# ACTUATORS FOR QUASI-STATIC APPLICATIONS

# - tutorial

This tutorial provides a basic introduction to actuators for quasi-static applications. This includes a description and comparison of the different actuator designs. The tutorial also describes, how a piezoelectric actuator behaves under load. Finally, the tutorial finishes with three vital points to use, when you select your actuator for a quasi-static application.

This tutorial can be seen as the basic introduction to actuators or Actuator 1. It can be beneficial to look at the tutorial "Actuators for dynamic applications” (Actuator 2) after this tutorial.

Go to Actuator 2

**Index of the tutorial on actuators for quasi-static applications:**

# DIFFERENT ACTUATOR DESIGNS

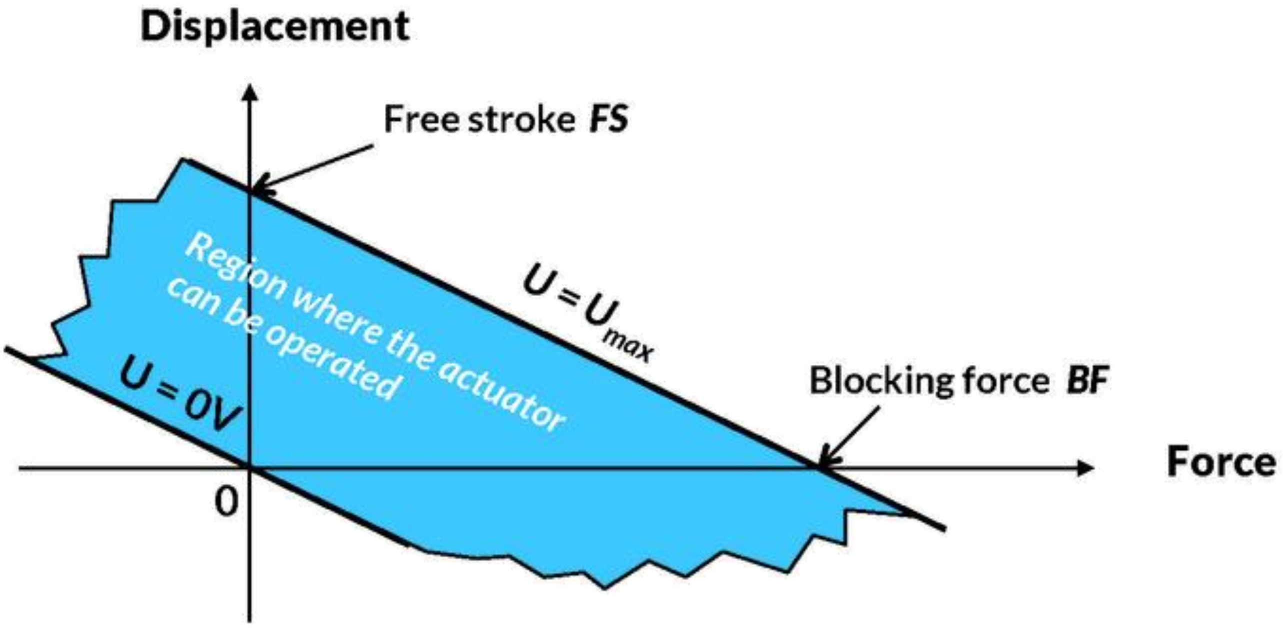
**There are different ways of using the piezoelectric effect for actuator purposes: with monolayer, multi-layer, stacks, benders or amplified actuators.**

## Definitions: axes, free stroke, blocking force

There are a few definitions that are important to get in place in order to get the full understanding of actuators, actuator design and how to select the right actuator: axes, free stroke and blocking force.

## Axes

Similarly to most materials, piezoelectric ceramic is elastic, i.e. it follows Hooke's law. In other words, strain is proportional to stress. In addition, the piezoelectric effect can be represented as an additional term in the relationship, in a first approach proportional to the electrical field. This can be visualized as a relationship on two axes. This "bilinear" relationship is valid at the material level (strain, stress, field) whatever the orientation of the material and can be extended to all types of actuators (displacement, force, voltage). As a result, any piezoelectric actuator can be described as a spring with a characteristic that can be shifted through the application of a voltage. Or in a displacement vs. force graph.



