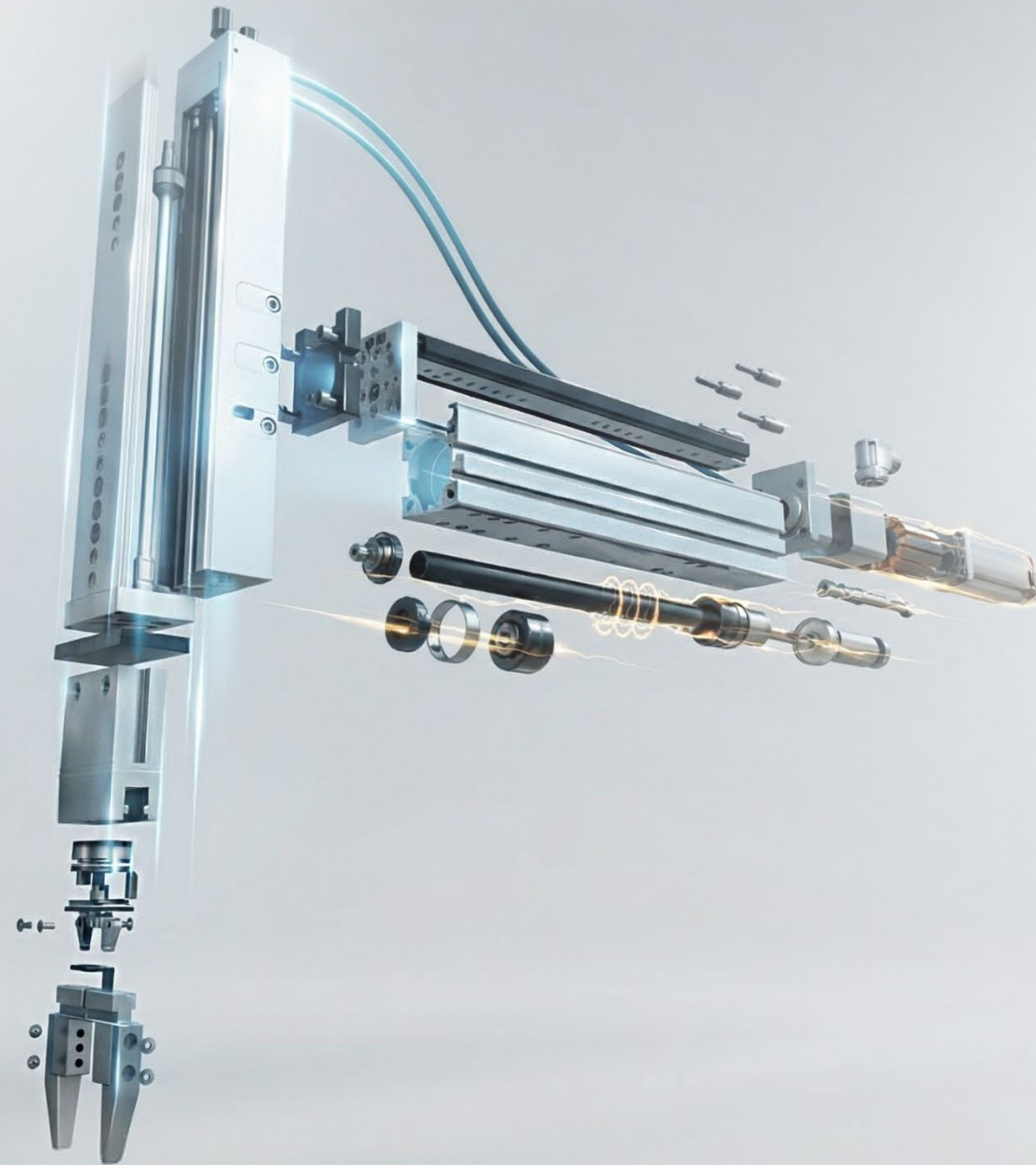


Pneumatics or Electrics in Factory Automation

How to choose the actuator technology that fits your needs



Pneumatics or Electrics in Factory Automation

How to choose the actuator technology that fits your needs

In modern manufacturing environments, design and automation engineers are frequently faced with the question which actuator technology is the optimal choice for a particular motion task: pneumatic or electric actuators? Both technologies are used extensively in factory automation, each offering its own advantages. Pneumatic cylinders are valued for their robustness, simplicity, and cost efficiency, while electric actuators stand out for their precision, flexibility, and energy efficiency. The choice of drive technology has a direct impact on the performance, efficiency, and cost-effectiveness of a production system.

However, there is no simple answer to the question “Pneumatics or electrics – which is better?” The optimal solution always depends on the specific requirements of the application. This white paper systematically compares the two technologies and their variations. It explains the most important decision criteria and illustrates, using typical industry examples, which aspects are particularly relevant in practice. The objective is to provide practical advice for designers, users, and technical decision-makers, ensuring that the solution that is technically and economically most suitable can be identified for every task.

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Pneumatic and Electric Actuator Technologies

Principle of operations, key characteristics, and typical application profiles

Before evaluating the advantages and disadvantages of the two technologies, it is worth taking a closer look at the operating principles and typical configurations of pneumatic and electric actuators.

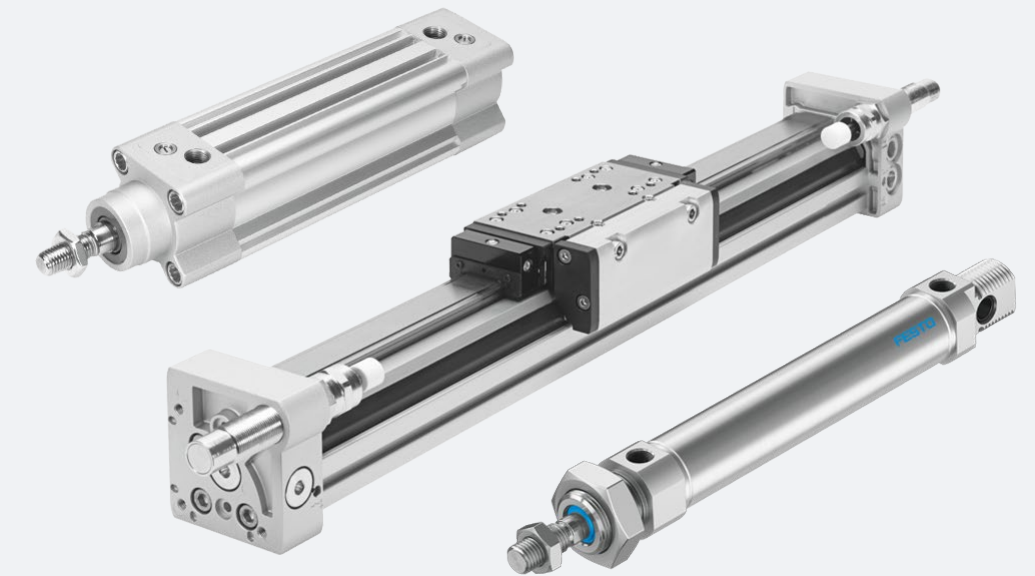
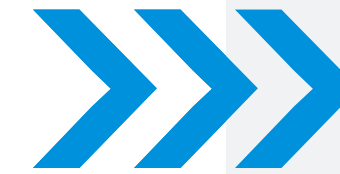
Pneumatic actuators – Standard and servo

