
☺	-	☺ ☺
☺	-	☺ ☺
☺ ☺	-	☺

■ Table 7.1: Short guide for mounted rack with Power supply and driver board arrangement

7. SELECTION GUIDE FOR DRIVERS

7.1 SELECTION GUIDE

7.1.1 INTRODUCTION

The driving electronics of CEDRAT TECHNOLOGIES piezoelectric and magnetic actuators are based either on the standalone board series (CA) or on the 19' board rack mounted (RK).

The standalone series called Compact Amplifiers (CA) is well adapted to fit with small area or embedded solutions providing with the best ratio power/price on the market. These standalone driver series are mainly open loop solutions (except for CA45) and closed loop solutions can be developed under request.

The rack electronic families (RK) are more versatile and mainly dedicated for laboratory use.

For driving piezo actuators between -20 and +150V, the 75 series rack includes at least:

- An AC/DC converter providing the required stabilised DC voltages (LC75 or SC75)
- An voltage electronic amplifier (LA75, SA75, SP75)

For driving magnetic actuators between -46 and +46V, the 24 series rack includes at least:

- An AC/DC converter providing the required stabilised DC voltages (LC24)
- A current electronic amplifier (LA24)

If fine motion control is required, these driving electronics can be completed by closed loop including at least:

- A sensor and its conditioning electronics
- A closed loop servo controller.

This is further described in chapter 8.

For any request about driving and control solutions, feel free to contact us at **actuator@cedrat-tec.com.**

■ Figure 7.2: Customised rack including 6 channels & 3 closed loops

7.1.2 RACK DIMENSIONS

Four standard RK racks are used to build the customer's configuration starting from 19 inches boards (Table 7.2). Multiple configurations can be customised from those racks. Figure 7.2 shows for instance an RK84F rack, including 3 LA75B-2 boards, 1 SG75-3 board and 1 UC45 interface.

■ Table 7.2: Rack characteristics

REFERENCES	UNIT	RK12F
Item Code		V-RK12F
Notes	-	-
Function	-	Rack for CA45 or ECS75OEM
Max. number of unit (amplifiers with control loop)	-	1 x CA45 1 x SG75-1 1x ECS75OEM-2
Total output peak current capacity	mA	1 x 30
Weight	kg	1.4
Width	mm	89
Height	mm	129
Depth	mm	260
Transformer	-	Yes
Cooling	-	No
Main voltage interface	-	IEC Inlet

Note: the RK63F4H is currently being replaced by the RK42F4H.

7.1.3 CONNECTIONS

The connection to the main is performed through a CEE22 connector including a 110V/230V selection. The high voltage cables used to drive the Piezo Actuators are ended by LEMO FFA.00.250.CTAC22 connectors. It terminates on the actuator's side by two-banana plug ∅1mm (Figure 7.3.a). They can be changed on request for specific applications or environments. Alternatively, a LEMO-BNC converter can be proposed (Figure 7.3b).

The strain gauges cable for piezo actuators uses a flex connection and a SMD 1mm pitch SMT connector (Figure 7.4).

For electrical push pull operation of two actuators, a specific cable is delivered by CEDRAT TECHNOLOGIES in order to connect the two pairs of banana plug to a single LEMO channel.


(a)


(b)

■ Figure 7.3a: Standard coaxial cable RG178B/U to drive APA® actuator

■ Figure 7.3b: LEMO – BNC converter

■ Figure 7.4: Cable to drive a Strain Gauges sensor

RK42F 3H	RK42F 4H	RK84F 4H
V-RK42F3H	V-RK42F4H	V-RK84F4H
-	Preliminary data	-
Rack for LA75A or B series	Rack for LA75C series Rack for SA75 series	Rack for LA75A&B, LA75C series, SA75 series For 19 electronic cabinet
1 x LA75A-3 or B-2 1 x SG75-3 or 1 x ECS75-2 1 x UC65 or 3 x UC45	1 x SA75D 1 x LA75C 1 x SG75-1 or 1 x ECS75-1 1 x UC65 or 1 x UC45	3 x LA75A-3 or B-2 2 x LA75C (in progress) 3 x SA75D 3 x SG75-3 3 x ECS75-2 1 x UC65 or 9 x UC45
2 x 360	1 x 30000	6 x 360 2 x 2400 (in progress) 3 x 30000
4.65	5.5	8
260	260	470
160	200	200
310	310	310
Yes	No	Yes with LA75 series No with SA75D series
Forced air - 1 fan	Forced air - 1 fan	Forced air - 2 fans for LA75 Forced air - 1 fan per SA75
IEC Inlet with voltage selector	IEC Inlet with voltage selector	IEC Inlet with voltage selector

7.1.4 STANDARD CONFIGURATIONS

The most standard configurations are displayed on Table 7.3 and correspond to:

- Up to 3 low bandwidth channels (operating in closed loop) in an RK42F3H rack,
- Up to 2 medium bandwidth channels (operating in closed loop) in an RK42F3H rack,
- One large or extra large bandwidth channel (operating in closed loop) in an RK42F4H rack
- Up to 5 low bandwidth channels (operating in closed loop) and a display interface controller in an RK84F4H rack,
- Up to 15 low bandwidth channels in a RK84F4H rack.
- Up to 3 extra large bandwidth channel (operating in closed loop) in a RK84F4H rack.

		AC-DC CONVERTER (PLEASE SELECT ONE TYPE)				PIEZO DRIVER (PLEASE SELECT ONE TYPE)			
Rack type	Remark	LC75x	LC75x	LC75x	SC75	LA75x-y	LA75x-y	LA75x-y	SA75x-y
Note		x: Type A	x: Type B	x: Type C	x: Type D	x: Type: A y: nbr of ch 1..3	x: Type B y: nbr of ch 1..2	x: Type C y: nbr of ch 1	x: Type D y: nbr of ch 1
RK42F, 3H		1				1 (3)			
RK42F, 3H			1				1 (2)		
RK42F, 3H			1			2 (6)			
RK63F, 4H	Obsolete			1				1 (1)	
RK42F, 4H				1	1			1	1 (1)
RK84F, 4H		1				1 (3)			
			1				1		
			1			2 (6)			
			1			3 (8)			
				2 (in progress)				2 (in progress)	
				2 (in progress)		3 (9)			
				2 (in progress)		5 (15)			
				2 (in progress)			2 (6)		
				2 (in progress)			3 (6)		
				2 (in progress)				Up to 2.4A	

■ Table 7.3: Overview of the standard RK configurations : possible implementations of converters and drivers

Note: Any RK can be completed with sensors and controllers boards (see chapter 8)

Other combinations are possible: please consult CEDRAT TECHNOLOGIES.

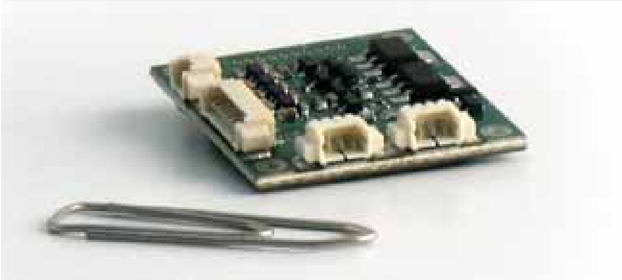
7.2 CA STANDALONE SERIES FOR PIEZO ACTUATORS

The CA-u10, CA-u20 and CA45 are standalone amplifiers. The CA-u10 is an extra-miniature two-channels Amplifier for piezo actuators in open loop, which is able to deliver 5 mA per channel and requires a DC voltage of 3.3 to 15 V.
CA-u20 is an extra-miniature single channel Amplifier for piezo actuators in open loop, which is able to deliver 100 mA and requires a DC voltage of 12 to 24 V.

The new generation of CA-uxx includes PCB interfaces with standards connectors or additional pins to solder on your PCB with 2 in lines 1.27mm pitch connectors.

The CA45 is a standalone single channel amplifier encased in an RK12 small rack. The CA45 is connected to the main source (220/240 VAC, 110 VAC upon request) and provides with all the necessary functions to obtain the highest accuracy from a piezo actuator: Drive & Control in open or closed loop of a piezo actuator equipped with Strain Gauges (SG option).

See table next page.



■ Figure 7.5: View of the miniature CA-u10 amplifier

■ Figure 7.6: View of the compact CA45 amplifier

OEM versions can be customised upon request.

The technical information on this leaflet is not contractual and can be changed without prior notice.

7.2.1 STANDALONE SERIES FOR PIEZO ACTUATORS

REFERENCES	UNIT	CA-U10	CA-U20	CA45-X
Item Code		V-CA-u10	V-CA-u20	V-CA45
Notes	-	- -	Preliminary data -	- x: Option Strain Gage
Function	-	Standalone voltage amplifier for piezo actuators	Standalone voltage amplifier for piezo actuators	Standalone voltage amplifier for piezo actuators
Max. number of channels	-	2 + push-pull	1	1
Protection	-	Overcurrent Overvoltage	Overcurrent Overvoltage	Thermal Overcurrent Overvoltage
Main Voltage	VDC VAC	5 - 12 -	12 - 24 -	- 110 - 264
Max Main Current	mA	200	750	150
Main frequency	Hz	-	-	47-63
Output voltage	V	5 / 150	-20 / 150	-20 / 150
Min Output voltage	V	5	-20	-20
Max Output voltage	V	150	150	150
Amplifier gain	V/V	45	20	20
Continuous max current	mA	5	100	36
Peak output power	VA	1	7	3
Output load capacitance	µF	40	40	400
Control input voltage	V	0 ... 3.3	-1 ... 7.5	-1 ... 7.5
Min input voltage	V	0	-1	-1
Max input voltage	V	3,3	7,5	7.5
Signal / Noise ratio	dB	70	85	85
Loaded output bandwidth	Hz	6,0	181,2	43,5
Unloaded output bandwidth	Hz	1000	33000	33000
Accuracy-Linearity	%	0,1	0,1	0,1
DC offset setting	-	-	-	10 turns potentiometer
Min DC offset	V	-	-	-1,0
Max DC offset	V	-	-	7,5
PZT connector	-	2 x Molex picoblade series 3pins Right angle male pitch 1.25 mm	2 x Molex picoblade series 3pins Right angle male pitch 1.25 mm	LEMO ERN.00.250.CTL
External Sensor connector	-	-	-	LEMO EGG.00.304CLL
Main voltage connector	-	Molex picoblade series 2pins Right angle male pitch 1.25 mm	Molex picoblade series 2pins Right angle male pitch 1.25 mm	IEC Inlet
External Control connector	-	Molex picoblade series 5pins Right angle male pitch 1.25 mm	Molex picoblade series 8pins Right angle male pitch 1.25 mm	BNC
Input impedance	kOhms	10	10	10
Weight	kg	0,01	0,15	1,2
Dimensions	W, L, H mm x mm x mm	PCB board 29x34.5x7	PCB board 55x55x15	12F, 3H, 260mm 12F rack 89x260x129
Cooling	-	Natural convection	Natural convection	Natural convection
Min-Max ambiant Temperature	-	0...40	0...40	0...40
Option	-	PCB mounting with 1.27 pitch for right pins connectors	PCB mounting with 1.27 pitch for right pins connectors	Strain Gage sensor UC45 controller

■ Table 7.4: Characteristics of the CA-u10, CA-u20 and CA45 standalone series

7.3 75 SERIES AC/DC CONVERTERS FOR PIEZO ACTUATORS

AC/DC or DC/DC converters of the 75 family are designed to produce stabilised DC voltages which are necessary to supply the amplifiers. AC/DC converters use the mains as primary source.

The LC75A AC/DC converter is used in the standard configuration, while the LC75B and the LC75C converters have a higher current capability and may be used for impulse and/or high frequency applications.

The SC75D AC-DC board is mainly used for the SA75D switching amplifier which requires specific voltage bus.

■ Figure 7.7: View of the LC75B AC/DC converter

REFERENCES	UNIT	LC75A	LC75B	LC75C	SC75D
Item Code		V-LC75A	V-LC75B	V-LC75C	V-SC75D
Notes	-	-	-	-	Preliminary data
Function	-	Bipolar AC/DC linear converter for piezo actuators	Bipolar AC/DC linear converter for piezo actuators	Bipolar AC/DC linear converter for piezo actuators	Unipolar AC/DC Switching converter for piezo actuators
Protection	-	Thermal Overcurrent Overvoltage	Thermal Overcurrent Overvoltage	Thermal Overcurrent Overvoltage	Thermal Overcurrent Overvoltage
Main voltage	VAC	110 - 263	110- 263	110 - 263	110 - 263
Max current	A	0,5	0,8	2,7	1,3
Main frequency	Hz	47-63	47-63	47-63	47-63
Regulated direct voltage	VDC	-36 / 165	-36 / 165	-36 / 165	0 / 240
Min regulated direct voltage	VDC	-36	-36	-36	0
Max regulated direct voltage	VDC	165	165	165	240
Continuous or Peak Current Limitation	A	0,12	0,78	2,4	30
Maximal output power (peak)	W	25	160	490	260
Switching frequency	kHz	-	-	-	>40
Ripple current	%	2	2	2	5
Back panel interface	-	DIN41612 type D Male 32 pins	DIN41612 type D Male 32 pins	DIN41612 type D Male 32 pins	DIN41612 type M Male 42 signals pins+ 6 power pins
Weight	kg	0,68	0,68	0,8	0,8
Dimensions	W, L, H mm x mm x mm	Compatible with rack 84F 4H, rack 42F 3H 12F wide, 3H high	Compatible with rack 84F 4H, rack 42F 3H 12F wide, 3H high	Compatible with rack 84F 4H, rack 42F 4H 12F wide, 3H high	Compatible with rack 84F 4H, rack 42F 4H 12F wide, 3H high
Cooling	-	Forced air	Forced air	Forced air	Forced air

■ Table 7.5: Characteristics of the LC75 converters

OEM versions can be customised upon request.

