White Paper

System Rigidity

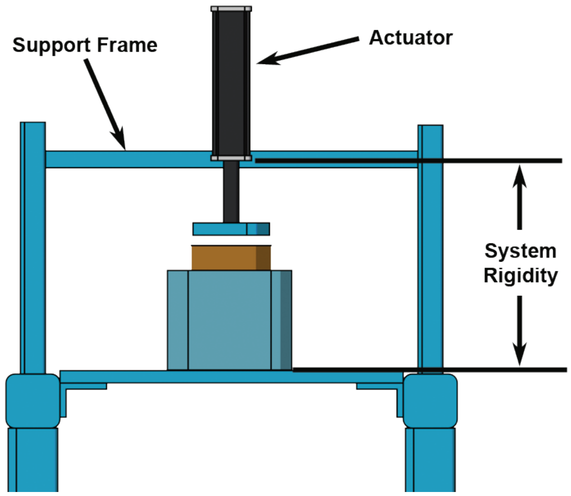
Reliable motion control is a necessary component in applications ranging from process control and defense to medical equipment and industrial automation. As a significant contributor to maintaining positional accuracy and repeatability, system rigidity is critical to ensuring continued system performance. Understanding how various motion control technologies, mounting methods and design factors impact rigidity is key to implementing actuator solutions that provide the ideal level of control and performance.

EXLAR

System Rigidity

System rigidity is defined as the amount of deflection between the end of the actuator housing and the opposing frame at the maximum system force.

System rigidity takes into account the rigidity of the actuator, actuator mounting and the supporting frame.



Systems that are designed to have low deflection at full load are considered rigid systems which will produce repeatable results over a range of system forces.

Systems with high deflection values will produce inconsistent results depending on the force being applied to a load.

As the amount of force applied by the actuator increases, the rigidity of the actuator, its mounting system, and the supporting frame become important factors in maintaining positional accuracy and repeatability.

Each of these components must be designed and evaluated to achieve the overall objective of the application. The following sections provide a methodology to evaluate differing design options.

Examples of applications where system rigidity is an important design factor:

Force Repeatability – A certain force is required to complete an operation. Typically, this is necessary in assembly processes that require a high force or a controlled force to mate parts.

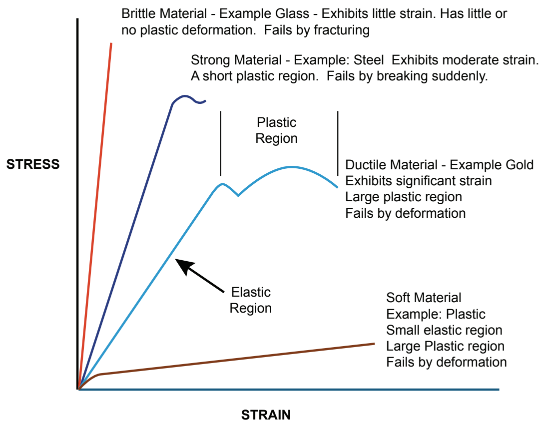
Positional Repeatability – Positioning a part for an assembly operation. If there is a variation in the force required to position a part and there is excessive flexing in the actuator, mounting or system design, the excessive flexing will impact positional repeatability.

Riveting – Both the correct positioning and force are needed to completely seat the rivet and deform it correctly.

Factors Determining System Rigidity

The rigidity of a given material is defined by its Modulus of Rigidity. Modulus of Rigidity is the coefficient of elasticity for a shearing force. It is defined as "the ratio of shear stress to the displacement per unit sample length".

Modulus of Rigidity can be experimentally determined from the slope of a stress-strain curve created during tensile tests conducted on a sample of the material. The higher the slope of the stress strain curve, or the higher the Modulus of Rigidity, the greater the materials rigidity.