Pneumatic actuators use compressed air as their energy source. The pressurized air in a cylinder acts on a piston, generating a force that produces linear motion and a pressing force in the end position. Standard pneumatic cylinders are typically operated from end position to end position (fully advanced and retracted) and their simple design makes them extremely reliable. They consist of only a few components, making the technology robust, low-maintenance, and relatively easy to operate. Pneumatics is widely used across many industries, for example for rapid workpiece movement, clamping, holding, or pressing tasks.

A major advantage of pneumatic actuators is that once a workpiece has been positioned (e.g., by a clamping cylinder), the actuator requires no additional energy to maintain the force. This characteristic makes pneumatic cylinders ideal for tasks such as holding and fixing, where electric actuators often consume power continuously to maintain the load.

However the simplicity of pneumatic cylinders also has its limitations. Without special adaptations, they primarily operate between end positions; intermediate positions or precise speed profiles can only be achieved by using additional valve technology or extra components. Furthermore, compressed air as a drive medium is inherently elastic — motions are “soft”, which can dampen shocks but reduces positioning accuracy.

To improve the controllability of conventional pneumatic systems, servo-pneumatics were developed. This approach combines regulated pneumatic actuators with sensors (e.g., position transducers on the cylinder) and electric proportional valves, enabling smooth positioning and force control. Servo-pneumatics effectively merges the advantages of both worlds: it facilitates intermediate positions and gentle deceleration using controlled back-pressure, so that the cylinder can stop without impact. It allows free positioning and even simple motion profiles. At the same time, typical advantages of pneumatics are retained: the actuators still operate with compressed air, adding no heat to the process, are still inherently flexible, which can be beneficial for delicate workpieces.



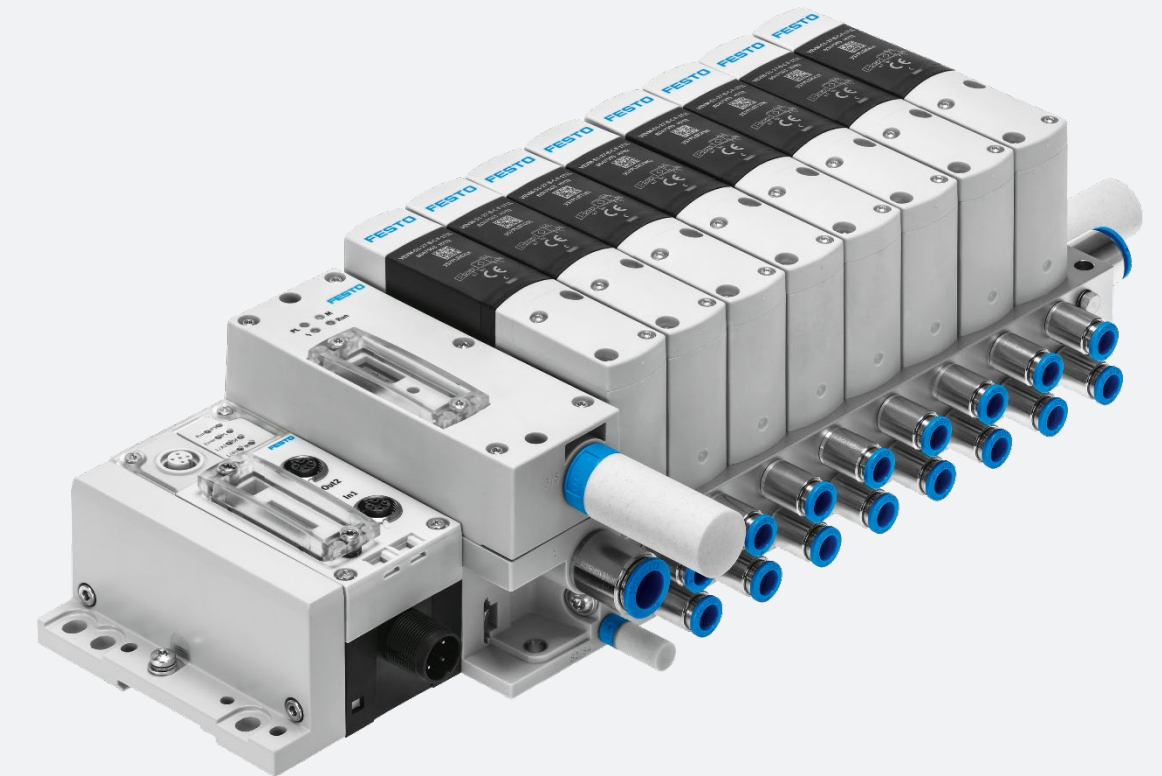
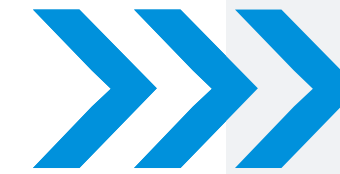
01 Typical pneumatic actuators

Pneumatic and Electric Actuator Technologies

Principle of operations, key characteristics, and typical application profiles

Servo-pneumatic axes demonstrate their potential particularly when low masses need to be moved at very high speeds or when rapid switching between positioning and force control is required during a process (e.g., during press-fitting operations). However, servo-pneumatics requires additional components (valve control, measurement systems controllers); this makes it more expensive to purchase and more complex to integrate than standard pneumatic solutions. It is therefore often used selectively for applications where conventional pneumatics is insufficient but a fully electric solution would be uneconomical or unnecessary.

An example of servo-pneumatics is the Motion Terminal VTEM developed by Festo“ a platform that allows a variety of pneumatic functions to be implemented via software apps – from simple switching valves to complex proportional controls – without hardware modifications. This digitalization greatly enhances process reliability and flexibility, as settings can be reproduced in software and format changes or cycle time optimizations can be implemented quickly. Developments like these demonstrate that pneumatics continues to evolve and remains a technology ready for the future.