7.4 LA75 LINEAR AMPLIFIER SERIES FOR PIEZO ACTUATORS

■ Figure 7.8: View of the LA75A-3 amplifier

The LA75 series of linear amplifier offer the most usual solution to drive Piezo Actuators. The Linear Amplifier LA75 is designed to drive capacitive loads like Piezoelectric Actuators with extremely low noise. It can perform amplifying operations in the -20/150 V range. The LA75A-x and LA75B-x can be equipped with the push pull option. LA75A-x is a low-power amplifier implanted on a 19' board and can have up to 3 independent channels. LA75B-x is a medium power amplifier implanted on a 19' board and can have up to 2 independent channels.

The LA75C has a much higher current capability, especially for high frequency and/or impulse applications. It shows the highest power capability of the linear amplifiers available on the market.

OEM versions can be customised upon request.

■ Table 7.6: Characteristics of the LA75 amplifier

REFERENCES	UNIT	LA75A-X	LA75B-X	LA75C
Item Code		V-LA75A-x	V-LA75B-x	V-LA75C-x
Notes	-	x : number of channel	x : number of channel	-
Function	-	Linear amplifier for piezo actuators	Linear amplifier for piezo actuators	Linear amplifier for piezo actuators
Max. number of channels	-	3 + Push pull	2 + Push pull	1
Protection	-	Thermal Current limitation Voltage limitation	Thermal Current limitation Voltage limitation	Thermal Current limitation Voltage limitation
Main voltage	VDC	-36 / 165	-36 / 165	-36 / 165
Output voltage	V	-20 / 150	-20 / 150	-20 / 150
Min Output voltage	V	-20	-20	-20
Max Output voltage	V	150	150	150
Voltage Gain	V/V	20	20	20
Continuous max current	mA	90	360	2400
Peak output power	VA	6	20	160
Output load capacitance	µF	400	400	400
Control input voltage	V	-1 ... 7.5	-1 ... 7.5	-1 ... 7.5
Min input voltage	V	-1	-1	-1
Max input voltage	V	7.5	7.5	7.5
Ripple current	%	-	-	-
Total Harmonic distorsion	%	0.1	0.1	0.1
Signal / Noise ratio	dB	85	85	85
Loaded output bandwidth	Hz	109	435	2899
Unloaded output bandwidth	Hz	33000	33000	33000
DC offset setting	-	10 turns potentiometer	10 turns potentiometer	10 turns potentiometer
Min DC offset	V	-1	-1	-1
Max DC offset	V	7,5	7,5	7,5
PZT connector	-	LEMO ERN.00.250.CTL	LEMO ERN.00.250.CTL	LEMO ERN.00.250.CTL
External Sensor connector	-	-	-	-
External Control Input	-	BNC type	BNC type	BNC type
Input impedance	kW	10	10	10
Back panel interface	-	DIN 41612 Male Form C 64/96	DIN 41612 Male Form C 64/96	DIN 41612 Male Form C 64/96
Weight	kg	1	1	0,86
Dimensions	W, L, H mm x mm x mm	Compatible with rack 84F 4H, rack 42F 3H 10F wide, 3H high	Compatible with rack 84F 4H, rack 42F 3H 10F wide, 3H high	Compatible with rack 84F 4H, rack 42F 4H 10F wide, 3H high
Cooling	-	Forced air	Forced air	Forced air
Min-Max ambiant Temperature	°C	0...40	0...40	0...40
Option	-	Push-Pull	Push-Pull	-

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7.5 SWITCHING POWER AMPLIFIER SERIES FOR PIEZO ACTUATORS

The switching power amplifiers are designed to be compatible with the RK rack family and to perform either linear continuous state or purely ON/OFF states on Piezo Actuators with extremely fast actuations. The switching technique allows high current peaks, required by impulse or by high frequency applications on large piezo actuators.

The SA75D is the most powerfull driver for piezo actuator. It integrates the highest level of power technology to drive piezo actuators up to 30 Amps.

It could be integrated in a 42F4H rack for 1 channel (Figure 7.9) or in a 84F4H rack for up to 3 channels. In the 3 channels configuration, 3 independent converters SC75D will be added to supply the 3 SA75D.

The SP75A is a 2 states power driving board (Figure 7.10).
Only two positions can be obtained:

- OFF position at rest (-20 Volt DC),
- ON position (150 Volt DC).

The two positions are controlled by a TTL signal. The overshoot of the Piezo Actuator can be reduced after calibrations of the slew rate. The SP75A-x can be equipped with the Push Pull option.

The Switching Amplifiers have been developped in collaboration with the G2ELAB of UJF Grenoble in the contexte of AVIBUS and PPSMPAB projects.
They can drive large piezo actuators allowing fast power actuation as requested in machine tools or helicopter flap applications.

See table next page.

■ Figure 7.9: View of the SA75D switching power rack

■ Figure 7.10: View of the SP75A-2 switching power

OEM versions can be customised upon request.

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7.5.1 SWITCHING POWER AMPLIFIER SERIES FOR PIEZO ACTUATORS

REFERENCES	UNIT	SA75D	SP75A-X
Item Code		V-SA75D	V-SP75A
Notes	-	Preliminary data	x : number of channel
Function	-	Switching power amplifier for piezo actuators	Switching 2 states power driver for piezo actuators
Max. number of channels	-	1	2
Protection	-	Thermal Current limitation Voltage limitation	Thermal Current limitation Voltage limitation
Main voltage	VDC	0 / 240	-20 / 150
Output voltage	V	-20 / 150	-20 / 150
Min Output voltage	V	-20	-20
Max Output voltage	V	150	150
Voltage Gain	V/V	20	-
Peak current limitation	mA	30000	360
Peak output power	VA	1900	-
Output load capacitance	µH	400	400
Control input voltage	V	-1 ... 7.5	TTL signal / CMOS
Min input voltage	V	-1	0
Max input voltage	V	7.5	5
Ripple current	%	0	-
Total Harmonic distorsion	%	2	-
Signal / Noise ratio	dB	70	-
Loaded output bandwidth	Hz	22508	1513
Unloaded output bandwidth	Hz	22508	-
DC offset setting	-	10 turns potentiometer	-
Min DC offset	V	-1	-
Max DC offset	V	7,5	-
PZT connector	-	LEMO EGH.2B.302.CC	LEMO ERN.00.250.CTL
External Sensor connector	-	Voltage monitoring BNC type Current monitoring BNC type	-
External Control Input	-	BNC type	BNC type
Input impedance	kW	10	10
Back panel interface	-	DIN41612 type M Male 42 signals pins+ 6 power pins	Din 41612 Male Form C 64/96
Weight	kg	-	0,5
Dimensions	W, L, H mm x mm x mm	Compatible with rack 84F 4H, rack 42F 4H 12F wide, 3H high	Compatible with rack 84F 4H, rack 42F 3H 18F wide, 3H high
Cooling	-	Forced air	Natural convection
Min-Max ambiant Temperature	°C	0...40	0...40
Option	-	Actuator temp. Sensor LEMO EPG-00-302-NLN	RS422 communication

■ Table 7.7: Characteristics of the switching power amplifier

7.6 SWITCHING PIEZO CONTROLLER SPC45

The Stepping Piezo Controller SPC45 is an off the shelf driver & controller dedicated to LSPA, LSPS & RSPA motors. It has been built to offer large possibilities to designers, from fast motion to fully controlled motion. In addition to previous functions, it includes a friendly PC software interface, as well as USB serial port to meet every designer's requirements.

The software allows the user to select the most efficient signal according to its need (speed, force, step size...) and to manage the closed loop when position sensor is used.
For OEM applications, the SPC45 can be easily adapted to meet customers' requirements.
It is supplied by a 12V to 24V AC/DC converter.

The LSPA30uXS piezo motor kit presented in section 9.3 gives an example of application of the SPC45 controller.

■ Figure 7.11: Stepping Piezo Controller SPC45

■ Table 7.8: Characteristics of the SPC45 ▶

REFERENCES	UNIT	SPC45
Item Code		V-SPC45
Notes	-	-
Function	-	Standalone Digital Servo Drive for Stepping Piezo Actuator
Max. number of channels	-	1
Protection	-	Thermal Overcurrent
Main voltage	V	12 - 24VDC
Output voltage	V	0.1 / 100
Min Output voltage	V	0,1
Max output voltage	V	100
Amplifier Gain	V/V	20
Continuous max current	mA	150
Peak output power	VA	7
Output load capacitance	µF	1
Control input voltage / Measurement range	V	0 ... 5
Min input voltage	V	0
Max input voltage	V	5
Signal / Noise ratio	dB	83
Order input range	V	0 ... 5
Analog to Digital Resolution	Bits	16
Sensor output range	V	0 ... 5
Digital to analog Resolution	Bits	16
Sampling rate	kS/s	10
PZT connector	-	ERNI Mini bridge series 8pins Right angle male pitch 1.27 mm
External Sensor connector	-	ERNI Mini bridge series 8pins Right angle male pitch 1.27 mm
External Control Input	-	ERNI Mini bridge series 8pins Right angle male pitch 1.27 mm
Input impedance	kOhms	>1000
Weight	kg	0,1
Dimensions	W, L, H mm x mm x mm	91 x 66 x 22
Cooling	-	Natural convection
Option	-	Position Sensor
Computer interface	-	USB compatible

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■ Figure 7.12: LC24A AC/DC converters for magnetic actuators

7.7 24 SERIES AC/DC CONVERTER FOR MAGNETIC ACTUATORS

CEDRAT TECHNOLOGIES has implemented the LA24 series of linear magnetic amplifier in its 19'cabinet in order to drive magnetic actuators.

AC/DC converters of the 24 family are designed to produce stabilised DC voltages which are necessary to supply the magnetic amplifiers. AC/DC converters use the mains as primary source. The LC24A AC/DC converter is used in the standard configuration.

REFERENCES	UNIT	LC24A	SC24
Item Code		V-LC24A	V-SC24
Notes	-	-	-
Function	-	Bipolar AC/DC linear converter for magnetic actuators	Bipolar AC/DC switching converter for magnetic actuators
Protection	-	Thermal Overcurrent Overvoltage	Thermal
Main voltage	VAC	110 - 263	110 - 263
Max current	A	0,6	2,8
Main frequency	Hz	47-63	47-63
Regulated direct voltage	VDC	-65 / 65	-48 / 48
Min regulated direct voltage	VDC	-65	-48
Max regulated direct voltage	VDC	65	48
Continuous or Peak Current Limitation	A	1,4	5,2
Maximal output power (peak)	W	20	250
Switching frequency	kHz	-	>100kHZ
Ripple current	%	2	NA
Back panel interface	-	DIN41612 type D Male 32 pins	DIN41612 type D Male 32 pins
Weight	kg	0,68	1,18
Dimensions	W, L, H mm x mm x mm	Compatible with rack 84F 4H, rack 42F 3H 12F wide, 3H high	Compatible with rack 84F 4H, rack 42F 3H 12F wide, 3H high
Cooling	-	Forced air	Forced air

■ Table 7.9: Characteristics of the Power supply converters for the 24 series

This bipolar power supply produces to symmetric high voltage with large current.

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7.8 LA24 LINEAR AMPLIFIER FOR MAGNETIC ACTUATORS

The Linear Amplifier LA24 is designed to drive inductive loads like Magnetic Actuators with extremely low noise. LA24A-x is a low-power amplifier implanted on a 19' board and can have up to 3 independent channels. It can perform amplifying operations in the -46/46 V range with up to 1400mA output current.

■ Figure 7.13: LA24A linear amplifier for magnetic actuators

REFERENCES	UNIT	LA24A-X
Item Code		V-LA24-x
Notes	-	x : number of channel
Function	-	Linear amplifier for magnetic actuators
Max. number of channels	-	3
Protection	-	Thermal Current limitation Voltage limitation
Main voltage	VDC	-65 / 65
Output voltage	V	-46 / 46
Min Output voltage	V	-46/-40 with LC24/SC24
Max Output voltage	V	46/40 with LC24/SC24
Current Gain	A/V	0,15
Peak current limitation	mA	1400
Peak output power	VA	100
Output load inductance	mH	100
Control input voltage	V	-10 ... +10
Min input voltage	V	-10
Max input voltage	V	10
Ripple current	%	-
Total Harmonic distorsion	%	0,1
Signal / Noise ratio	dB	85
Loaded output bandwidth	Hz	63
Unloaded output bandwidth	Hz	33000
DC offset setting	-	10 turns potentiometer
Min DC offset	V	-10
Max DC offset	V	10
PZT connector	-	EPG.0B.302.HLN
External Sensor connector	-	- Current monitoring
External Control Input	-	BNC type
Input impedance	kW	10
Back panel interface	-	Din 41612 Male Form C 64/96
Weight	kg	1
Dimensions	W, L, H mm x mm x mm	Compatible with rack 84F 4H, rack 42F 3H 10F wide, 3H high
Cooling	-	Forced air
Min-Max ambiant Temperature	°C	0...40
Option	-	

■ Table 7.10: Characteristics of the LA24 amplifier

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8. SELECTION GUIDE FOR SENSORS & ELECTRONIC CONTROLLERS FOR PIEZO ACTUATORS

8.1 SELECTION GUIDE

For fine motion control, CEDRAT TECHNOLOGIES proposes several solutions in terms of sensors and controllers.

These sensors and controllers are generally used for close loop control to achieve fine motion control. They are compatible with piezo and magnetic actuators (chapter 4 to 6), as well as the drive electronics (chapter 7) from CEDRAT TECHNOLOGIES.

With this offer, the customer can build its own system according to its needs (Table 8.1 and Table 8.2) by combining a driver, a sensor and a controller.

Two kinds of sensor technology are available:

Strain Gauges (SG) are contact sensors measuring deformation. They are a standard option in piezo actuators (APA, MLA, PPA) and in some piezo mechanisms (TT, XY...). Although not standard, they can be used in magnetic actuators if elastically guided.

Eddy Current Sensors (ECS) are contacless sensors measuring position. They are a standard option in some piezo mechanisms (TT, DTT, XY). They can be used also with piezo and magnetic actuators.