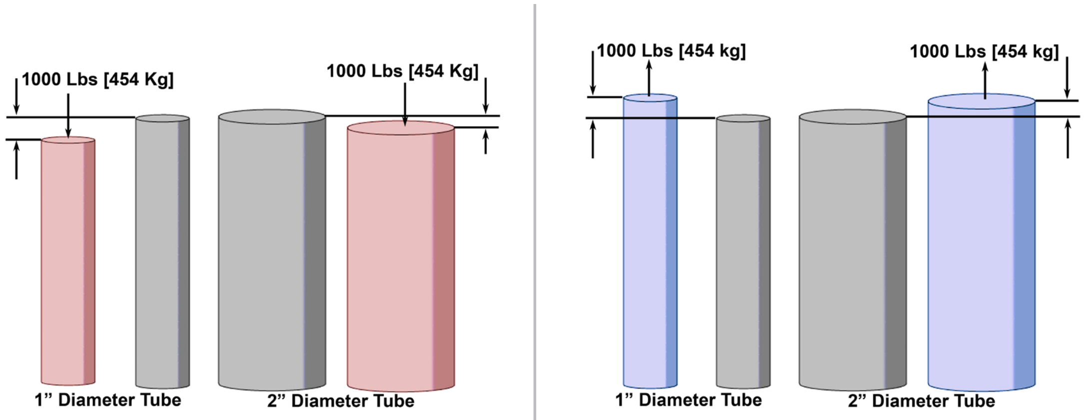


As stress is applied to each of the system components, it produces a corresponding strain or deflection that can either be measured or calculated. Stress is generally measured in Pounds per Square Inch (PSI) or Newtons per Meter Squared (N/m^2).

The amount of strain generated depends on the type of material, its hardness, its length and how the strain is applied to the component.

Stress Applied in Compression or Tensile (Elongation)

Strain is the amount of deformation or dimensional change which is directly related to the force (stress) per square area and the length of the support.



Compression Tensile

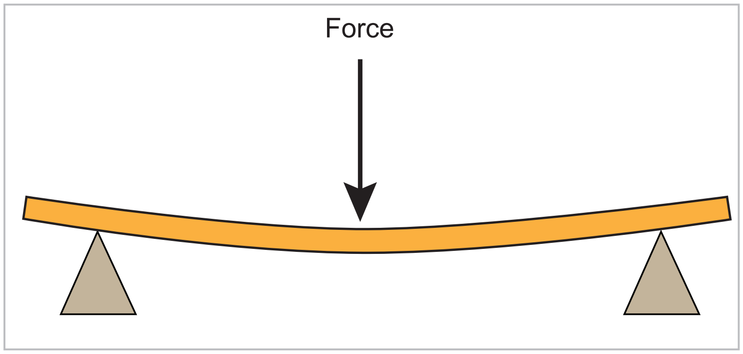
Factor	Change	Result
Length of Object	Increase	Compression Increased
Cross Sectional Area	Increase	Compression Decreased

Stress Applied in Deflection (Bending)

Deflection or bending applies to beams or flat plates that are supported at one or both ends.

Stress is applied perpendicularly causing a deflection in the material.

The amount of deflection depends on a number of factors:



- The distance between supports.
- Modulus of rigidity
- The cross sectional area of the material.
- Distance between support and the applied force.
- The structure of the component. (Flat sheet, I Beam, Tube etc.)

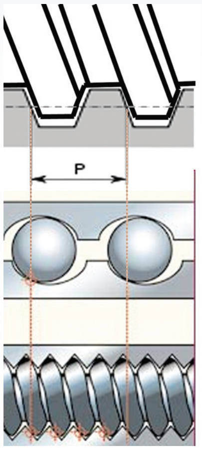
Factor	Change	Result
Distance Between Supports	Increase	Deflection Increased
Modulus of Rigidity	Increase	Deflection Decreased
Cross Sectional Area	Increase	Deflection Decreased
Distance between support and the applied force	Increase	Deflection Increased

Actuator Rigidity

Type of Actuator

The rigidity of the actuator screw is directly related to the contact surface area between the screw and the output rod. The technologies providing the best rigidity for comparably sized actuators are as follows.

- Roller Screw
- Ball Screw
- ACME Screw



Roller screws offer better rigidity because they are able to provide a greater surface area for the transfer of force as compared to Ball Screws and ACME Screws.

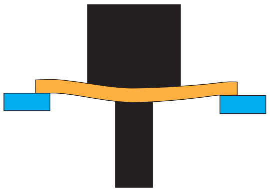
Exlar's planetary roller screw design provides many more contact points than what is possible on comparably sized ACME or ball screws. The diagram at right illustrates the difference in the number of contact points between comparable ACME screws, Ball screws and Roller screws.