02 Servo-pneumatics with Festo Motion Terminal VTEM

Pneumatic and Electric Actuator Technologies

Principle of operations, key characteristics, and typical application profiles

Electric actuators — Ball screws, belt drives, and other types

Electric actuators convert electrical energy into mechanical motion using motors. The type of actuator most used in factory automation is the electromechanical linear actuator, which has a rotating servo or stepper motor that generates linear motion via a mechanical transmission system. The most common designs include:

Ball screws (ball screw actuators):

A motor drives a ball screw that moves a nut, producing linear motion. Ball screw actuators provide high positioning accuracy and repeatability as well as excellent force transmission due to the screw mechanism. However, their maximum speed is limited, and long strokes require long screws. Therefore, they are best suited for applications requiring high forces or precision over relatively short travel distances, such as for precisely positioning heavy workpieces.

Belt drives:

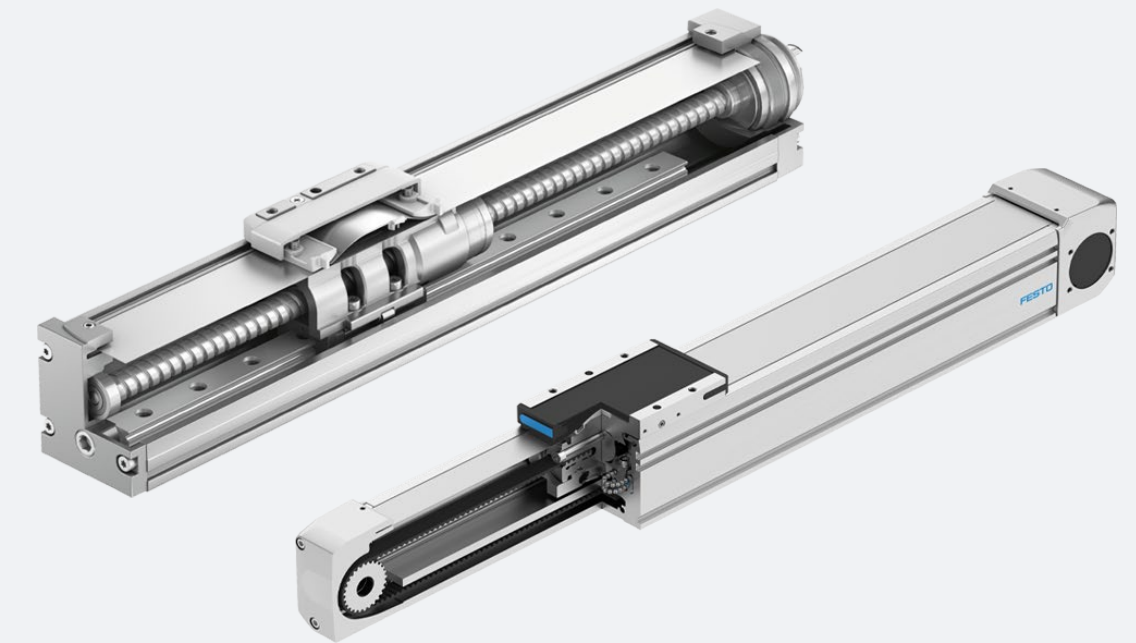
Here, the motor drives a toothed belt connected to a carriage or axis. Belt-driven actuators enable long travel distances and high speeds but offer lower stiffness and accuracy, as the belt is elastic and allows a slight deflection. They are widely used in pick-and-place systems, gantry axes, and packaging machines, where high dynamics and extended stroke length are more important than maximum precision or force.

Electric cylinders (integrated linear actuators):

These are electromechanical actuators in the form of a cylinder with a motor and linear mechanics (e.g., ball screw) integrated into one unit. Often used as direct replacements for pneumatic cylinders, they fit into similar installation spaces and usually include built-in linear guides. They are easy to install since both motor and encoder are typically integrated.

In addition to these main types, there are other designs. Linear motor axes (direct drives) use electromagnetic forces instead of mechanical transmission to generate linear motion; they offer high dynamic response and precision but are more costly and more complex to control. Rack-and-pinion systems convert rotary motion via a pinion to linear motion along a gear rack, mainly applications with high forces or long travel distances. For very short strokes with a high dynamic response, solenoids or voice coil actuators are commonly used.

Modern electric actuators are considered true all-rounders in automation: they are suitable for linear and rotary multi-axis systems, enable precise, fast, and highly dynamic movements including synchronized motion across multiple axes and can be flexibly tailored to each task by combining motors, gearboxes, and mechanics.



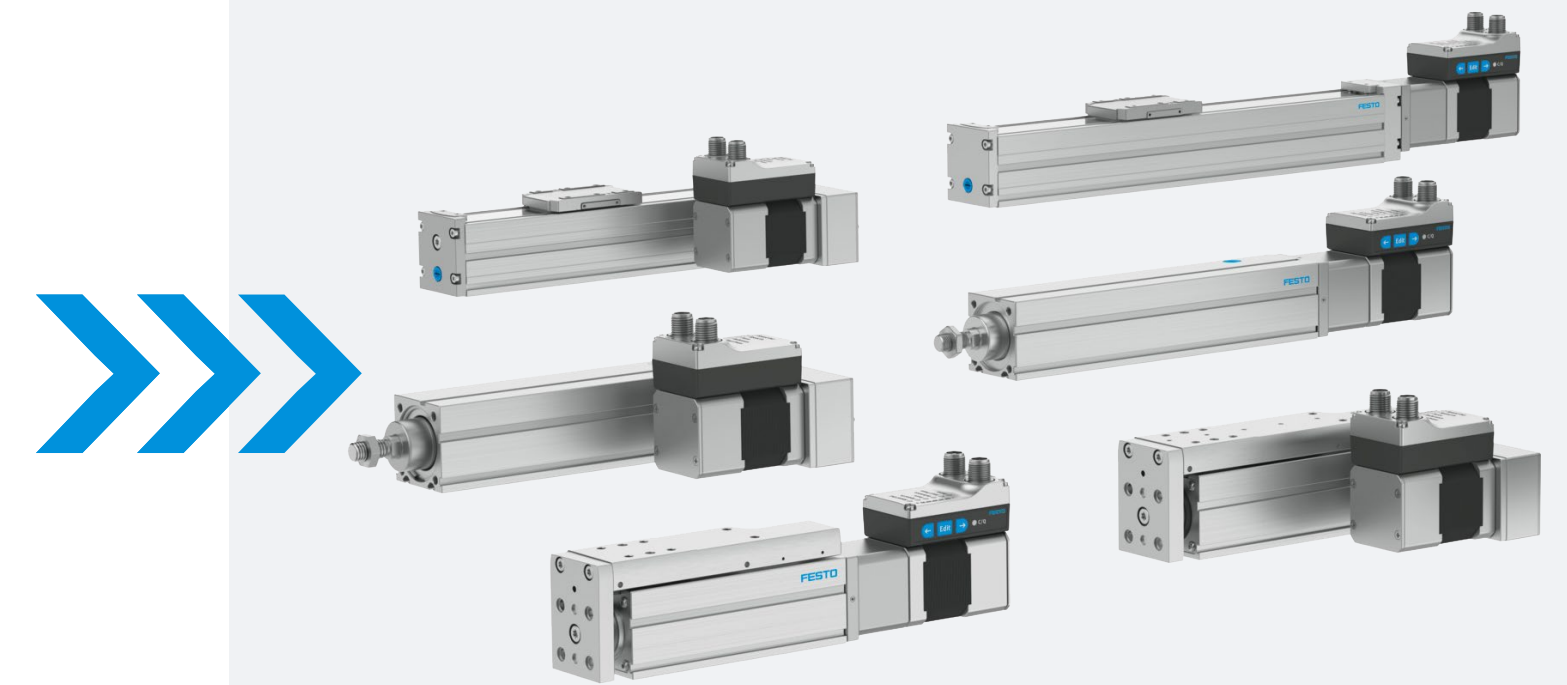
03 Ball screw (left) and belt drive (right)