Both technologies are further presented in the sections 8.2 (probes) and 8.3 (conditioners).

Other commercial sensors could be used in interface with our products (capacitive sensors...)

SENSORS			
Model serie	Unit	Strain gauges + SG75	PC-x + ECS75
Notes	-	-	-
Type	-	"Contact Resistive "	"Contactless Eddy current"
Function	-	"Strain Gauges conditioner"	Eddy current sensor conditioner with linear output
Resolution	-	☺	☺☺
Linearity	-	☺☺	☺
Thermal behaviour	-	☺	☺☺
Bandwidth	-	☺	☺
Number of channels	-	3	2

CONTROLLERS				
Model serie	Unit	UC45	U65	UC75
Notes	-	-	-	-
Function	-	µ-controller based Real-Time controller	DSP-based Real-Time controller	FPGA-based Real-time Open platform
Sampling rate	kS/s	10	60 @ 1 channel 20 @ 3 channels	typ. 30 @ 3 channels
Capabilities	-	☺	☺☺	☺☺☺
Number of channels	-			Program up to 3 millions of gates - 8 Dig-Ana slots
Thermal behaviour	-	☺	☺☺	
Bandwidth	-	☺	☺	
Number of channels	-	3	2	

Three types of controllers are proposed by CEDRAT TECHNOLOGIES. The choice between these controllers depends on the required control bandwidth, the number of channels and the required computation power.

The UC45 control board can be plugged to an amplifier board and integrates a one channel low-frequency digital controller and a link to a host PC. This link is managed through a hub on the 75 Rack Family to handle several channels (up to 3).

The UC65 control board is based on a DSP core, and can control up to three channels in a standard control configuration with more speed than UC45. This controller is well adapted for matrix control of piezo mechanisms which requires processing. As for UC45, a link to a host PC allows to modify the parameters of the control.

The UC75 control board is a powerful platform based on Labview® Real-Time offering the state of the art in digital control and the capability to handle several channels. This open plateform is usefull to fit with your needs. In this case, CEDRAT TECHNOLOGIES could adapt the software to your specifications.

Additionally a GUI is delivered including possibilities of tuning laws.

Please do not hesitate to contact CEDRAT TECHNOLOGIES by phone or email at **actuator@cedrat-tec.com** for more detailed information and help in the selection of your configuration.

CEDRAT TECHNOLOGIES sensors and electronics are compatible together with actuators and interact to form complete mechatronic systems offering motion control.

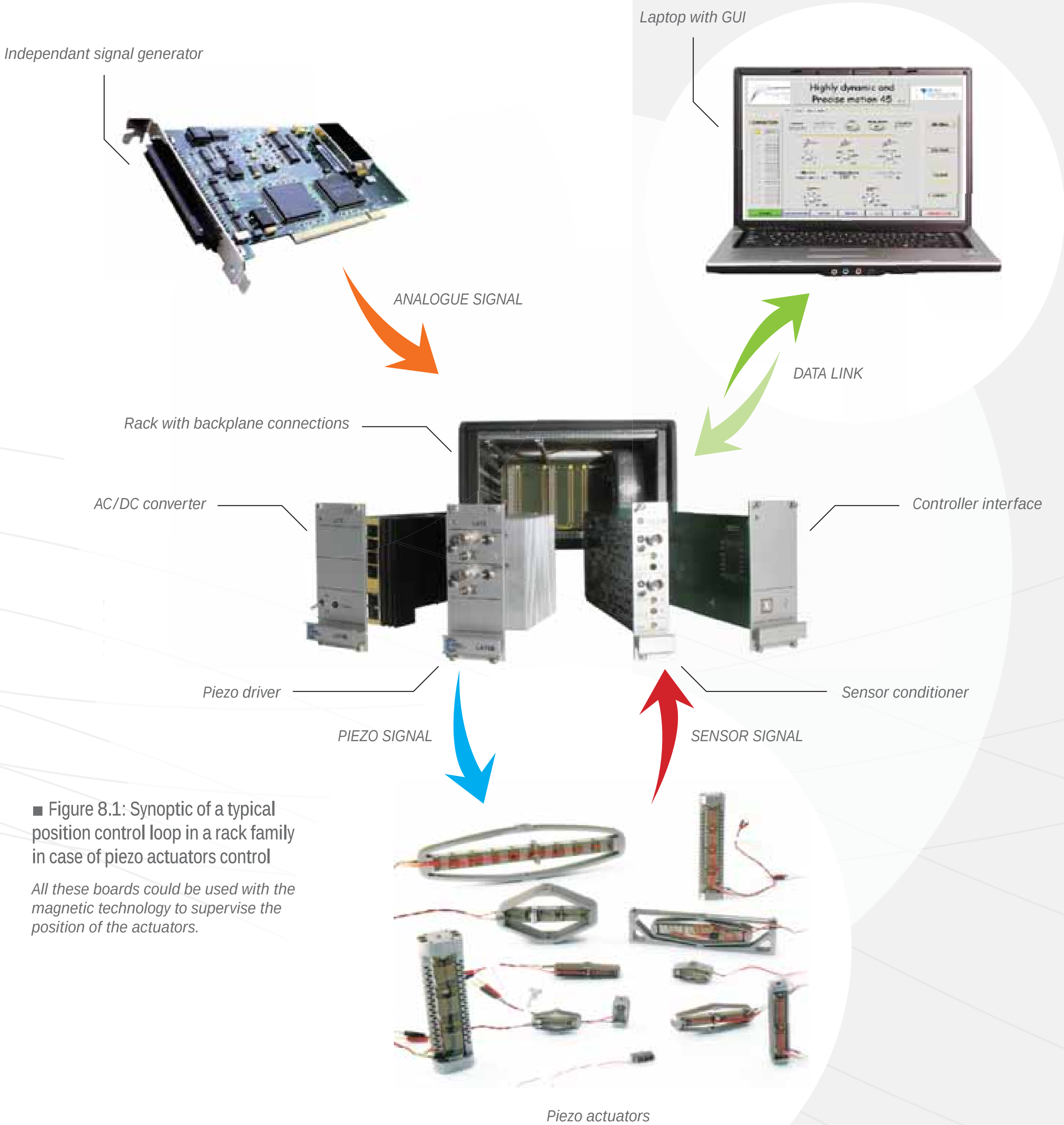
The sensor conditioner features a Transducer Electronic Data Sheet (TEDS) function monitored by the UC45 & UC65 controllers (Figure 8.1). The TEDS function relies on a memory integrated inside the conditioner board, storing the gain of the sensor and other calibration data. Hence, the controller is automatically able to read this memory.

Other sensors from the market than SG and ECS, such as incremental magnetic sensors (MAG), optical encoders, accelerometers, capacitive sensors, end-of-stroke detectors, thermal sensors... can be easily coupled to CEDRAT TECHNOLOGIES controllers.

◄ Table 8.1: Selection guide for sensors and controllers

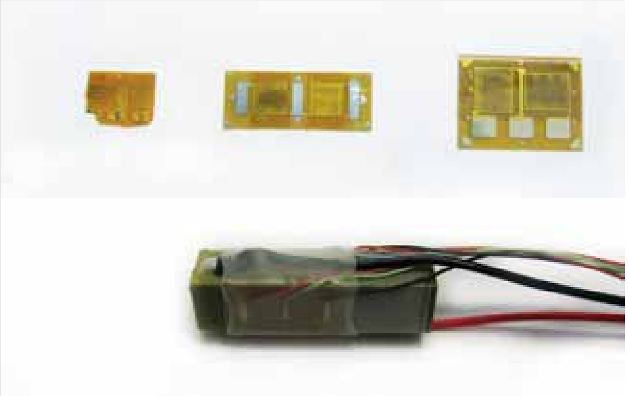
The sensor conditioning boards and the control boards can be implemented in the RK racks in combination with AC-DC converters and amplifiers to get a complete closed loop system.

Examples of such combinations are given in chapter 9, where demo kits and evaluation packs are presented.



■ Figure 8.1: Synoptic of a typical position control loop in a rack family in case of piezo actuators control

All these boards could be used with the magnetic technology to supervise the position of the actuators.



■ Figure 8.2: Strain gages implemented into piezo actuators

8.2 SENSOR PROBES

The mechatronic demands more and more precise motion in compact volume. Actuators have been designed to answer to these problematic of compact integration and accuracy for several years. Nevertheless, positioning sensors available on the market can hardly keep pace with the accuracy demand when scaling down the mechatronic system size.

That is why CEDRAT TECHNOLOGIES has developed two kinds of sensor for answering to this problematic of accuracy/resolution requirement in compact size.

These kinds of probes could be used with standard product of the RK family:

- Strain gage sensor (SG) using strain gages directly mounted on the piezo ceramic to measure the strain on the MLA: This is a contact sensor,
- Eddy current sensor (ECS) using the eddy current effect mounted in regards of the displacement: This is a contactless sensor.

REFERENCES	UNIT	STRAIN GAUGES	PLANAR COIL-500	PLANAR COIL-2000
Item Code		V-SG	V-PC500	V-PC2000
Notes	-	-	Preliminary data	Preliminary data
Type of measurement	-	Contact Resistive	Contactless Eddy current	Contactless Eddy current
Applications	-	Contact position sensor Contact strain / force sensor	Contactless position sensor Contactless force sensor	Contactless position sensor Contactless force sensor
Type of conditionning	-	Full Wheastone bridge Push pull Wheastone bridge	Single ended Differential	Single ended Differential
Excitation voltage	V	2.5 ... 10	5	5
Excitation Frequency	Hz	DC	4M	1M
Output voltage	mV	-10 ... 10	0 ... 5000	0 ... 5000
Maximum Stroke	ppm µm	2000 -	- 500	- 2000
Electrical interface	-	4 wires Flex connexion	2 wires SMC 50Ohms	2 wires SMC 50Ohms
Temperature range	°C	-75 ...95	-45 ...150	-45 ...150
Dimensions	mm	Mounted on Multi Layer ceramics	diam7 x 5, height 0.8 Diameter 7, lenght 20	diam7 x 5, height 1.8 Diameter 7, lenght 20
Option	-	-	High integration package Stand alone package	High integration package Stand alone package

■ Table 8.2: Characteristics of the sensor probes

Strain gauges are standard sensor probes in industry and they are bonded on the MLA piezo ceramic, this is why we call it contact sensor (Figure 8.2).

It is commonly known that the strain gauge transforms strain applied into a proportional change of resistance. The relationship between the applied strain ε (ε=ΔL/Lo) and the relative change of the resistance of a strain gauge is described by the equation :

$$\frac{\Delta R}{R_0} = k.\varepsilon$$

where k is the gauge factor of the strain gauges.

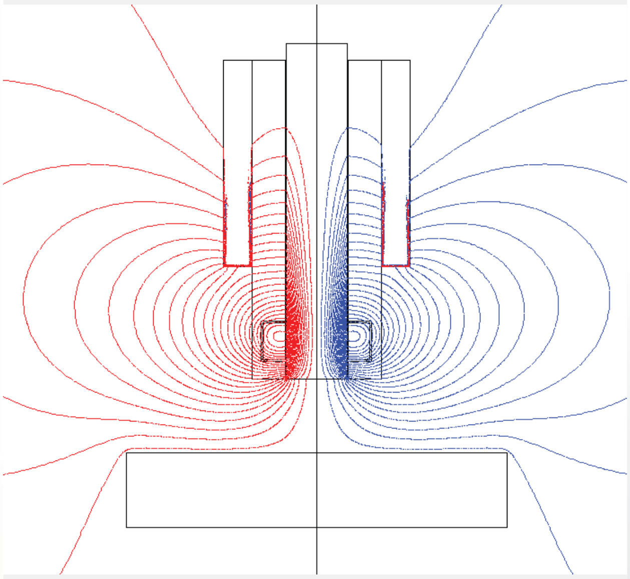
Mounted in a Wheatstone bridge (Figure 8.2), the small variation of resistance is converted in a variation of voltage directly conditioned for the position control loop.

Eddy Current Position Sensor (ECS) are able to sense nano-metric position in the sub-millimetric range. The challenge was to reduce the overall volume and so to implement the probe on a standard Printed Circuit Board in respect to the optimal performances.

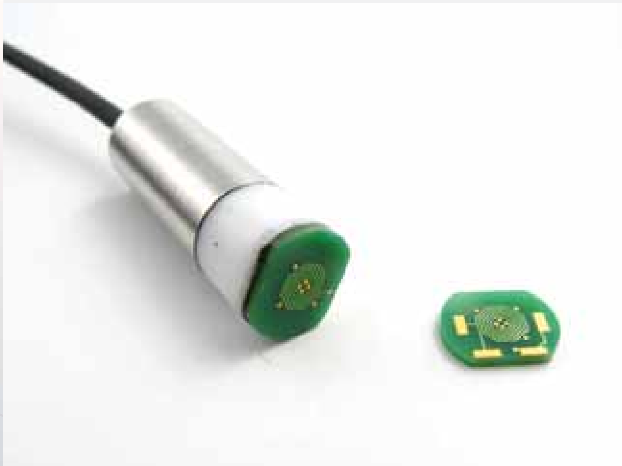
The physical model of measurements (Figure 8.3a) consists of the target object and the main component of the sensor that is an induction coil. When an alternating voltage or current is applied to the induction coil, it generates an oscillating magnetic field, which induces eddy currents on the surface of the conductive target, according to the principle of eddy current induction. Eddy currents circulate in a direction opposite to that of the coil, reducing the magnetic flux in the coil and thereby its inductance. Eddy currents also dissipate energy, and therefore lead to a resistance increase of the coil. For high-precision measurements, preferable applications should make use of nonmagnetic conductive target materials like Aluminium or stainless steel

The PC-x could be used for two ranges meeting your stroke request. Additonally standalone or high integration packaging exist and could be chosen depending on your application (Figure 8.3b).

The probe of the strain gauge sensor is well adapted for application requiring resolution and linearity. The Eddy current sensor probe is well adapted for contactless application requiring higher resolution and a contactless sensing area.