Field testing of Exlar roller screw actuators has demonstrated a rigidity of 800,000 lbs/Inch [14,286 Kg / mm]. The amount of deflections at a given load can be calculated using the following formula: Compression = Actual Force/Rigidity. An actuator with a rigidity of 800,000 lbs / inch [14,286 Kg / mm] generating a force of 5,000 lb [2268 Kg] would deflect 0.0062 inches [0.159 mm].

Generally, the larger the actuator, the greater its rigidity. An actuator rated at 7,000 lbf [31137 N] will be more rigid than a 2,000 lbf [8896 N] actuator. If high rigidity in the actuator is required, it is advisable to select an actuator with a higher force rating and use it at a lower force in the actual application.

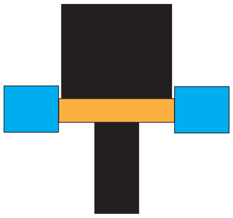
Actuator Mounting Methods

Beyond the rigidity of the internal mechanism of the actuator, the method of mounting can also impact overall actuator rigidity. For example, a front flange mounting can introduce an undesirable deflection.



Front Flange Mounted Actuator Deflection Under Load

The internal force of the actuator is transmitted to the front face of the actuator. Mounting directly to the front face plate can improve the overall rigidity of the actuator because the force is not transmitted through the actuator housing or tie rods. Ideally the mounting method should direct the force to the center line of the actuator housing.



Double Side Mounted Actuator

The order of preferred mounting methods for the highest rigidity are as follows:

- Double Side Mounts
- Rear Clevis
- Single Side Mount both front and back
- Extended Tie Rod
- Side Trunnion
- Front Flange

System Integration

Controlling aspects of the actuator, actuator mounting and the associated framework is key to obtaining the desired system rigidity. Care must be taken to ensure that the framing that supports the actuator and the intended load do not introduce dimensional instability.

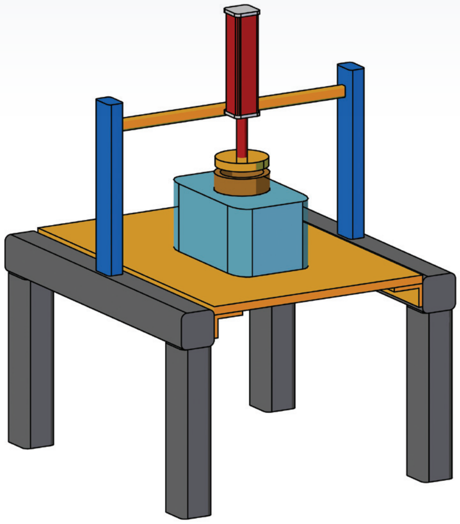
The figure on right shows a simplified system designed to press a bearing into a housing.

The system components are color coded to illustrate the system components which impact system rigidity.

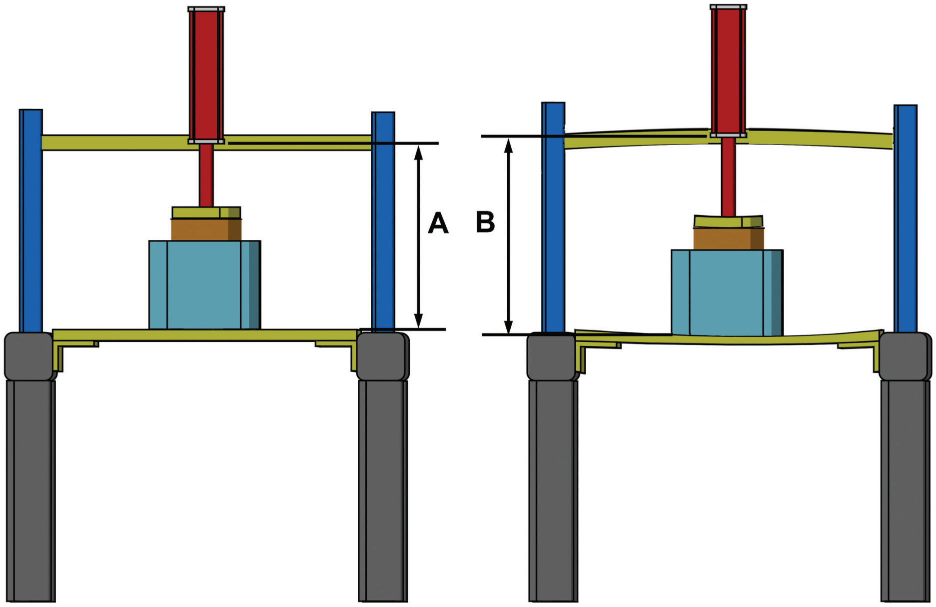
Red indicates deformation due to compression.