Pneumatic and Electric Actuator Technologies

Principle of operations, key characteristics, and typical application profiles

Electric servo systems are inherently versatile, making commissioning relatively complex as it involves the parameterization of amplifiers and controller tuning. However, recent developments show that electric actuators are becoming increasingly user-friendly. Simplified electric actuators are now available that work almost “out of the box.” One example is the Simplified Motion Series from Festo, which requires no programming. The positions are set via integrated end stops, speed and force are adjusted using push buttons, and yet modern features such as IO-Link communication for diagnostics and flexible force control are included.

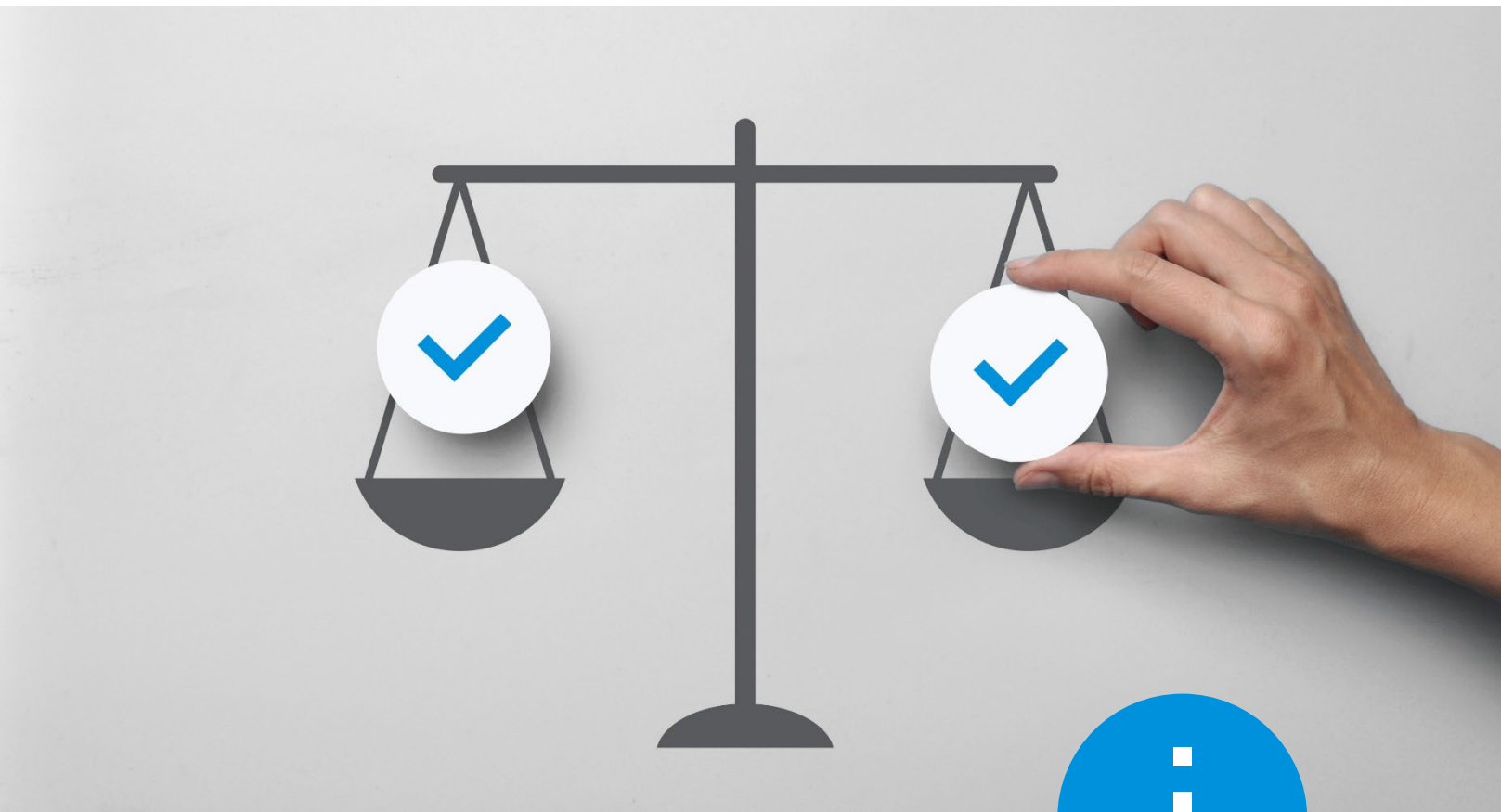
Such integrated solutions effectively offer features that are common in pneumatics, such as easy commissioning and a compact design while retaining the core advantages of electric actuators: higher precision, freely programmable motion profiles, smooth acceleration and deceleration, and seamless integration into modern control architectures.



04 Components of the Simplified Motion Series

Evaluation Criteria for Technology Comparison

Advantages and disadvantages of the two technologies



Which technology most suitable for which application?

On the following pages, the key selection criteria are examined, from dynamics and force to cost, maintenance, and sustainability. For each aspect, a brief explanation is provided along with a concise comparison of pneumatic and electric actuators.