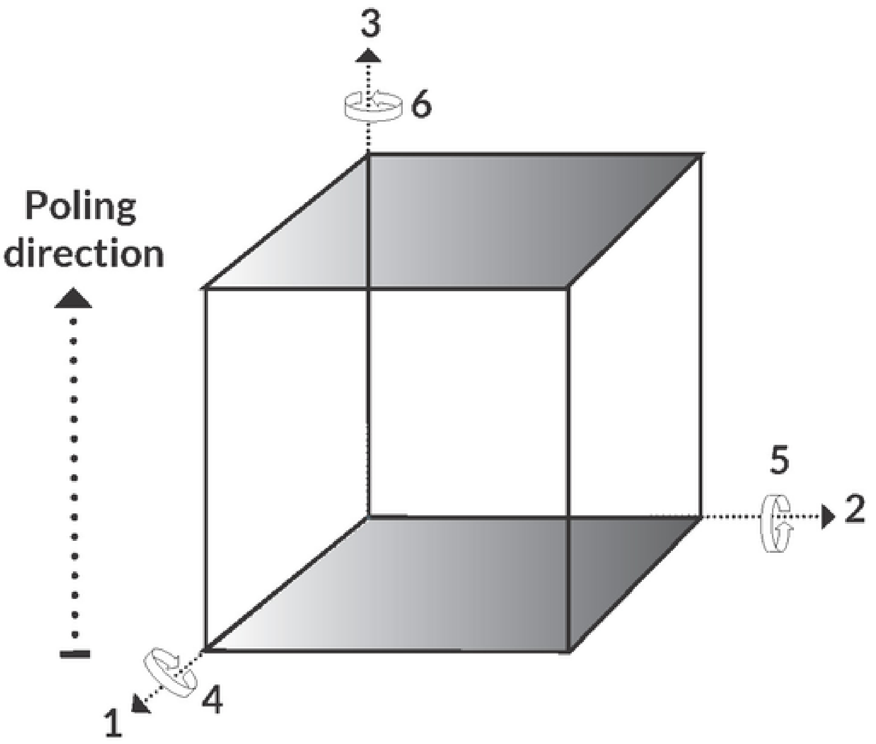
## Free stroke and blocking force

It is an industry standard to describe this behavior using the terms "free stroke" and "blocking force". Free stroke is the vertical distance between the curves while blocking force is the horizontal distance between the curves. Note that in this model, the stiffness of the actuator is (blocking force)/(free stroke) and is supposed constant.This characteristic might be limited by a minimum/maximum force allowable on the actuator. However, these parameters are not necessarily related to the blocking force.

Further reading: Constitutive equations

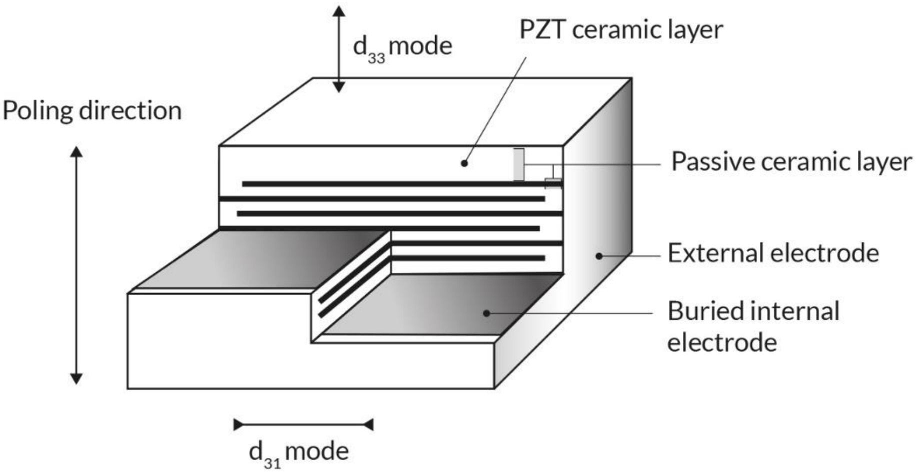
## Monolayer components

The most common configuration of a monolayer component is with the electrodes perpendicular to the poling direction. Here, the application of an electric field on the surface electrodes will lead to a contraction in directions "1" and "2" to gether with an expansion in direction "3". Monolayer components are available as rectangular plates, discs, rings, tubes. As actuators, they provide micrometer displacement but require high voltage for operation (kV range).