Blue indicates deformation due to tensile (elongation).

Orange indicates deformation due to deflection or bending.



As the force generated by the actuator increases, the various components in the system react in a predictable manner. The following illustration shows an exaggerated view between the system at zero force and one at full load. The difference between dimensions A and B represent the system's rigidity.

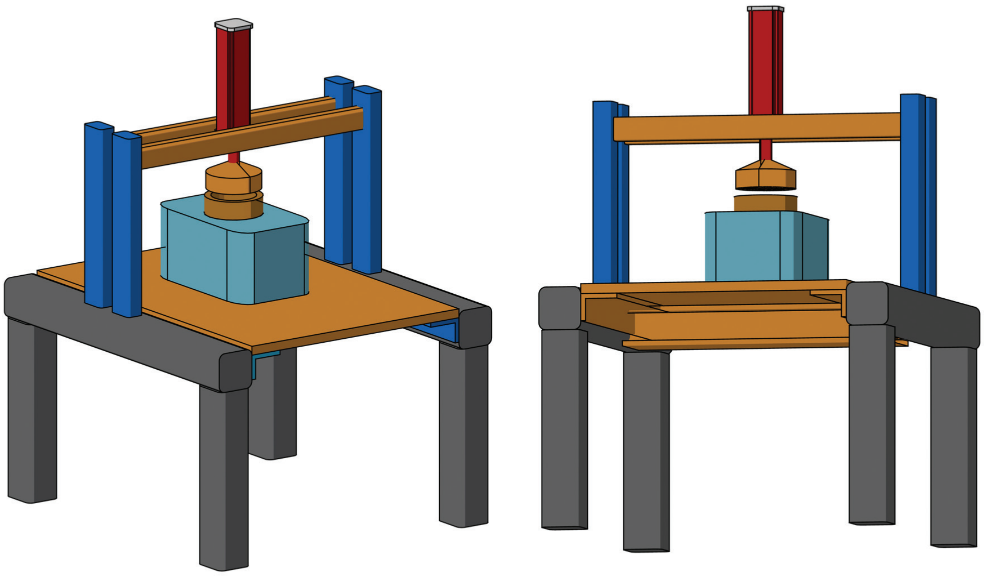


By analyzing individual components impacting system rigidity we can develop a systematic approach to defining and improving the system's rigidity.

Component	Dimensional Change at 5,000 lbf [22,241 N]
Actuator	0.006 in [0.15 mm]
Press Tool	0.005 in [0.13 mm]
Structure Supporting the Product	0.080 in [2.03 mm]
Vertical Posts Supporting the Actuator	0.002 in [0.05 mm]
Cross Support and Actuator Mounting	0.030 in [0.76 mm]
Total System Deflection	0.123 in [3.12 mm]

System Rigidity

Using a systematic analysis of the overall system design, changes can be made to dramatically improve system rigidity within the limits for the applications.



Component	Proposed Design Change	Original Dimensional Change	Original Dimensional Change with Design Changes
Actuator	None	0.006 in [0.15 mm]	0.006 in [0.152 mm]
Press Tool	Increase the thickness of the tool and improve the geometry of the part.	0.005 in [0.13 mm]	0.0005 in [0.013 mm]
Structure Supporting the Product	Add an "I" beam under the support plate.	0.080 in [2.03 mm]	0.0005 in [0.013 mm]
Vertical Posts Supporting the Actuator	Add two additional vertical supports	0.002 in [0.05 mm]	0.0005 in [0.013 mm]
Cross Support and Actuator	Increase the size of the support beam. Add a second cross beam and mount the actuator to each cross beam.	0.030 in [0.76 mm]	0.001 in [0.025 mm]
Total System Deflection		0.123 in [3.12 mm]	0.0085 in [0.216]