Dynamics and motion quality

The required motion dynamics - that is, how fast and with what force an actuator must operate - is a key selection criterion. In principle, both technologies can achieve high speeds, but they do so in different ways and under different conditions.

Pneumatic actuators

Pneumatic actuators are capable of generating high peak accelerations, particularly when the mass to be moved is low. Short strokes of just a few centimeters can be completed in fractions of a second. In packaging or assembly machines, small cylinders can achieve cycle rates of several hertz. The response time (valve actuation to movement start) is typically in the range of a few tenths of a second or less.

Since pneumatic actuators normally do not generate heat, they can be operated continuously at high cycle rates over long periods of time.

However, in highly dynamic applications, motion quality and end-position damping can become challenging. In classic pneumatic systems, speed and cycle rates must be reduced when noticeable shocks occur in the end position. In these cases, servo-pneumatics can be used as it enables smooth deceleration and improved end-position control.

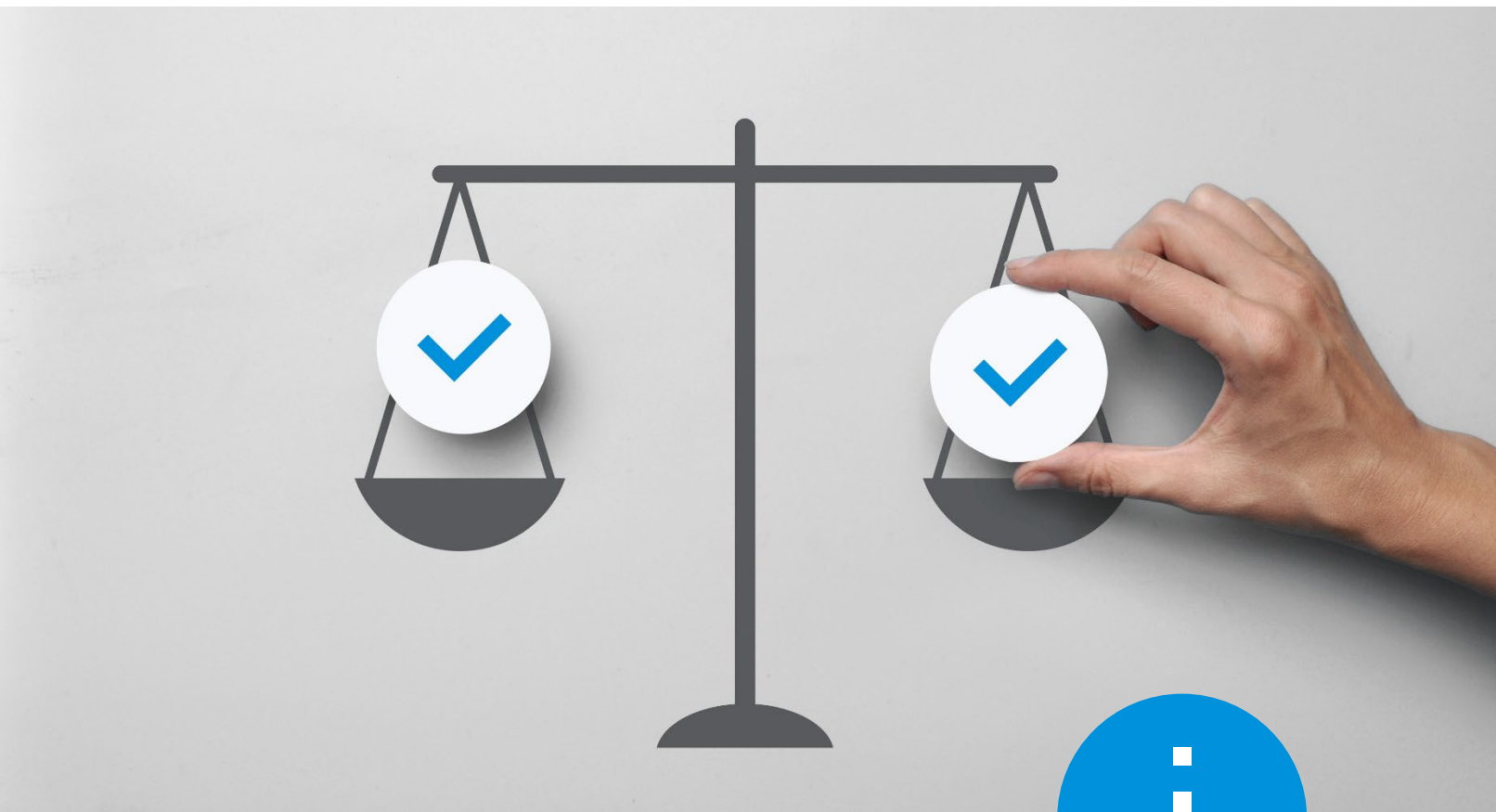
Electric actuators

Electric actuators, particularly belt drives, can deliver an extremely dynamic performance. They allow for high accelerations and precise motion paths, which can be reproduced even under varying loads. Freely programmable motion profiles, such as S-shaped acceleration ramps, also enable smooth, high-speed movements.

However, a note of caution: electric systems may have mechanical limitations at high speeds. A ball screw actuator has a maximum rotational speed, and a belt may be susceptible to vibrations. Nevertheless, electric actuators are generally the first choice for demanding dynamic profiles, especially when movements must be synchronized across multiple axes or when a wide range of speeds is required. They provide stable motion characteristics and have proven their performance in applications with high dynamic requirements.

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Force and power density

In many applications, the goal is to achieve the highest possible force while keeping the installation space as compact as possible. Both technologies can cover a wide range of force requirements, but each has its own strengths.

Pneumatic actuators

Compressed air can generate remarkable forces. The thrust force of a linear cylinder (neglecting friction) is the result of the supply pressure p multiplied by the piston area. As a rule of thumb: per bar and cm^2 , the output is about 10 N. With larger cylinders (e.g., diameter 100 mm and a typical supply pressure of 6 bar), forces exceeding 4000 N can already be achieved.

The power density (force relative to installation volume) of pneumatic systems is very high. This makes pneumatics advantageous in compact machines where high forces are required. For example, pneumatic press cylinders are frequently used for punching or pressing in small parts at high cycle rates, because they deliver a high force and are very compact.