■ Figure 8.3a: Physical principle of an Eddy current sensor probe



■ Figure 8.3b: View of a PC-x in standalone or high integration packaging

■ Figure 8.4: View of a SG75-1 board

8.3 SENSOR CONDITIONERS

After selecting the right probe for your application, the dedicated conditioner shall be chosen to be compatible with the selected probes.

8.3.1 STRAIN GAUGES CONDITIONER

The SG75 Strain Gauges conditioner uses the signals issued from the strain gauges probe and is implemented on a 19' board. It can include up to 3 independent channels. The conditioners should normally drive full Strain Gauges bridges.
The gain of each channel is generally set when the Strain Gauges bridges are bonded onto the Piezo Actuators. This board can be provided alone in an RK12F rack.

REFERENCES	UNIT	SG75-X
Item Code		V-SG75-x
Notes	-	x : number of channel -
Function	-	Strain Gauges conditioner
Max. number of channels	-	3
Main voltage	VDC	-15 / +15
Max current	A	-
Output voltage	V	-12 ... 12
Min output voltage	V	-12
Max output voltage	V	12
Resolution	% of FS	0,01
Bandwidth	kHz kS/s	15
Accuracy - Linearity	+/- % of FS	0.25
Accuracy - Thermal Offset drift	% FS / °C	0,1
Accuracy - Thermal gain drift	% FS / °C	0,1
DC offset setting	-	10 turn potentiometer
Min DC offset	V	-12
Max DC offset	V	12
External Sensor output connector	-	LEMO EGG.00.304.CLL
External output connector	-	BNC
Main voltage connector	-	-
Back panel interface	-	DIN 41612 Form C 64/96
Weight	kg	0,18
Dimensions	W, L, H mm x mm x mm	Compatible with rack 84F 4H, rack 42F 3H or 4H 6F wide, 3H high
Option	-	Differential measurements Synchronization of sensors

■ Table 8.3: Characteristics of the SG75 Strain Gauges conditioner

8.3.2 EDDY CURRENT SENSOR CONDITIONER

The Eddy Current Sensor conditioners manage the signal from the Eddy current probe PC-x:

- The ECS75-x is an Eddy Current Sensor that could be implemented on a 19'board, offering up to 2 independent channels.
- The ECS75OEM is an OEM version which is integrated in a rack 12F supplied by an external DC power supply.

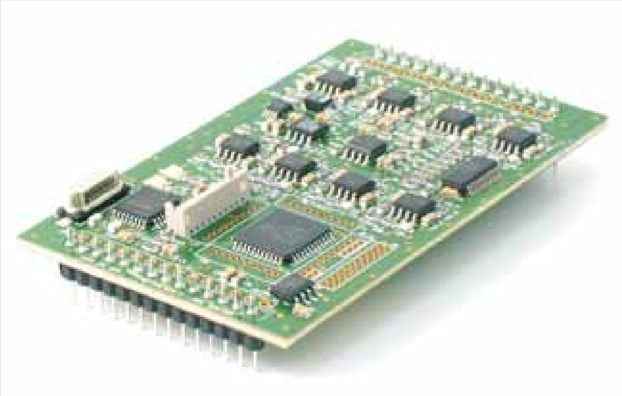
Both these conditioners linearise the output from the PC probe with a high order polynomial function programmed in a digital component. In option, differential function and probes synchronisation are possible. The gain of each channel is generally set when the Eddy Current probe is embedded in the mechanism.

The ECS-u10 is a cost-effective conditioner. It is built around the input analogue stage of the ECS75 board but without the digital stage performing the linearization. It includes only one channel but in option differential measurement and synchronisation are possible.

■ Figure 8.5: View of a ECS75-2 board

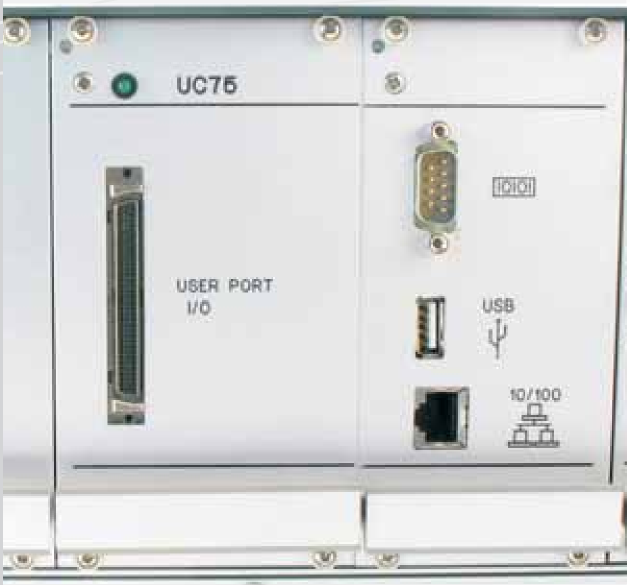
■ Table 8.4: Characteristics of the Eddy Current Sensor conditioner

REFERENCES	UNIT	ECS75-X	ECS75OEM-X	ECS-U10
Item Code		V-ECS75-x	V-ECSOEM75-x	V-ECS-u10
Notes	-	x : number of channel -	x : number of channel Preliminary data	- Preliminary data
Function	-	Eddy current sensor conditioner with linear output	Eddy current sensor conditioner with linear output	Eddy current sensor conditioner with nonlinear analog voltage/current output
Max. number of channels	-	2	2	1
Main voltage	VDC	-15 / +15 / +5	9 - 24	12 - 15
Max current	A	0.25 / 0.4 / 0.3	1.2 - 0.6	0.1 - 0.12
Output voltage	V	-10 ... 10	-10 ... 10	0 ... 10
Min output voltage	V	-10	-10	0
Max output voltage	V	10	10	10
Resolution	% of FS	0,005	0,005	0,001
Bandwidth	kHz kS/s	10	10	15
Accuracy - Linearity	+/- % of FS	1	1	25
Accuracy - Thermal Offset drift	% FS / °C	TBD	TBD	TBD
Accuracy - Thermal gain drift	% FS / °C	0,1	0,1	0,1
DC offset setting	-	10 turn potentiometer	10 turn potentiometer	10 turn potentiometer
Min DC offset	V	-12	-12	-10
Max DC offset	V	12	12	0
External Sensor output connector	-	SMC 50Ohms	SMC 50Ohms	SMC 50Ohms
External output connector	-	BNC	BNC	DB9 Male
Main voltage connector	-	-	2 ways RCA	DB9 Male
Back panel interface	-	DIN 41612 Form C 64/96	-	-
Weight	kg	0,2	1,2	0,06
Dimensions	W, L, H mm x mm x mm	Compatible with rack 84F 4H, rack 42F 3H or 4H 6F wide, 3H high	12F, 3H, 260mm 12F rack 89x260x129	Box packaging 66 x 66x 28
Option	-	Differential measurements Synchronization of sensors	Differential measurements Synchronization of sensors	Differential measurements Synchonization of sensors PCB mounting with 1.27 pitch for right pins connectors Comparator output



■ Figure 8.7: View of a UC45 board

■ Figure 8.8: View of a UC45 hub



■ Figure 8.9: View of a UC75 board

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8.4 DIGITAL CONTROLLERS

When your application needs a close loop, CEDRAT TECHNOLOGIES offers different solutions built around digital controllers with more or less versatility and capabilities.

The UC45 digital controller is implemented as an option on the amplifier board (Figure 8.7). The UC45 is a digital adjustable PID controller with selectable output filter. It can control one channel with a sampling rate of 10KHz. The bandwidth is set by the sampling rate.
When used in the RK family rack, the UC45 features also a USB link to an external PC, in order to read and set the control parameters (Figure 8.8). The UC45 comes with the HDPM45 GUI, downloadable on our web site. From the HDPM45, it is possible to adapt your control by changing the values of the PID controller, the type of filters (2nd /4th orders low pass filter or notch filter) and the limitation of output voltage to limit the damage on piezo actuator during tuning process.

The UC65 controller is a board that can be plugged in the 75 family rack (Figure 8.10). It is based on a powerful DSP core, and it can control several independent or coupled channels. The UC65 can implement a very fast control loop with sampling

REFERENCES	UNIT	UC45
Item Code		V-UC45
Notes	-	-
Function	-	µ-controller based Real-Time controller
Max. number of channels	-	1
Main voltage	VDC	-15 / +15 / +5
Input voltage range	V	-10 ... 10
Analog to Digital Resolution	Bits	16
Output voltage range	V	-10 ... 10
Digital to analog Resolution	Bits	16
Option inputs		Incremental encoder inputs
Sampling rate	kS/s	10
Control possibilities	-	PID, 2nd order Low pass filter, 2nd order Notch filter, 4th order Notch filter, 2 x 2nd order Notch filters
Electrical interface	-	2 lines of Male headers 2.54mm pitch
Weight	kg	0,05
Dimensions	W, L, H mm x mm x mm	Compatible with LA75x, SA75x boards PCB Board 50 x 70
Option	-	PCB mounting 2 channels only for ECS equiped mechanisms
Computer interface	-	USB compatible

rates up to 60KHz for one channel. It has a USB connector on its front panel, so that it can be connected to a computer. It is fully compatible with the free GUI interface HDPM45, where the control parameters can be visualised and adjusted with the same possibilities as explained for the UC45 and the dedicated HDPM45.

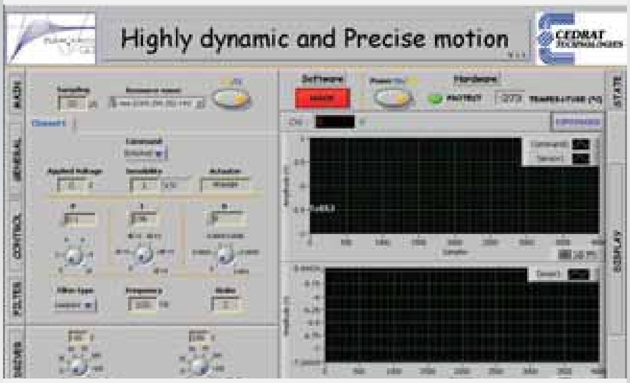
The versatile UC75 real time platform uses a National Instrument Core based on Compact RIO@NI and the power of Labview® from National Instruments Libraries to control any system. The NI CompactRIO programmable automation controller (PAC) is a low-cost reconfigurable control and acquisition system designed for applications that require high performance and reliability. The native parallelism of graphical programming is the best alternative solution to the physical implementation of FPGAs. Indeed parallel loops map used to separate regions of FPGA silicon truly operate in parallel.

The UC75 (Figure 8.9) can be connected to a host PC to analyse the behaviour of the system in real time, to adjust the parameters of the control loops via an Ethernet link at 100Mbytes/s or to work standalone. The standard offer comes with the HDPM75 front panel executed on a PC (Figure 8.11). The last version can be downloaded from our web site.

UC65-X	UC75-X	HUB
V-UC65	V-UC75	V-HUB
Preliminary data x : number of channel	x : number of channel	-
DSP-based Real-Time controller	FPGA-based Real-time Open platform	USB concentrator for UC45 controllers
3	Program up to 3 millions of gates - 8 Dig-Ana slots	3 in standard, up to 4
-15 / +15 / +5	-15 / +15 / +5	+5
-10 ... 10	-10 ... 10	-
16	16	-
-10 ... 10	-10 ... 10	-
16	16	-
Incremental encoder inputs	Compatible with National Instrument products range	-
60 @ 1 channel 20 @ 3 channels	typ. 30 @ 3 channels	-
PID, 2nd order Low pass filter, 2nd order Notch filter, 4th order Notch filter, 2 x 2nd order Notch filters	Open plateform to fit with your needs	-
DIN 41612 Forme C 64/96	DIN 41612 Forme C 64/96	USB port on front face
0,2	1,3	0,08
Compatible with rack 42F 3H or 84F 4H 6F wide, 3H high	Compatible with rack 84F 4H 26F wide, 3H high	Compatible rack 42F 3H or 4H or 84F 4H 10F wide, 3H high
-	-	-
USB compatible	Ethernet link 10-100 Mb/s	USB comptaible

■ Table 8.5: Characteristics of Digital controllers

■ Figure 8.10: View of a UC65 board



■ Figure 8.11: View of the Software HDPM 75 front panel

If you have the Labview® Real Time software, you can have a flexible platform and you can make it communicate with other sub-systems. CEDRAT TECHNOLOGIES could develop the specific software for your application thanks to its competences in mechatronics.

9. MECHATRONIC SOLUTIONS

CEDRAT TECHNOLOGIES also proposes different types of complete mechatronic solutions:

- Kits for evaluations or for developments
- Turn-key mechatronic modules for machine tools

The mechatronic kits can be seen as first plug and play solutions to discover and to practice different aspects of piezo mechatronic for different purposes. For instance, are presented in the following paragraphs:

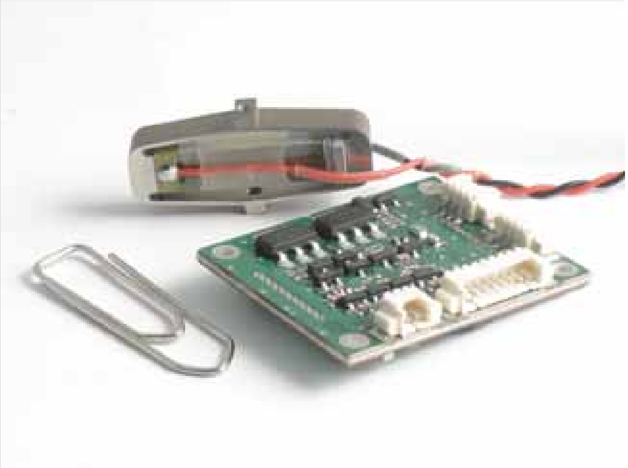
- the EP120S : an evaluation pack for low cost access and practice of piezo actuator & driver
- the ACV Edu kit : an active control of vibrations set up for educational purpose
- the LSPA30uXS Dev kit : a developer kit to experience miniaturised LSPA piezo motor and its controller

The turn-key mechatronic modules for machine tools include:

- the SPT : Servo Piezo Tools for fast position of tools in turning operation
- the VTH : Vibrating Tool Holders for Vibration Assistance in machine tool applications

Beyond and through the availability of these complete mechatronic solutions as off the shelves products, CEDRAT TECHNOLOGIES shows its capabilities to master the development of any mechatronic systems including an actuator, a sensor and a controller for different industrial applications requiring compact, dynamic and precise solution.

