

01 / TECHNICAL GUIDE

NLT143 RESEARCH

What is an actuator and how does it work.

A first-principles technical reference. Physics, families, selection, anatomy of a representative actuator.

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Frame

An actuator is the device that turns a signal into motion. Every example you can name, a Boeing 787 flap motor, a piezoelectric fuel injector, the wrist joint of a humanoid robot, the hydraulic ram on an excavator, the thermal expansion element in a thermostat, fits this definition. The interesting work is in the conversion. The signal arrives in one form, almost always electrical, and leaves in another, almost always mechanical. The actuator is the bridge.

The three required ingredients

Every actuator needs three things, and removing any of them stops the device from being one.

- **A power source.** Electrical, hydraulic, pneumatic, chemical, or thermal energy that the device can draw on.
- **A converter.** The element that translates that power into useful mechanical work.
- **A control input.** A signal, often small, that commands the converter to produce a specific position, velocity, force, or torque.

The physics, in four equations

The math an engineer reaches for when sizing an electric actuator is small. Four equations cover most of the work.

$$\text{torque} = K_t \times \text{current}$$

$$\text{force} = (2\pi \times \eta / L) \times \text{torque}$$

$$F_{\text{net}} = \text{mass} \times \text{acceleration}$$

$$V_{\text{back_emf}} = K_e \times \text{angular_velocity}$$

K_t is the torque constant of a brushless DC motor. K_e is the back-EMF constant. η is mechanical efficiency. L is the lead of a ball screw. Efficiency in real-world actuators ranges from about 30 percent for cheap pneumatic systems to 95 percent for direct-drive electric machines.

The eleven families

- **Electric rotary.** Robot joints, EV traction, factory servos.
- **Electric linear.** Window blinds, hospital beds, satellite arrays.
- **Stepper.** 3D printers, CNC, camera focus rings.
- **Hydraulic.** Excavators, aircraft control surfaces, presses.

- **Pneumatic.** Pick-and-place, brakes, soft robotics.
- **Piezoelectric.** Microscope stages, fuel injectors.
- **Shape memory alloy.** Aerospace deployables, stents.
- **Electrostatic.** MEMS mirrors, micro-pumps.
- **Magnetostrictive.** Sonar, precision tooling.
- **Dielectric elastomer.** Artificial muscles, haptics.
- **Pyrotechnic.** Airbag deployment, separation bolts.

Anatomy of a representative actuator

A typical industrial linear actuator built for robotics: a brushless DC motor drives a ball screw through a planetary or harmonic gearbox. The screw rotates inside a non-rotating push tube. As the screw turns, the nut translates, pushing or pulling the tube.

Stroke	200 mm
Force	2.5 kN
Max speed	50 mm/s
Lead	5 mm/rev
Repeatability	±0.05 mm
Cycle life	10 ⁷ cycles
Power	350 W peak
Mass	1.8 kg
Latency	1 to 5 ms (command to motion)

How to choose

Selection is five questions, in order. Most misallocations come from skipping question one.

- How much force or torque does the load require, peak and continuous.
- How fast must it move, and how often.
- How precisely must it stop.
- What is the environment.
- What is the cost target.

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