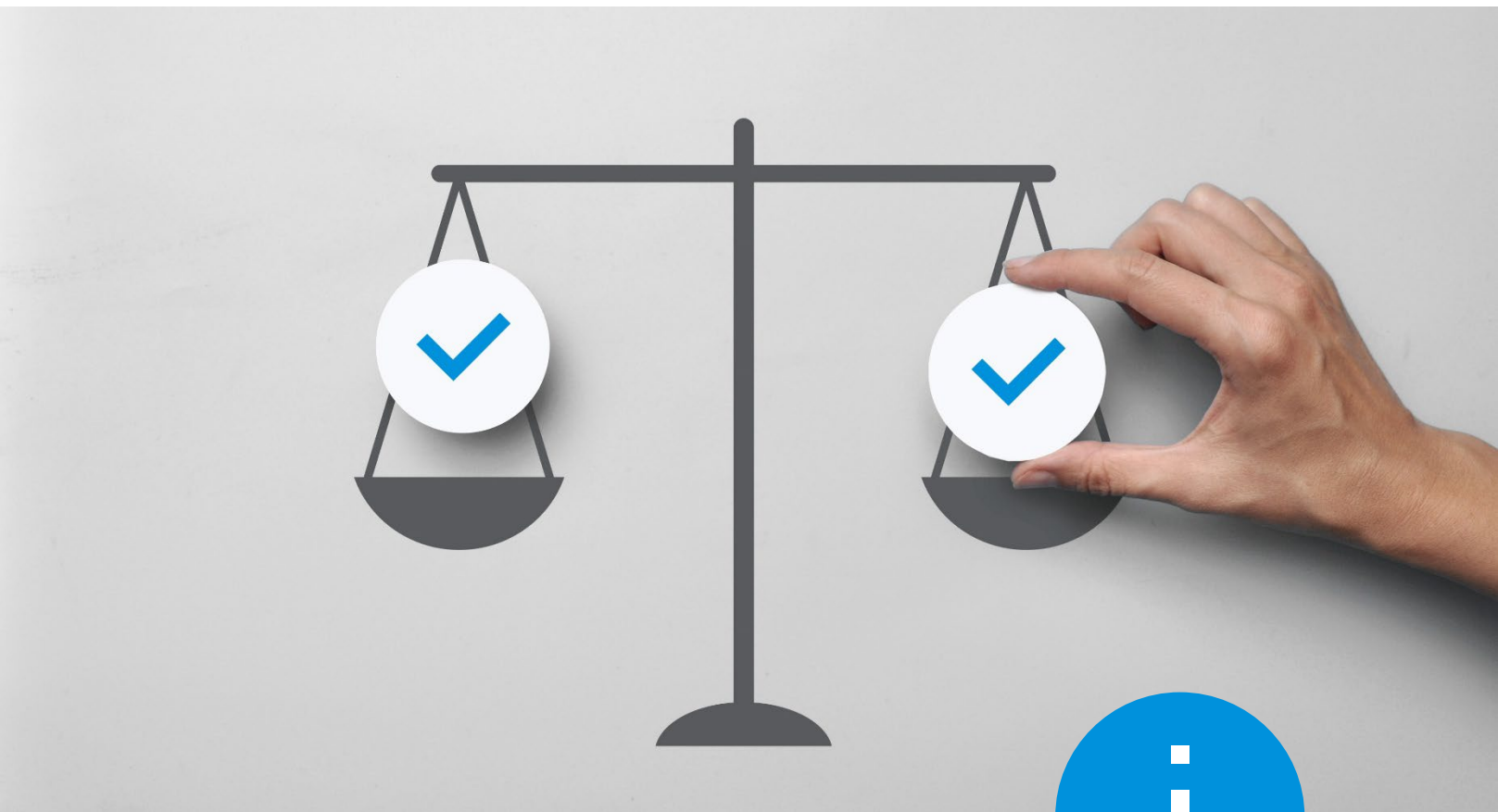
Electric actuators

Electric linear axes can also generate high forces using gearboxes or ball screws. A ball screw with a low pitch acts as a force amplifier. Commercially available electromechanical cylinders with integrated servo motors can reach forces of 10 to 20 kN.

In theory, the force is limited only by motor power and transmission ratio. However, increasing either the motor power or the transmission ratio inevitably results in a larger, heavier, and more costly actuator, as higher forces require more robust components and materials. While the force density of electric actuators has improved in recent years (thanks to advances in motors and materials), it generally still remains lower than that of pneumatics.

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Holding forces

In some applications, a holding force needs to be maintained after the movement, for example when clamping or pressing workpieces. These holding phases can be relatively long, such as when the workpiece is being processed during this time. This aspect should therefore also be taken into account when evaluating pneumatic and electric actuators.

Pneumatic actuators

Pneumatic cylinders are supplied with compressed air to generate a movement. In the end position, they develop a holding force that remains available without any additional energy input. A pneumatic cylinder therefore enables “power-free holding”, even over long periods of time.

Applications requiring high continuous forces can be found, for example, in automotive body manufacturing, where sheet metal parts must be securely held during welding. This is why pneumatics often is the preferred choice.