9.1 EVALUATION PACK EP120S



■ Figure 9.1: Evaluation Pack EP120S: APA120S actuator & Cau10 amplifier

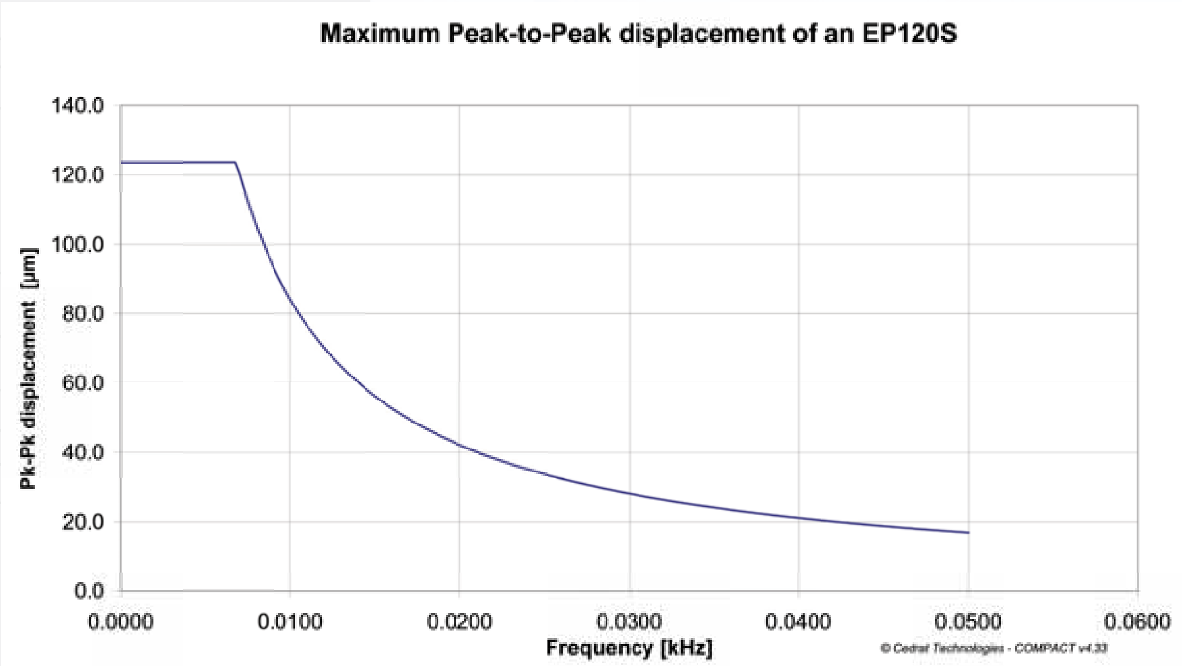
The evaluation pack provides with an easy evaluation of CEDRAT TECHNOLOGIES's piezo offer in quasi static conditions (Figure 9.1). It includes:

- An amplified actuator APA120S
- A linear amplifier CA-u10
- Related Cables

The actuator APA®120S can bear load up to 0.5 kg over 140µm and in a compact size.
The CA-u10 can deliver a voltage up to 150V and has 2 channels.

Please refer to the data sheet of APA®120S actuator and CAu10 amplifier for technical specifications and drawings.

The typical diagram stroke/frequency of the EP120S is presented here below:



The main features enlightened by the evaluation pack are:

- A high stiffness of the actuator
- A nanometer resolution
- A good repeatability
- An excellent reliability
- An easy implementation
- A low cost of ownership

9.2 EDUCATIONAL KIT ACV (ACTIVE CONTROL OF VIBRATIONS)

A real opportunity for students to DISCOVER mechatronics & piezoelectricity.

AN UP TO DATE TOPIC...

In the actual industry, a growing number of enquiries deals with mechatronics and particularly Active Control of Vibrations. Stabilization of wafers during lithography process, noise reduction of helicopter blades, elimination of motion blur in optical devices, damping of machine tool vibrations... are few examples of industrial applications.

AN INNOVATIVE SETUP...

The kit contains an original and innovative amplified piezo actuator APA®, patented technology from Cedrat Technologies attached to a mechanical beam (Figure 9.2). When the beam is externally excited, the vibrations are measured with a precise accelerometer. The control is realized with an industrial driver & controller from CEDRAT TECHNOLOGIES using variable PID parameters and additional filters. The controller drives the piezo actuator in order to cancel the vibrations of the beam. The result is very visual and impressive!

MADE BY TEACHERS FOR STUDENTS...

Developed with CETIM, a centre of excellence in mechanics, SUPMECA and Polytech Annecy-Chambéry, two recognized engineering schools, it fits the curricula of many engineering courses, especially the ones in the forefront of mechanics, mechatronics, control systems and industrial data processing.
The material is delivered with several practical works from 4 to 8 hours developed by teachers (Figure 9.3).
It is easy and fast to set up. The treated topics are required know how for engineers: system analysis, PID control, signal post treatment, modal analysis...

ROBUST EQUIPMENT...

Similarly to the whole range of products of CEDRAT TECHNOLOGIES, the kit is extremely robust. It is well protected against mishandlings which relieves students and teachers when using the material.

■ Figure 9.2: Educational Kit ACV

■ Figure 9.3: Two Practical Works included with the Educational Kit ACV

ALREADY AWARDED...

The Educational Kit received the first price (Figure 9.4) in the University Challenge 2011 organized by Bruel&Kjaer for the project relative to "Study and control of the vibration behaviour of a ski".

■ Figure 9.4: Laureate at B&K University Challenge 2011

MORE INFORMATION
The written practical works in PDF, the precise description of the material and videos can be downloaded on our website:
www.cedrat-technologies.com

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9.3 LSPA30uXS PIEZO MOTOR DEVELOPER KIT

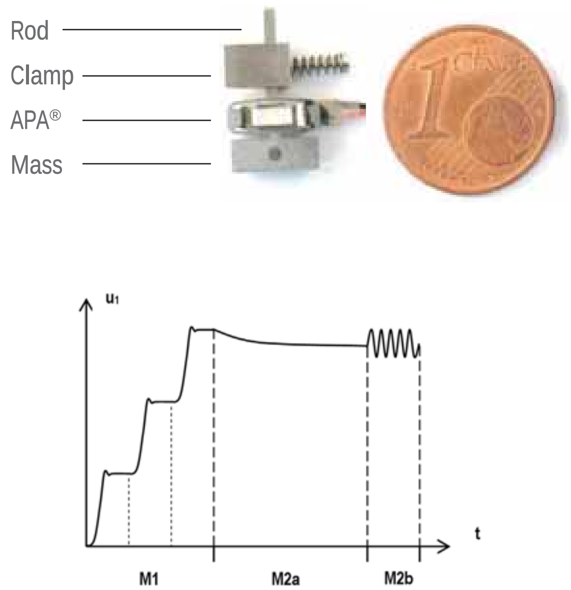
Linear Stepping Piezo Actuators (LSPA) are long stroke linear piezoelectric motors for high precision positioning (see 2.6). Classified as inertial piezo actuators, they benefit from the APA® heritage, especially from their large deformation and high reliability. LSPA operates by accumulation of small steps (M1), produced by a sawtooth-like signal (Figure 9.5). Between each step, the motor (see section 5.9) is locked in position and that, without any consumption. As a complementary mode, fine adjustment (M2) of the APA® allows to reach nanometre resolution.

The LSPA30uXS Developer kit offers the possibility to discover the potential of the LSPA30uXS, smallest existing LSPA, in stepping mode (M1). With an external dedicated miniature driver (SPC45), and coupled to a high resolution magnetic sensor, the Developer kit is a fully closed-loop solution for high resolution millimetre motion (see section 7.6).

The LSPA30uXS Developer kit is made of different sub-systems (Figure 9.6):

1. LSPA30uXS kit (LSPA30uXS motor coupled with an incremental sensor on a holding platform)
2. SPC45 driver
3. SPC45 Power Supply
4. Cables
5. USB cable for GUI control

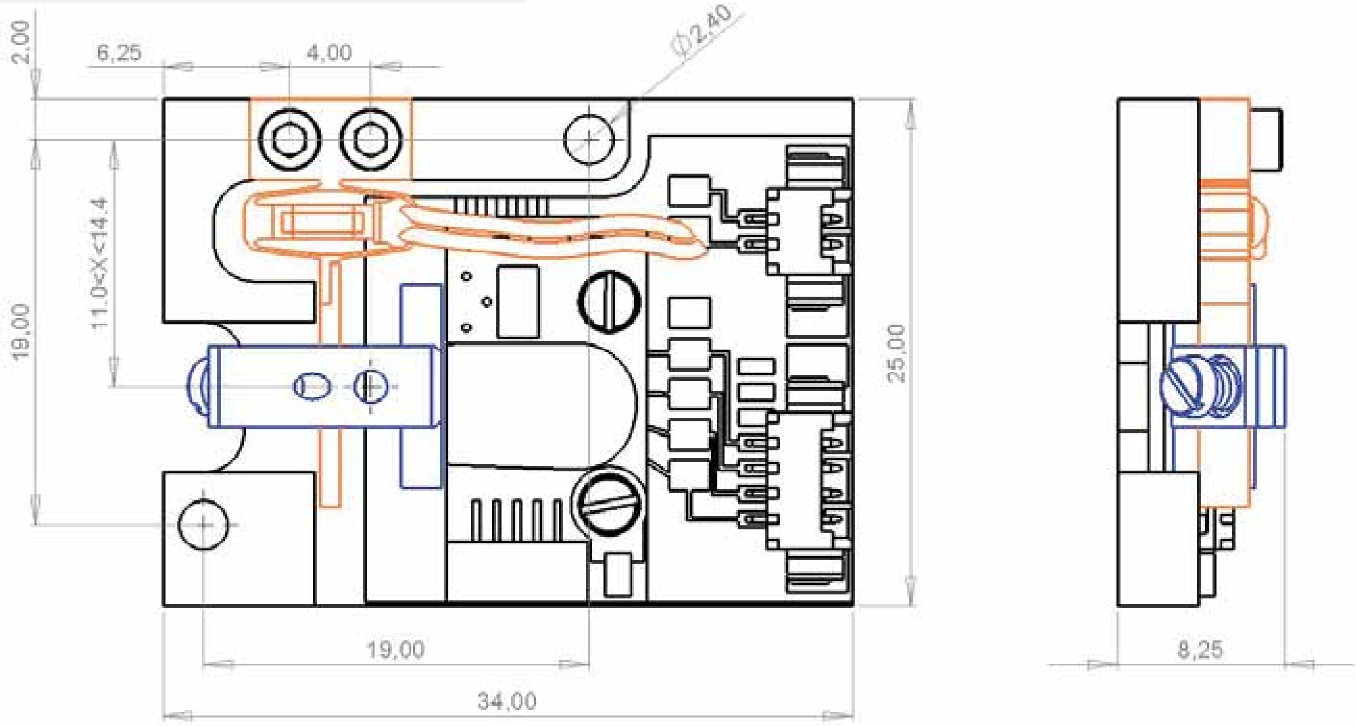
See mechanical configurations and interfaces next page...



■ Figure 9.5: LSPA30uXS components and principle

■ Figure 9.6: Components of the LSPA30uXS developer kit

The Developer kit is a plug and play solution. It allows learning quickly how to use the LSPA motor. The LSPA30uXS motor can be extracted from the holding platform and integrated directly onto the user's test bench.



■ Mechanical configuration, with fixed (orange) and mobile part (blue) of the motor

The dedicated driver, the "Stepping Piezo Controller" SPC45 (Figure 9.7) has been built to offer large possibilities to designers, from fast motion setup to completely controlled movement. Both USB interface and serial port are available to meet every designer's requirements.

■ Table 9.1: Characteristics of the LSPA30uXS Developer Kit ▶

REFERENCES	UNIT	LSPA30UXS DEVELOPER KIT
Item Code		
Notes		-
Sensor		MAG
Base		APA30uXS
Stroke	mm	3,4
Stiffness1	N/µm	0,11
Sensor Resolution	µm	2,00
Max speed	mm/s	30
Typical Holding Force at rest	N	0,8
Typical actuation force	N	0,2
Short high resolution stroke	µm	42
Capacitance	µF	0,052
Height along active axis	mm	8,25
Base size	mm	34 * 25
Mass	g	8,1
DC input voltage	V	12
Max input current (incl. Driver)	A	0,4
Holding consumption	A	0
Electrical interfaces		ERNI 8 broches CMS

9.4 DEDICATED MECHATRONIC SOLUTIONS FOR MACHINE TOOLS

Several dedicated mechatronic modules have been developed by CEDRAT TECHNOLOGIES for machining and production application.

SPT are Servo Piezo Tools for fast position of tools in turning operation (figure 9.8). They can move the lathe cutting tool with stroke up to in 500µm.
This SPT module includes a position sensor and is driven by a powerful drive and control electronics allowing the precise control of the tool on a several hundred hertz frequency bandwidth.

Applications of SPT concerns oval piston machining, aspherical lens machining, free-form optics.
Please contact us or visit our web site to get more.

VTH are Vibrating Tool Holders for Vibration Assistance in machine tool and production applications.

VTH developed for vibration assisted drilling (figure 9.9) perform chips breaking as well as faster and better quality holes. Produced small chips are easily ejected from the hole reducing/eliminating the need for lubrication.