## Multilayer actuators

Noliac's plate and ring actuators (NAC20xx and NAC21xx) can be used either in direction "3" or "1" similar to monolayer components. The difference compared to monolayer components is that the active volume is divided into many thinner layers, allowing high electric field under lower voltage. Free displacement is up to 5 µm withblocking force in the range 200 to 10000 N depending on material and cross-section.

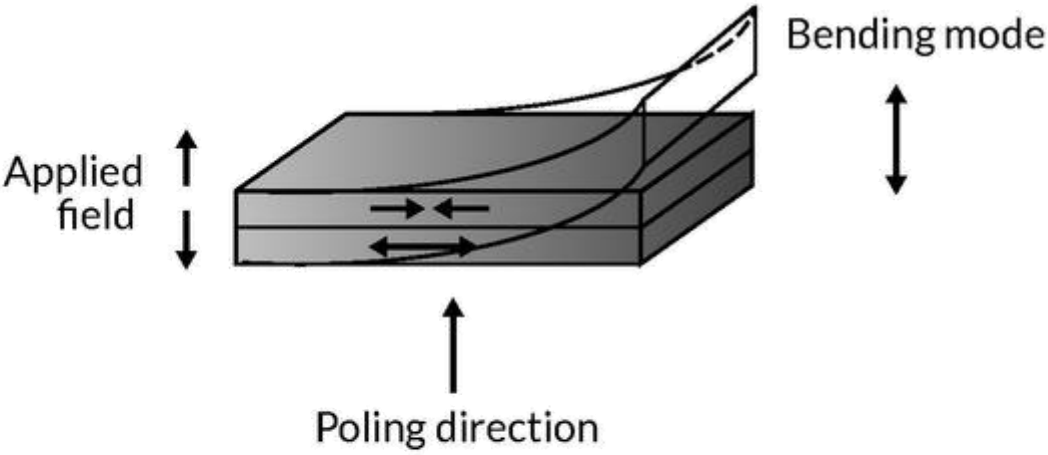


Stacked actuators

NAC20xx and NAC21xx actuators can be stacked in order to multiply the displacement. As a result, free displacement is proportional to the height of the stack. Blocking force is almost unchanged.

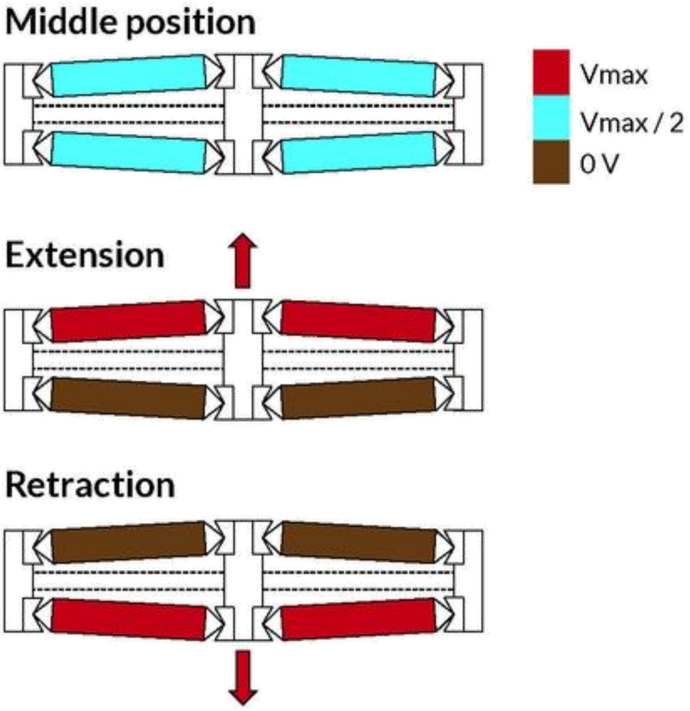
## Benders

Noliac's bender plates and bender rings (CMBP and CMBR) exploit the contraction in direction "1" and amplify it through a bending motion. As a result, large free displacements can be achieved (up to the millimeter range).