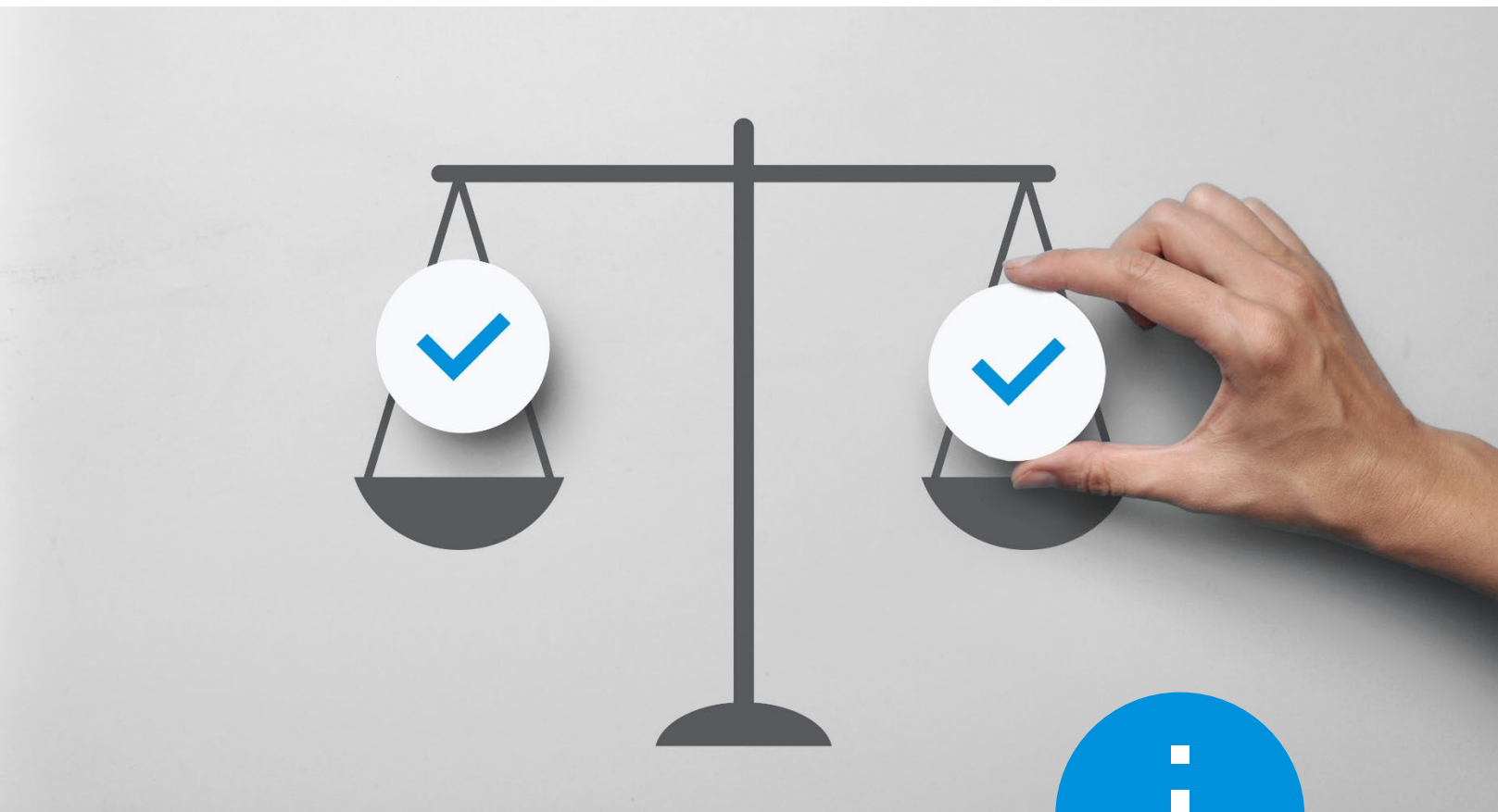
Electric actuators

Electric linear actuators without self-locking mechanisms (e.g., belt drives) require a continuous power supply or an additional holding brake to maintain their position and force. This can be a disadvantage in terms of energy consumption, especially during long holding phases.

In contrast, self-locking ball screws maintain their position without further energy input. In addition, electric actuators offer precise position control, which is useful for applications requiring high accuracy.

Evaluation Criteria for Technology Comparison

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Stiffness vs. flexibility

There is no general statement that can be made about this particular feature. In some applications, considerable stiffness is required, particularly when precise positioning is essential. In other applications, a certain degree of flexibility is advantageous, for example with sensitive workpieces or when there is a risk of collision within the motion range.

Pneumatic actuators

The behavior of pneumatic drives when external forces act on them is relatively flexible as the compressed air behaves much like a mechanical spring. Under load, the cylinder yields until the pneumatic force and the external force are in equilibrium.

This characteristic is useful, for example, if there is a risk of external shocks or impact loads potentially damaging an electric drive. It is also advantageous when assembling delicate parts or handling fragile workpieces. If there is actually a need for a certain flexibility, the spring stiffness can even be predefined and adjusted within limits by selecting cylinders with appropriate piston areas and setting a specific holding pressure via a regulator.

However, in applications requiring high positioning accuracy or in form-fitting processes, this flexibility can be a disadvantage.

Electric actuators

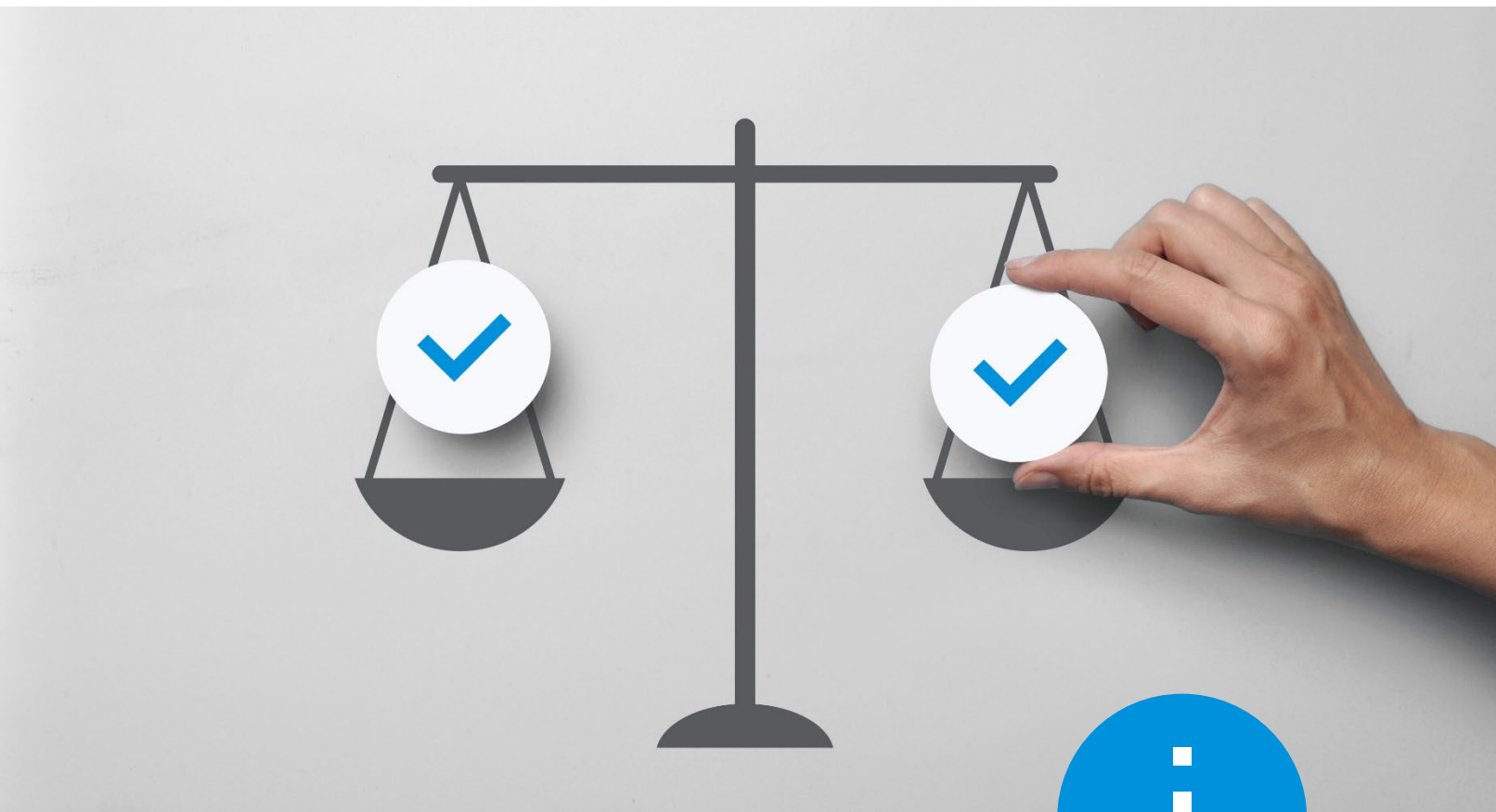
Electric actuators – particularly ball screws — are inherently stiff due to their mechanical design. Ball screw actuators are made up of positively or frictionally engaged components (ball screw, nut and roller bearings) that permit only very little elastic deformation.