To achieve such results VTH provides an electrically-controlled axial vibration to the drill bit. The forced vibration features a stroke up to 150µm and a 8kN blocked force in a bandwidth up to 400Hz. This vibration can be produced to the drill when rotating at speed up to 6000rmp. VTH can withstands large parasitic forces and torques in static and dynamic operations.
VTH have been developed in collaboration mainly with ARTS, CETIM and G2ELAB in the context of AVIBUS FUI project coordinated by CEDRAT TECHNOLOGIES.

Applications of VTH are drilling of Titanium alloys, composite materials and metal-composite sandwiches...

Other customised Vibration Assisted Machining (VAM) modules have been successfully developed by CEDRAT TECHNOLOGIES.

More generally, CEDRAT TECHNOLOGIES can easily develop customised mechatronic systems for specific requirement using its standard components.
Feel free to send your requirement and specifications at ***actuator@cedrat-tec.com*** .

■ Figure 9.7: Stepping Piezo Controller SPC45

■ Figure 9.8a SPT500L for oval piston machining lying on the associated electronics

■ Figure9.8b VTH Vibrating Tool Holder for vibration drilling assistance

10. APPLICATION NOTES

10.1 GLOSSARY OF TECHNICAL TERMS

10.1.1 NOTES ABOUT THE STANDARD PIEZOELECTRIC PRODUCTS SHOWN IN THE CATALOGUE

ACV: Active control of vibrations including at least a piezo actuator, a sensor and a controller, aiming at reducing or controlling vibrations coming from an external source.

APA®: Amplified Piezoelectric Actuators (patented & trade mark by CEDRAT TECHNOLOGIES), for linear pulling actuation. In the APA®, the piezoelectric ceramic is pre-stressed along the major axis of an elliptic shell made from stainless steel.

DPA: Direct Piezoelectric Actuator, for linear pushing actuation.

LPM: Linear Piezoelectric Motor, for linear motion. Note that the LPM displays an important blocking force at rest (off power).

MLA: Multilayer piezo ceramics. Actuators include different sizes of piezoelectric ceramics. The thickness of a layer and an internal electrode inside the ceramic are respectively equal to 100 and 2 µm.

PMA: Proof Mass Actuator.

PPA: Parallel Pre-stressed Actuator, for linear pushing actuation.

RPM: Rotating Piezoelectric Motor, for rotary motion. Note that the RPM displays an important blocking torque at rest (power off).

SPA: Stepping Piezo Actuator: Amplified piezoelectric actuator coupled to a grip and using a dynamic motion to slip relatively to the grip, leading to an actuator displaying both a large stroke, a positioning capability at rest without power and a resolution as usually offered with APA®.

SPS: Stepping Piezo Stage: Stepping Piezo Actuator combined with a precise guiding. This allows the stage to be suited to long stroke positioning purposes.

SPT: Servo Piezo Tool: Piezo actuators used to actuate a machining tool and combined with a controller synchronizing the piezo loop to the master loop a the lathe.

10.1.2 A FEW DEFINITIONS CONCERNING ACTUATORS

Accuracy, relative and absolute: There is a distinction between relative and absolute accuracy although both result from an uncertainty calculation. The relative accuracy is equal to the uncertainty over the displacement value between two determined positions. The absolute accuracy is the uncertainty over the position. These uncertainties are the result of several parameters such as the hysteresis intrinsic to piezoelectric ceramic, the temperature range, and the signal-to-noise ratio of the driving electronics in an open loop configuration. The accuracy can be improved by using a sensor in a closed-loop configuration, in which case the uncertainty over the position depends on the accuracy of the sensor and connected electronics.

Bandwidth: Frequency interval between 0Hz and the maximum operating frequency of the actuator. The maximum operating frequency depends on the resonance frequency of the actuator, which is generally specified by the user and determines the choice of the electronic drive. Knowing this value is essential to calibrate any feedback loop associated with the actuator.

Blocked force: Minimum amount of force that completely blocks the displacement of an actuator under the maximum applied voltage (piezo) or current (magnetic).

Capacitance: Like all dielectric systems, the electrical behaviour of a piezo actuator is analogous to that of a capacitor. The capacitance value (in µF, or micro-farads) that is given in CEDRAT TECHNOLOGIES' actuator specifications corresponds to quasi-static free conditions. Under dynamic conditions, the capacitance value increases with the temperature because of dielectric losses. Piezo devices are voltage driven. In dynamic conditions (DS, DF modes), the capacitance determines, through the admittance, the current and the reactive power that are required to supply the actuator.

Command: Signal sent to the driving amplifier of the actuator through an external signal generator to get a motion. The command can be sent directly to the amplifier in the open-loop mode or through the controller in the closed loop mode.

Controller: Function used to stabilize and to improve the performances of the control loop (also called regulator).

Converters (ADC and DAC): Input and output blocks used in digital loop. Analogue digital converters are used to convert analogue signals into discrete signals. Digital to analogue converters are used to convert discrete signals into analogue signals.

Current: In static applications, a piezo actuator draws currents of a few microamperes. Under dynamic conditions, the current consumption increases with the operating frequency. Therefore, selecting the optimum power amplifier for an application depends on the maximum current drawn by the actuator.

Drift or Creep: Positive or negative small change in ceramic strain over time under a dc applied voltage, resulting from a repoling or depoling of the active material. For precise and static positioning, the drift effect is cancelled with a closed loop.

Electrical booster: Additional electrical circuit used with a standard power amplifier to reduce the reactive power required by the actuator.

Effective mass m_{eff}: Mass perceived by the actuator at resonance. For example, when unloaded, it is not equal to the total mass of the actuator, and can be determined by the formula given in section 2.8. The effective mass therefore depends on the mechanical interface conditions, that-is-to-say, free-free or blocked-free.

Life time: The life time of a piezo actuator depends on its conditions of use. Under cycling conditions, up to 10^{10} full stroke cycles can be achieved. Under static DC voltage, life time can be limited to a few hundred hours under high humidity level. In the case of piezoelectric motors, the lifetime depends greatly on the wear of the contact surfaces, as well as on other parameters. The lifetime of magnetic actuator is depending from its guiding. With elastic guiding it is infinite.

Load time: Time required for the driving electronics to load an actuator at a given voltage. This parameter depends on the voltage order, on the capacitance or inductance of the actuator and on the current or voltage limitation of the driving electronics.

Maximum force: This is the maximum external force that an actuator can withstand without any damage to the actuator.

Operation modes: Correspond to the frequency range at which a piezoelectric device (including actuator and payload) can be driven. Specifying one or more operating modes from the list below is essential for a successful definition of the actuation mechanism.

> Dynamic strain (DS) - The frequency excitation is below the resonance; several modes can be excited and both electrical and thermal limits may be encountered.

> Dynamic force (DF) - The frequency excitation is above the resonance, meaning that the actuator produced force against the inertia force.

> Static (S) - The frequency is equal to zero. A dc voltage is applied to the device to reach and hold a precise position. The resulting current consumption is low (a few microamperes). The static operating mode is commonly used in positioning applications.

> Impulse - Used for fast actuation and for taking advantage of the short response times of piezoelectric actuators. A voltage pulse, which corresponds to a required displacement, is applied to the device.

> Quasi-static - The frequency is well below resonance (the operating frequency is less than a third of the resonance frequency). The frequency is such that dynamic effects (inertia effects and dynamic stresses) do not affect the behaviour of the device, which can be excited by a variety of signals, including sine, triangle and square, in such a way that the actuator's displacement is in phase with the excitation voltage.

> Resonant (R) - The resonant operating mode, in which the device is driven at its resonance frequency, is particularly interesting. APA®, which display a high mechanical quality factor (Qm) excepted with MD option, may also be used in resonant mode in special applications. However, as this condition is severe, please contact CEDRAT TECHNOLOGIES to take advantage of the full lifetime of APA® and PPA in resonant applications..

Payload: Designates the load applied to the actuator. It is expressed in Newton (N) and can be of the following types:

> Gravitational - Gravitational force that corresponds to the mass moved by the actuator.

> Elastic - Elastic force (or stiffness) applied to the actuator.

> Inertial - Transient or dynamic force induced by the displacement (acceleration) of the actuator.

Precise qualitative and quantitative specification of the payload is crucial to the proper selection of the actuator.

Phase and Gain margins: Criteria used to characterize the behaviour of the closed loop Phase margin and Gain margin are computed in open loop and values of 45° and +6dB correspond to a stabilized loop.

Preliminary data: To offer its customers the "state of the art" of Piezo Products, some new products are given with "preliminary data", which means that the product has been designed but has not been tested as much as requested by CEDRAT TECHNOLOGIES quality standards at the time of printing. In that case, the customer is considered as a "pilot customer".

Pre-load: Force required in piezo motors (LSPA...) to ensure the contact between the piezo stator and the mobile part. A Pre-load Play-Recovery System (PPRS), developed by CEDRAT TECHNOLOGIES on both linear and rotary motors, allows the level of the pre-load to be maintained at a precise value, thus improving the contact efficiency as well as the lifetime of the piezoelectric motors patented by CEDRAT TECHNOLOGIES.

Pre-stress: Static pressure applied, at rest, to the piezoelectric ceramic stack inside the actuator. A precise calibration of the pre-stress to the optimum value of that piezoelectric material (specified by the ceramic manufacturer) improves the dynamic behaviour of the actuator as well as its resistance to vibrations.

Repeatability: Ability of an actuator to return precisely to a previous position. Due to hysteresis, drift and other high-order phenomena, repeatability can be guaranteed only for actuators operating in closed-loop conditions (position feedback). The exception is repeatable command, where 2% can be achieved.

Resolution: Displacement achieved for a minimum variation of the applied voltage. The resolution is independent of the hysteretic effects and is unlimited as far as the actuator is concerned. The practical resolution values in open loop given in the catalogue are computed with a signal-to-noise ratio of 100 dB.

Resonance Frequency: Frequency at which the fundamental mode of the device (actuator and payload) is excited. For the unloaded actuator, the resonance frequency only depends on the mechanical boundary conditions:

> Free-free - the actuator is fixed in such a way that its mechanical interfaces can move freely.

> Blocked-free - One of the two interfaces of the actuator is fixed to a rigid base; the other can move freely.

Response time: Time required for an actuator in open loop to reach the total motion corresponding to a given electric signal level. This parameter mainly depends on the resonance frequency of the device.

Settling time: Time required for an actuator in closed loop to reach 95% of the maximum motion corresponding to a given electric signal level. This parameter mainly depends on the resonance frequency of the device.

Stabilizing filters: Generic filters used to stabilize the closed loop: Low pass filters, Notch or stop band filters, Lead-Lag filters.

Stiffness: Proportionality coefficient between the elastic force and the displacement generated by the actuator. The quasi-static or dynamic mechanical behaviour of the piezo actuator is analogous to that of a spring with stiffness K (expressed in N/µm).

Stroke: Maximum no-load displacement generated by the actuator. It is expressed in micrometres (1µm = 10^{-6}m) or in millimeters (1mm=10^{-3}m).

Voltage range: Defines the range of the input voltage that results in the linear strain of the piezoelectric ceramic. The stroke is achieved for the maximum voltage value.

Resistance: The electric behaviour of magnetic actuators is analogous to an inductor. Its electrical impedance includes a resistance and an inductance. The resistance (in Ohm) is given by CEDRAT TECHNOLOGIES in DC condition at low excitation current level. At maintained high current level, heating occurs: This increases the coil temperature, which induces a resistance increase of 0.39%/°C. At high frequency, because of eddy currents, the resistance increases.

Inductance: The electric behaviour of magnetic actuators is analogous to an inductor. Its electrical impedance includes a resistance and an inductance. The inductance (in µH: micro Henry or mH: milli Henry) is given by CEDRAT TECHNOLOGIES at 10Hz at low excitation level. At high frequency, because of eddy currents, the inductance decreases. Magnetic devices are current driven. In dynamic conditions, the inductance and the driving current strongly determine the required voltage. This should be analysed to determine amplifiers with appropriate current and voltage limits.

Loaded output bandwidth: The effective bandwidth of an electronic amplifier is depending on the load. To give a hint about this issue, CEDRAT TECHNOLOGIES amplifiers datasheet includes a loaded output bandwidth. This has been measured with following normalized loads:

- 1.55 µF in case of amplifiers for piezo actuators
- 1.5 mH in case of amplifiers for magnetic actuators

10.2 YOUR OWN APPLICATION SELECTION GUIDE

Here follows the main questions that you should ask yourself in order to find the right actuator and its best suited driving electronic:

10.2.1 STEP 1: ACTUATOR

- Function & Working Conditions
- Maximum of displacement required for my application,
- Required bandwidth (At which maximum frequency do I have to drive the Actuator?),
- Forces acting on the Actuator,
- Mass to be moved by the Actuator (What is the inertia?),
- Spring loading (Is my Actuator loaded by a spring? What is the spring's stiffness?),
- External damping forces (What is the damping coefficient?),
- Maximum acceptable settling time (If I have an impulse application, how much time should it take perform the actuation?),
- Required accuracy (Do I need a position sensor or not?),
- Temperature range (Is it an ambient, hot temperature or a cryogenic application?),
- Environment (A I under vacuum conditions? A I under moisture conditions? What kind of gas (air ,He ,N2 ,...) will surround the Actuator?),
- Size (What volume and dimensions are allowed for the Actuator in my application?).

10.2.2 STEP 2: DRIVING & CONTROL ELECTRONIC

- What is the capacitance or inductance of the selected actuator?
- What is the maximum required current?
- Do I need a specific voltage order?
- Do I need a piezo voltage with low total harmonic distorsion?
- Do I need a closed loop?