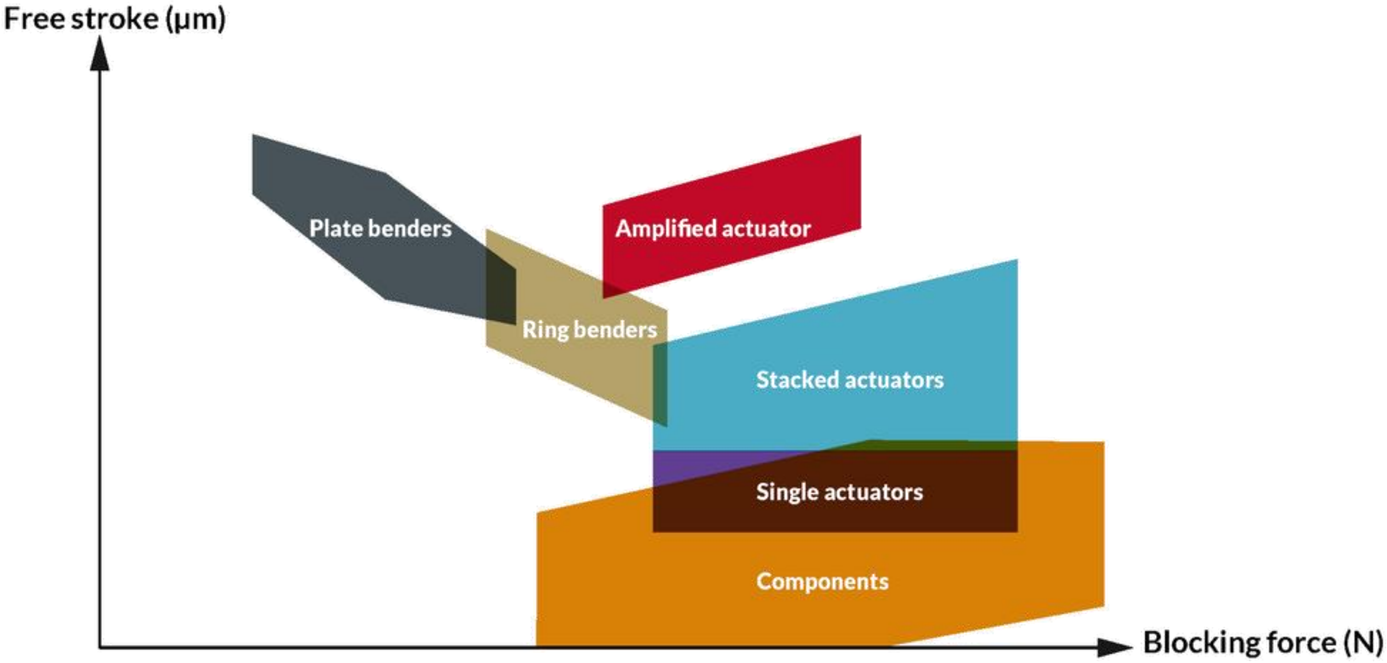
## Amplified actuators

In order to obtain even larger displacement, actuators can be coupled to an amplifying mechanical structure. The trade-off is a lower stiffness and blocking force. Many schemes can be found (lever, flextensional, hydraulic etc.). Noliac's own amplification mechanism is commonly called "diamond frame" and is based on the differential expansion of two sets of multilayer stacks in a "V" configuration. See the illustration below.



## Comparison of all actuator designs

The different actuator designs provide a wide range of performance, each with their preferred characteristics. Blocking force and free displacement performance can be plotted on a graph for the different actuator families, providing an overview of available products. Custom designs can of course expand the plotted areas.

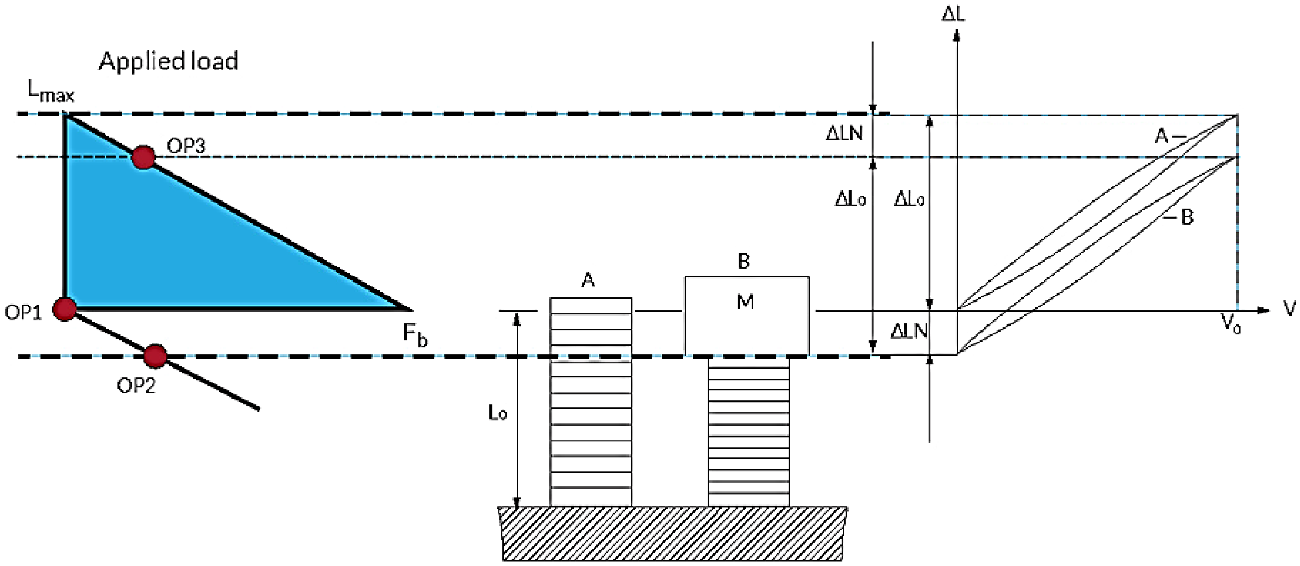


# BEHAVIOUR UNDER LOAD

**The load applied to a piezoelectric actuator plays a crucial role in defining its performance. At a given voltage, the model described in Different actuator designs defines a characteristic line on the displacement vs. force diagram, where the actuator could be. The actual operating point (force, displacement) depends on the load.**