ELECTRONIC SERIE		CA-U10	CA-U20	CA45	LA75A	LA75B	LA75C	SA75D
Current limitation	mA	5	150	36	90	360	2400	30000
Actuator serie	Capacitance µF	Load time @ 170 V (milliseconds)						
APA - µXS	0,052	1,77	0,06	0,25	0,1	0,03	0,004	0,000
APA - XXS	0,150	5,1	0,17	0,7	0,3	0,07	0,01	0,001
MLA_2*5*10 - APA - XS	0,250	8,5	0,28	1,18	0,5	0,12	0,02	0,001
MLA_5*5*20 - APA - S, SM	1,55	53	1,76	7,32	3	0,73	0,11	0,01
APA - M	3,15	107	3,57	15	6	1,5	0,22	0,02
APA - MML	10,00	340	11,33	47	19	4,7	0,7	0,06
APA - ML	20,00	680	23	94	38	9,4	1,4	0,11
APA - L	40,00	1360	45,33	189	75	19	2,8	0,23
APA - XL	110,00	3740	125	519	208	52	7,8	0,62
MLA_5*5*10 - PPA10M	0,70	24	0,79	3,3	1,3	0,33	0,05	0,004
PPA20M	1,40	48	1,59	6,6	2,6	0,66	0,1	0,008
PPA40M	2,70	92	1,76	12,75	5,1	1,28	0,19	0,015
PPA40L	13,30	452	3	62,80	25	6,28	0,94	0,075
PPA60L	20,00	680	15	94	38	9,44	1,4	0,11
PPA80L	26,60	904	23	126	50	12,56	1,9	0,15
PPA40XL	24,00	816	30	113	45	11	1,7	0,14
PPA80XL	48,00	1632	27	227	91	23	3,4	0,27
PPA120XL	72,00	2448	54	340	136	34	5,1	0,4

ELECTRONIC SERIE		CA-U10	CA-U20	CA45	LA75A	LA75B	LA75C	SA75D
Current limitation	mA	5	150	36	90	360	2400	30000
Actuator serie	Capacitance µF	Bandwidth (sinus) @ -3 dB -120V (Hz)						
APA - µXS	0,25	282	8484	2036	5090	20362	33000	33000
APA - XXS	0,15	98	2941	705	1764	7058	33000	33000
MLA_2*5*10 - APA - XS	0,25	58	1764	423	1058	4235	28235	33000
MLA_5*5*20 - APA - S, SM	1,55	9	284	68	170	683	4554	33000
APA - M	3,15	4	140	33	84	336	2240	28011
APA - MML	10,00	1,5	44	10	26	105	705	8823
APA - ML	20,00	0,7	22	5	13	52	352	4411
APA - L	40,00	0,4	11	2	6	26	176	2205
APA - XL	110,00	0,1	4	1,0	2	9	64	802
MLA_5*5*10 - PPA10M	0,70	21	630	151	378	1512	10084	33000
PPA20M	1,40	10	315	75	189	756	5042	33000
PPA40M	2,70	5	163	39	98	392	2614	32679
PPA40L	13,30	1	33	8	19	79	530	6634
PPA60L	20,00	0,7	22	5	13	52	352	4411
PPA80L	26,60	0,6	16	4	10	39	265	3317
PPA40XL	24,00	0,6	18	4	11	44	294	3676
PPA80XL	48,0	0,3	9	2	5,5	22	147	1838
PPA120XL	72,00	0,2	6	1,5	3,7	14	98	1225

■ Table 10.1: Load time & bandwidth comparison between drivers

(*) The max bandwidth of the LA75 and SA75 amplifiers is rated at 33kHz.

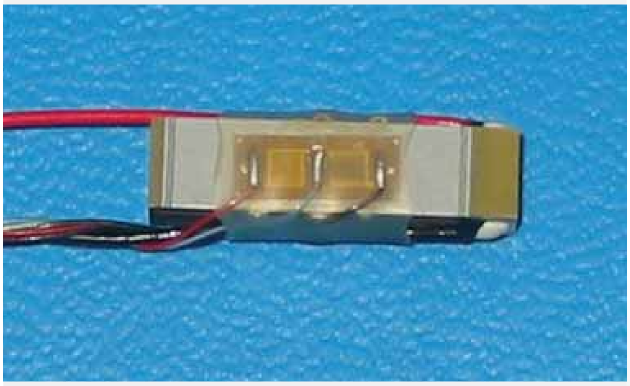
10.2.3 STEP 3: CHECK YOUR DESIGN USING COMPACT TOOL

Once your technical specifications are settled, select one or several piezo actuators and linear amplifiers which seem able to meet your needs. Then we recommend you to check the relevance of each selection with the help of our new tool: COMPACT.

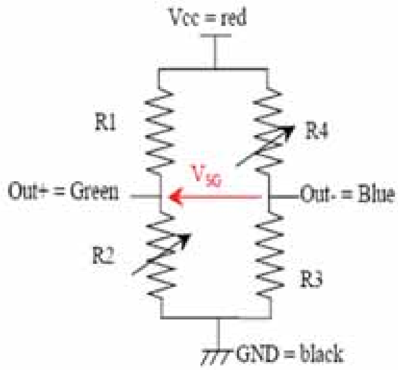
The compact Pre-Design Software Tool utilizes Microsoft® Excel® to create a self documenting spreadsheet to automate the calculation and graphical representations of the electro-mechanical response of systems combining CEDRAT TECHNOLOGIES actuators and drivers against various loads.

Examples of applications of COMPACT are given in previous sections for the computation of the actuator limits versus the frequency.

You can download COMPACT in the section mechatronic products/download available on our web site ***www.cedrat-technologies.com***.
For any question regarding this tool, please call us or email us at ***actuator@cedrat-tec.com***.



■ Figure 10.1: View of Strain Gauge on an MLA component



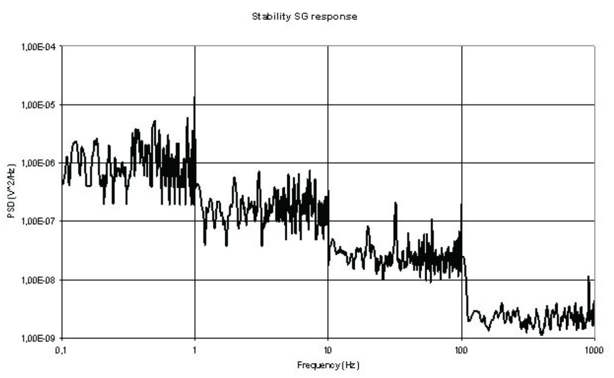
■ Figure 10.2: View of a Wheastone bridge

10.3 STRAIN GAUGES PERFORMANCES & PROPERTIES

Strain Gauges Sensors (SG Option) are the most miniaturized sensors to monitor the displacement of the piezo actuator. This technical note sums up the performances of the SG. A SG sensor consists of a resistive film bonded to the piezo stack (Figure 10.1) or to a guiding element; the film resistance changes when strain occurs. Up to four strain gauges (the actual configuration varies with the actuator construction) form a Wheatstone bridge (Figure 10.2) driven by a DC voltage (5 to 10 V). When the bridge resistance changes, the sensor conditioner converts the resulting voltage change into a signal proportional to the displacement. Only full Wheastone bridges are used. A SG is an indirect sensor since it measures the displacement through the strain and since a calibration is necessary.

10.3.1 DEFINITION

- Range of measurement: Range of values that can be measured by the sensor,
- Resolution: The resolution is often compared to the SNR (Signal to Noise Ratio), where the Signal is the Range of Measurement and the Noise is the Resolution over a given



■ Figure 10.3: Cumulated noise of a full SG bridge

bandwidth, and corresponds to the minimum change of displacement that can be sensed,

- Accuracy: Refers to the uncertainty of sensing the real displacement after calibration,
- Absolute/relative displacement: An absolute sensing of the displacement includes the measurement of the reference (zero) position.

10.3.2 PERFORMANCES & TESTS RESULTS

Several parameters affect the resolution of the SG:

- Temperature: Even though the full bridge is used, it is not fully compensated, or may come from the thermal gradient within the piezo actuator. This means that the offset response is subjected to change while the gain remains correct,
- Bandwidth: the resistive nature of the SG creates a thermal noise,
- The major affecting parameters come from the conditioning electronics.
- Lifetime: SG may be subjected to fatigue effect. However, as the piezo material exhibits a strain of 1500 ppm, it falls in the infinite region of the SG: At least, 109 cycles have to be expected when securing the cables.

For APA®, there is additional SG's sensitivity to temperature, because such actuators exhibit an internal thermo-mechanical mismatch between the piezo ceramic and the amplifying shell. The SG sensor cannot monitor accurately the absolute displacement over a change of temperature. For instance an APA60S actuator displays a thermal behaviour of 0.8 µm/K, whilst the SG will indicate a thermal behaviour of -0.11 µm/K. This limitation does not apply to piezoceramics, Parallel Prestressed Actuators and push-pull mechanisms.

Some tests have been performed on Piezo actuators or Piezo mechanisms equipped with Strain Gauges. In the Figure 10.3, the position of the piezo mechanism (used in closed loop with SG and submitted to a constant command) was measured with an external capacitive sensor and a spectrum analyzer. The capacitive sensor indeed measures the stability performances of a closed loop based on SG and includes the performances of the SG conditioner, the driver amplifier and the digital controller.

Given the gain of the conditioner, the total RMS noise on a 1 kHz bandwidth corresponds to a 1/1400 of the full scale displacement.

10.3.3 SUMMARY OF PERFORMANCES

The range of measurement matches the full scale displacement.

RESOLUTION

1/10.000 of the full scale displacement.

STABILITY

1/1500 of the full scale displacement over a 1 kHz bandwidth,

TEMPERATURE DEPENDENCY

Valid on -20 / 80 °C (other temp. on request),

ABSOLUTE ACCURACY IN CLOSED LOOP

1/700 of the full scale displacement.

10.4 DIGITAL CONTROL

10.4.1 BUILDING A GENERAL PIEZOELECTRIC ACTUATOR MODEL

The principal task before controlling a piezo actuator is to build a model integrating the parameters of the actuator from the catalogue. This model allows the tuning of the controller's parameters in advanced processes or for an optimal control. Several parameters are given inside and recalled below:

- Stroke: U (Unit, meter)
- Blocked force: F, Maximum force generated by the actuator (Unit, Newton)
- Force factor: N, means the force that the piezo actuator is able to generate with 170V. $N = \frac{F}{V\max}$ (Unit, Newton/Volts)
- Stiffness: The stiffness K of a piezo actuator that deflects a distance u under an applied force F $k_m = \frac{F}{u} \, . \, c_m$ (Unit, Newton/meter). Elasticity is the opposite of stiffness $c_m = \frac{1}{k_m}$
- Resonant frequency in free-free configuration or blocked free configuration:

Resonant frequency of the first mode computed with the stiffness and effective Mass:

$$F_{resonant} = \frac{1}{2\pi}\sqrt{\frac{k_m}{m_m}}$$ (Unit, Hz)

- Effective Mass: m_m mass (Unit, kilogram)
- Quality factor: Q indicates a rate of energy dissipation relative to the oscillation frequency.

$$Q = \frac{m_m \times 2\pi \times F_{resonant}}{r_m}.$$

Generally piezo actuator have a quality factor upper than 100 (Unit, None)

- Voltage range: Vmax maximal voltage applied on the piezo actuator to reach the maximal stroke (Unit, Volt)
- Applied Voltage: V, voltage that the driver applies on the piezo actuator (Unit, Volt)

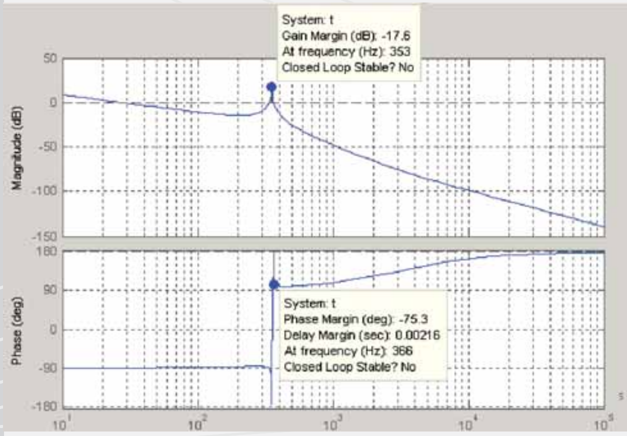
From these parameters and as the actuator is driven in voltage the transfer function of this continuous plant can be written:

$$H(j\omega) = \frac{u}{V} = \frac{Nc_m}{1 + r_m c_m j\omega + m_m c_m (j\omega)^2}$$

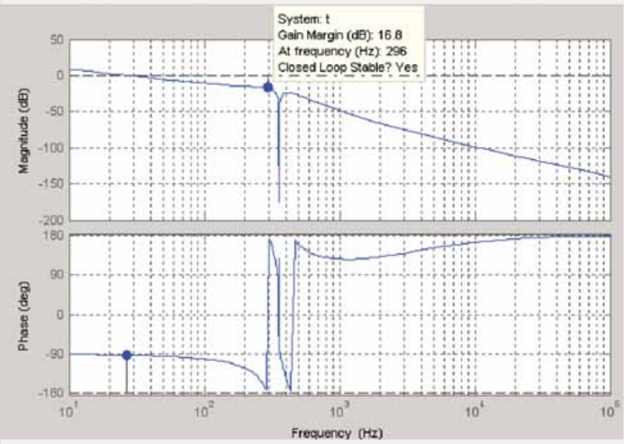
The generic model is a second order filter with high quality factor. When multi mode mechanisms are used, the plant must contain each mode built with the same formulae.

Of course, this model is a rough model excluding the non-linearities of the piezo actuator such as the hysteresis, the creep effect and other non linear effects. Nevertheless, this model can be used to design the control loop.

Note: To conclude the modelling phase of each block of the loop must be integrated: the driver with at least a gain of 20, the sensor with its sensibility, the PID controller and the stabilizing filters.



■ Figure 10.4: Open loop response without stabilizing filter



■ Figure 10.5: Open loop response with PID controller and stabilizing filter

10.4.2 MANAGING THE PERFORMANCES OF THE CONTROL LOOP

Controlling a piezo actuator is not different from controlling other actuators. Nonetheless, because of the very high quality factor, the tuning process is more important to reduce the settling time avoiding any unstability.

Two cases are studied: A closed loop designed with analogue electronic functions and a closed loop designed with a digital controller. The frame of the study is very similar:

- A study of the analogue control loop is based on transfer functions with p (jω) operator,
- A study of the digital control loop is based on transfer functions with z operator.