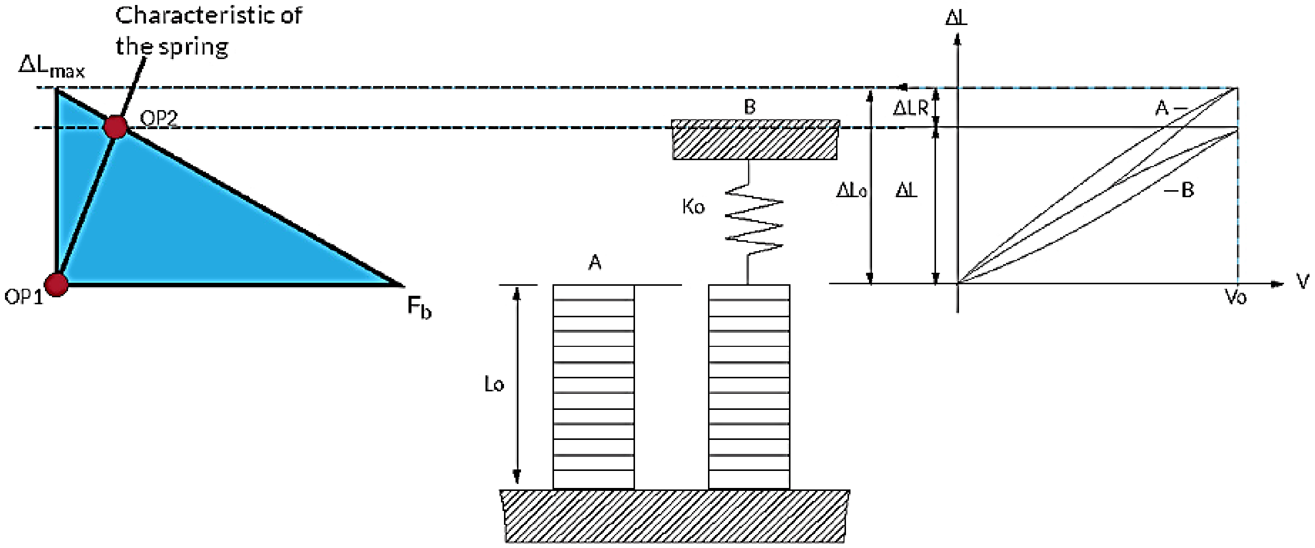
## Constant load

For example, in the case of a simple positioning table where a piezoelectric actuator moves the table in the Z direction, the load is a simple mass. Upon initial loading, the element is compressed by the mass and the actuator moves (illustrated by the operating point moving from OP1 to OP2). After that, in quasi-static operation, the force applied on the piezo element by the load is a constant force, i.e. a vertical line on the displacementvs. force diagram (the operating point moving from OP2 to OP3). The actuator can therefore generate a displacement (curve B) sensibly equal to the free displacement (curve A).



## Spring load

In another ideal case, the load can be modeled by a spring. This spring has an elastic behavior, which can be represented on the displacement vs. force diagram by a straight line with a given slope. Upon actuation, the operating point of the system will follow this line (illustrated by the operating point moving moving from OP1 to OP2). The force applied on the actuator will increase as it expands. As a result, the actuator will generate a displacement (curve B) smaller than the free displacement (curve A) and a force lower than the blocking force. See the illustration below.



## A combination of loads

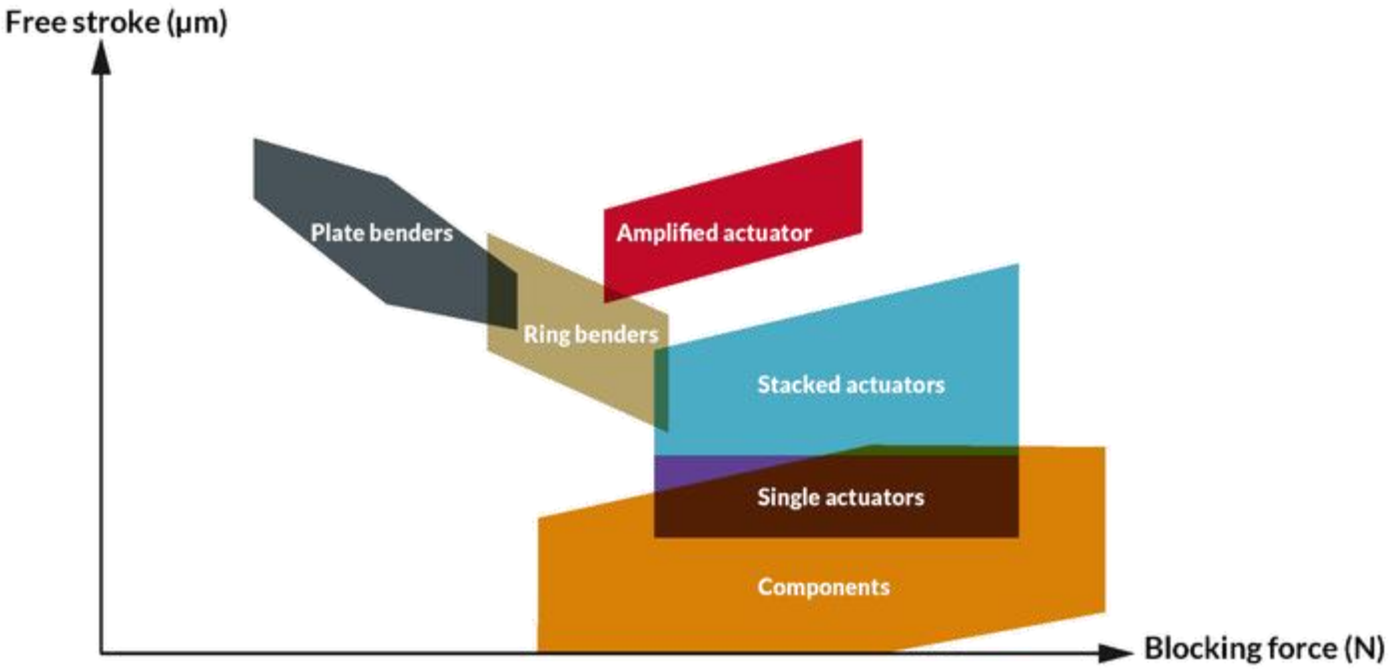
In the general case, the load is a combination, an arbitrary curve on the displacement vs. force diagram. The load can even vary during operation, so it might be a set of curves. When designing a piezo-based system, it is important to ensure that all load cases are covered so the actuator can deliver the required performance in all conditions.

# HOW TO SELECT

**When selecting a piezoelectric element for a quasi-static actuator application, the main parameter to observe is the load, i.e. the force vs. position characteristics of the load.**

## Start with force vs. displacement

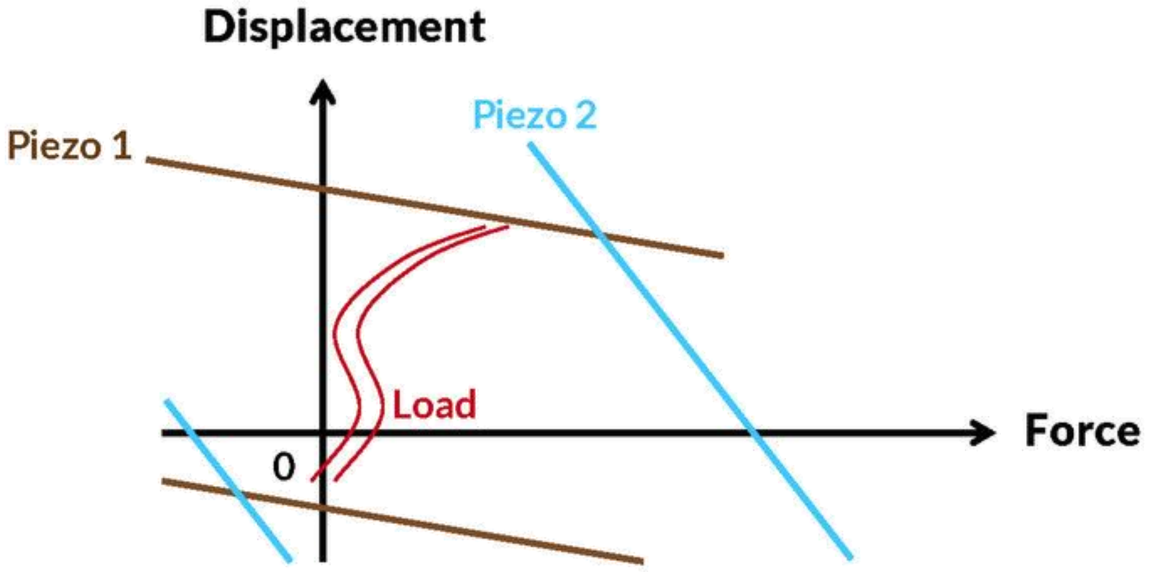
There might be a number of actuators that can fulfill the displacement vs. force requirements, i.e. whose characteristics include the load curve. A first starting point for selecting candidates can be the comparison of the different actuator designs based on actuator blocking force vs. free displacement or stroke - also to be found in the section Different actuator designs.



## What is the target of your design?

In order to choose from these options, it is important to know the optimization parameters. For example, is the target to optimize volume/mass, one particular dimension or stiffness/frequency response?

In addition, there might be other requirements, such as environmental conditions, response time, drift. It is of course important to consider these requirements as early as possible in the design process in order to make sure that the objectives are met. See the illustration below.



## Operate in the best conditions

Finally, the actuator must be used in the best conditions. Typically, an actuator can tolerate a certain range of external force. For example, we do not recommend to use linear stack (NAC20xx-Hxx or NAC21xx-Hxx) in tension. This means that, if the load has to be both pushed and pulled, a preload must be added in parallel to the actuator, to make sure that the actuator is only submitted to compressive stress. Such a preload should be designed to have a stiffness much lower than the actuator (factor 10). This ensures that the preload does not ”divert” too much of the strain energy from the piezoelectric actuator.