The usual process begins with the study of the behaviour in open loop. In this case, we can define the phase and gain margins with additional filters working as stabilizers. On the following Bode diagrams, we show the impact of stabilizing filters on a standard analogue PID controller coupled with a piezo actuator. In parallel, the performances in closed loop are computed and plotted on the following graphs (fig 10.6 & 10.7).

These curves show the impact of a low-pass filter placed with a cut-off frequency of 400Hz. With the roll-off of the filter the phase and gain margins increase and the stability of the closed loop is better. This impact is shown principally with the step response without oscillations.
The study is very similar with a digital controller. The open loop must be analyzed to find the destabilized criteria. However, since the controller is based on quantization converters, the model of the controller is now expressed with the z transformation and new main criteria must be taken into account:

- The sampling rate or sampling,
- The quantization.

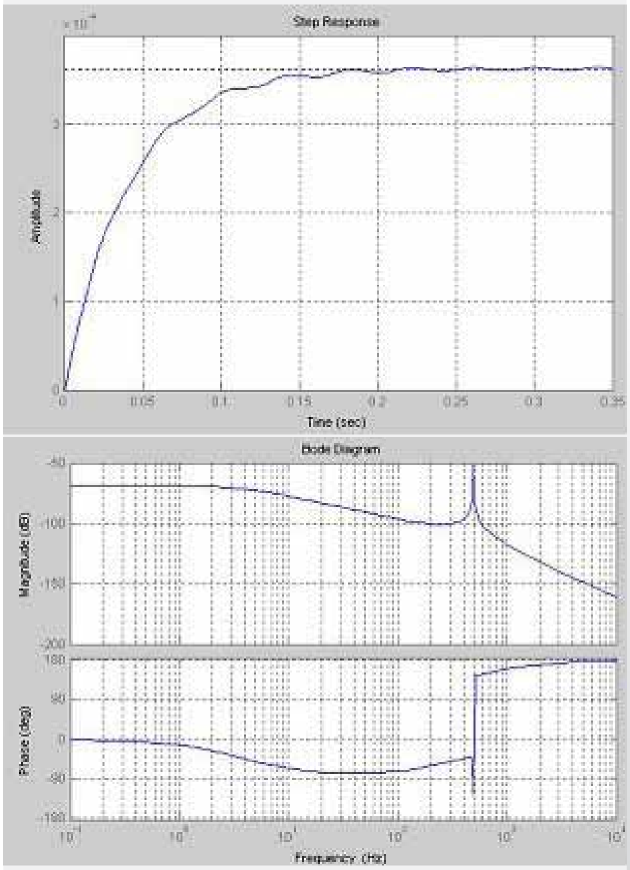
An ADC has the following functions.

The sampling rate is the speed at which the ADC converts the input analogue signal to digital values that represent the voltage level, after passing through the analogue input path. This means that the digitizer will sample the signal after any attenuation, gain, and/or filtering is applied by the analogue input path, and convert the resulting waveform to digital representation. The higher the sampling rate is, the better the signal is defined.
The sampling rate is directly linked to the frequency of the signal you would like to digitalize. The Nyquist theorem states that a signal must be sampled at a rate greater than twice the highest frequency in order to accurately reconstruct the waveform; otherwise, the high-frequency content will alias at a frequency inside the spectrum of interest (passband).

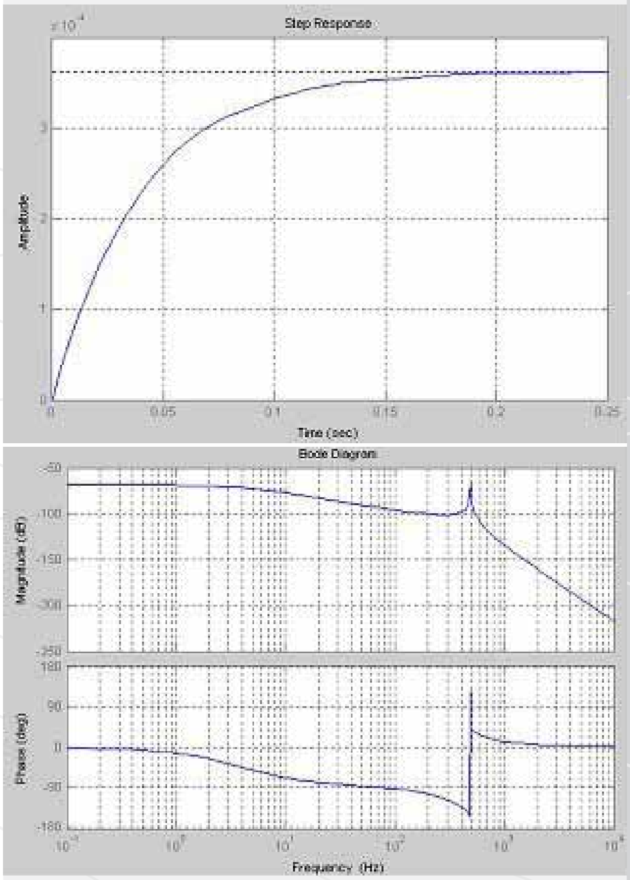
Sampling rate or Ts > 2 x F max

With the sampling rate of the loop's cycle time and Fmax being the highest frequency of the digitalized signal.

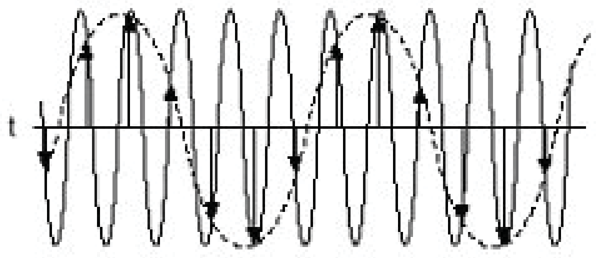
Aliasing is of course not acceptable and it is therefore essential to place an analogue low-pass filter at a frequency fc < fs/2 before the ADC. However analogue prefilters have dynamics and a sharp cut-off frequency of the magnitude is associated with a phase lag at the cut-off frequency. As fc is related to fs, it is always a good idea to sample at a high rate and to make sure that the cut-off frequency of the prefilter is substantially higher than the crossover frequency of the control system. If the phase lag of the prefilter is significant, it is necessary to include the prefilter dynamics in the design of the loop. A



■ Figure 10.6: Closed loop response without stabilizing filters.Step response and Bode response



■ Figure 10.7: Closed loop response with stabilizing filters Step response and Bode response



■ Figure 10.9: Example of an Aliased signal: dotted line: Alias recorded by the converter

simple solution is to introduce a second analogue order-filter based on Butterworth filters.
As the ADC (or DAC) includes a zero-order hold, its transfer function can be written:

$$H_o(p) = \frac{1 - e^{-pT_s}}{p}$$

It introduces a linear phase lag - ωTs/2. The phase lag can also be applied to the computation delay.

To conclude on the effect of the sampling rate in a digital loop, we recall that the output of a DAC is also a staircase function. As a consequence, it may be interesting to smooth the control output with an interpolation filter to remove the high frequency component of the signal which could excite high frequency resonances (with high Q). The use of such output filters should be considered with care because they have the same effect on the phase as the prefilter on the input.

In applications, it is recommended to use a sampling frequency of at least 30 times the crossover frequency to preserve the behaviour of the continuous system at a reasonable degree.

The other parameter of the ADC is the quantization parameter. Quantization is defined as the process of converting an analogue signal to a digital representation. After the zero hold, the signal is passed into the ADC for sampling and conversion into a digital signal of a finite word length (16 bits for example) representing the total range of the analogue signal. The signal to noise ratio is of order of 2^N and the quantization error is 2^{-N} , (N is the number of bits). This point can also be applied for the DAC output.

10.4.3 METHODOLOGY TO TUNE THE CONTROLLER

The methodology to correctly tune the controller is the same with an analogue controller or a digital controller. One has to carefully follow several steps:

Step 1 - Open loop verification:

1. Install the hardware (driver, actuator, sensor, sensor conditioning, command generation) and perform a small signal (e.g. 1/10 of the full amplitude) sine command at low frequency (1 Hz):
2. Check that the driver effectively reproduces the command and does not saturate,
3. Check that the sensor reproduces the motion and is correctly calibrated (offset and gain),
4. With a numerical controller, check that the signal discretization does not produce a stepping motion of the actuator,

Once you've passed this steps, apply a full amplitude and low frequency command and verify that the sensor response still remains correct (no saturation).

Step 2 - Closing the loop

- If the open loop behaviour is fully correct, close the loop and add a proportional corrector with a low gain value,
- Your corrector has been settled at the factory: start in closed loop with a low amplitude, low frequency command.

Verify the step response is similar to the one indicated in the factory verification sheet.
Please note that CEDRAT TECHNOLOGIES is available for after-sales services or consulting, for your closed loop application.

10.4.4 NOTE ON THE DISCRETIZATION OF A CONTINUOUS CONTROLLER

It is quite common to perform a continuous design and to discretize it in a second step. This procedure works well if the sampling rate is much higher than the cross over frequency (in the case of the sampling rate is lower, you must include in your design the previous models of each ADC functions, ie anti-aliasing, sample & hold...).
Example: The transfer function of the compensator can be written in continuous state:

$$\frac{U(p)}{Y(p)} = H(p) = \frac{b_1 p^{n-1} + \ldots + b_n}{p^n + a_1 p^{n-1} + \ldots + a_n}$$

For digital implementation, it must be transformed to the form of a difference equation (k represents the sample)

$$u(k) = \sum_{i=1}^{n} \alpha_i u(k-i) + \sum_{j=0}^{m} \beta_j y(k-j)$$

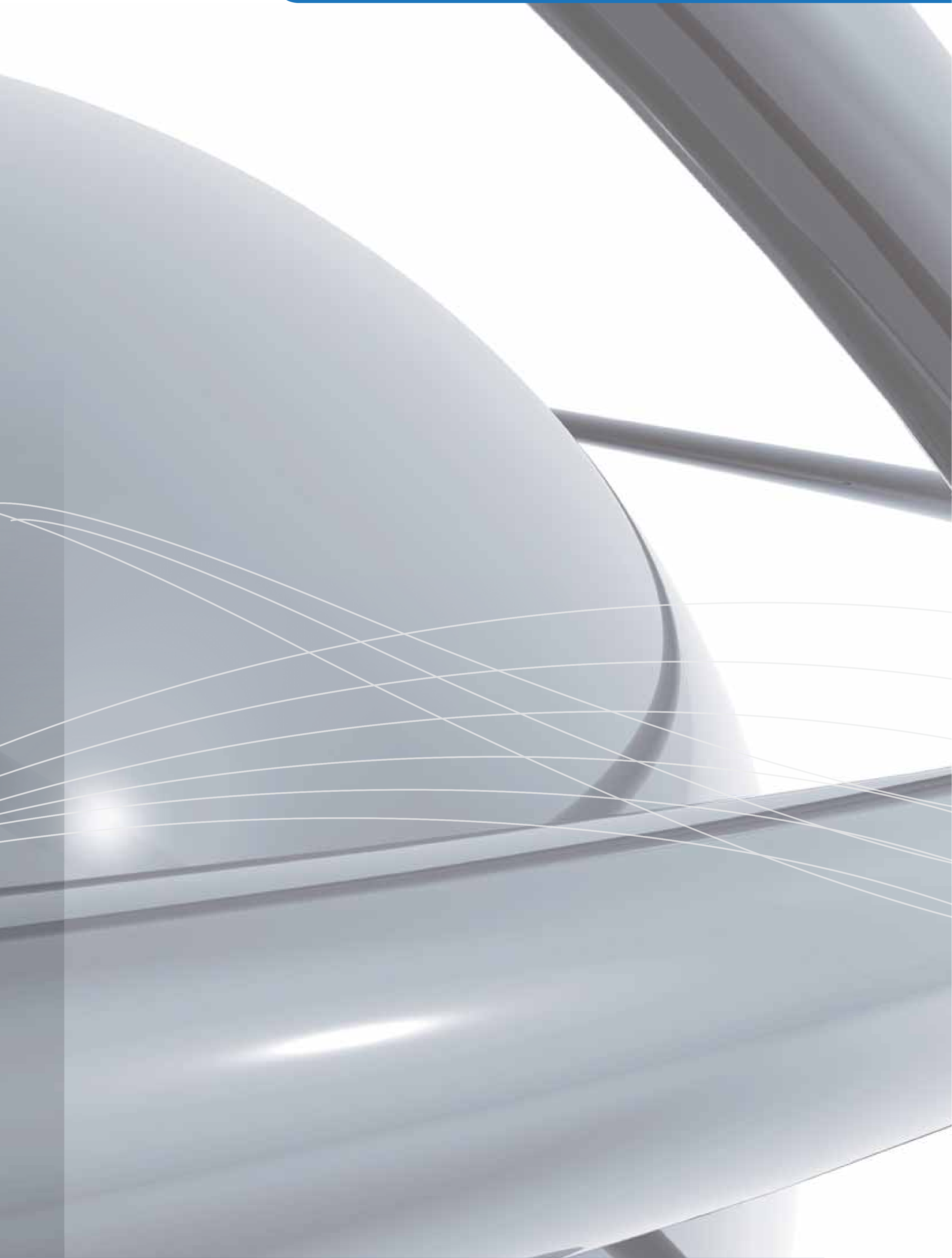
The corresponding z-domain transfer function is:

$$\frac{U(z)}{Y(z)} = H(z) = \frac{\sum_{j=0}^{m} \beta_j z^{-j}}{1 - \sum_{i=1}^{n} \alpha_i z^{-1}}$$

where z-1 is the delay operator.

The coefficients α and can β be obtained from those of H(p) following the Tustin's method. H(z) and H(p) are linked by the bilinear transform.

$$p = \frac{2(z-1)}{T_s(z+1)} \text{ or } z = \frac{1+T_s/2}{1+T_s/2}$$



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