High stiffness is a major advantage for applications requiring precise positioning. Even under varying loads, the position is held accurately and consistently.

If needed, electric actuators can be made to be flexible by activating a force control mode in the controller or using a software-based elasticity model. However, these solutions require appropriate sensors and are therefore relatively complex.

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Adaptability and programmability

Adaptability refers to the ability to adjust motion sequences to new requirements without mechanical modifications. This can be done, for example, by adjusting target positions, varying speeds, or integrating the actuator into complex control systems.

Pneumatic actuators

Conventional pneumatic actuators typically move between two fixed end positions. Intermediate positions or variable motion profiles can only be achieved with significant mechanical and control effort.

Servo-pneumatics can improve flexibility, but it also increases the need for sensors and control technology. As a result, the system becomes more complex and costly.

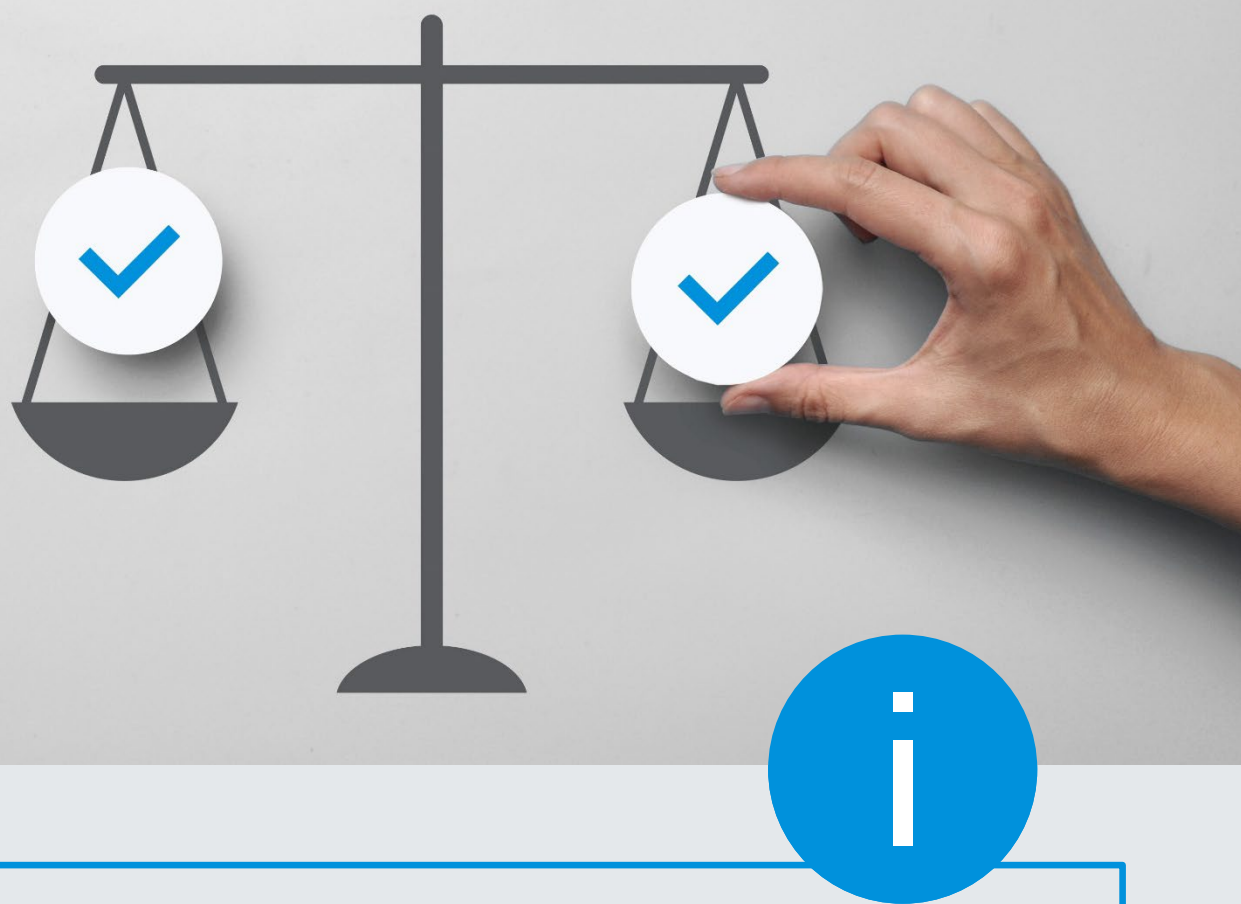
Electric actuators

Electric actuators can be flexibly programmed and freely positioned. Speed, position, force, and motion profile can all be individually adapted to the application.

Thanks to integrated sensors and control technology, they are particularly well suited for changing requirements, complex movements, and seamless integration into automated control systems.

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Ease of installation, commissioning, and maintenance

Practical criteria such as engineering effort, ease of use, and maintenance requirements should not be underestimated. Depending on company culture and available technical staff, a “keep it simple” approach can be a decisive factor.

Pneumatic actuators

Pneumatic systems are easy to install and commission. Cylinders are mechanically mounted, connected via tubes, and controlled using valves. A test pulse is often sufficient for verification. Most maintenance engineers are familiar with the technology, and operation is intuitive.

Spare parts are also easy to obtain, as many components are standardized and inexpensive. Maintenance is usually limited to checking for leaks and ensuring correct air preparation. Faulty cylinders or valves can be easily replaced, often without special tools.

Pneumatics is particularly quick to get up and running in simple applications – an advantage in environments in which automation experience or staffing is limited.

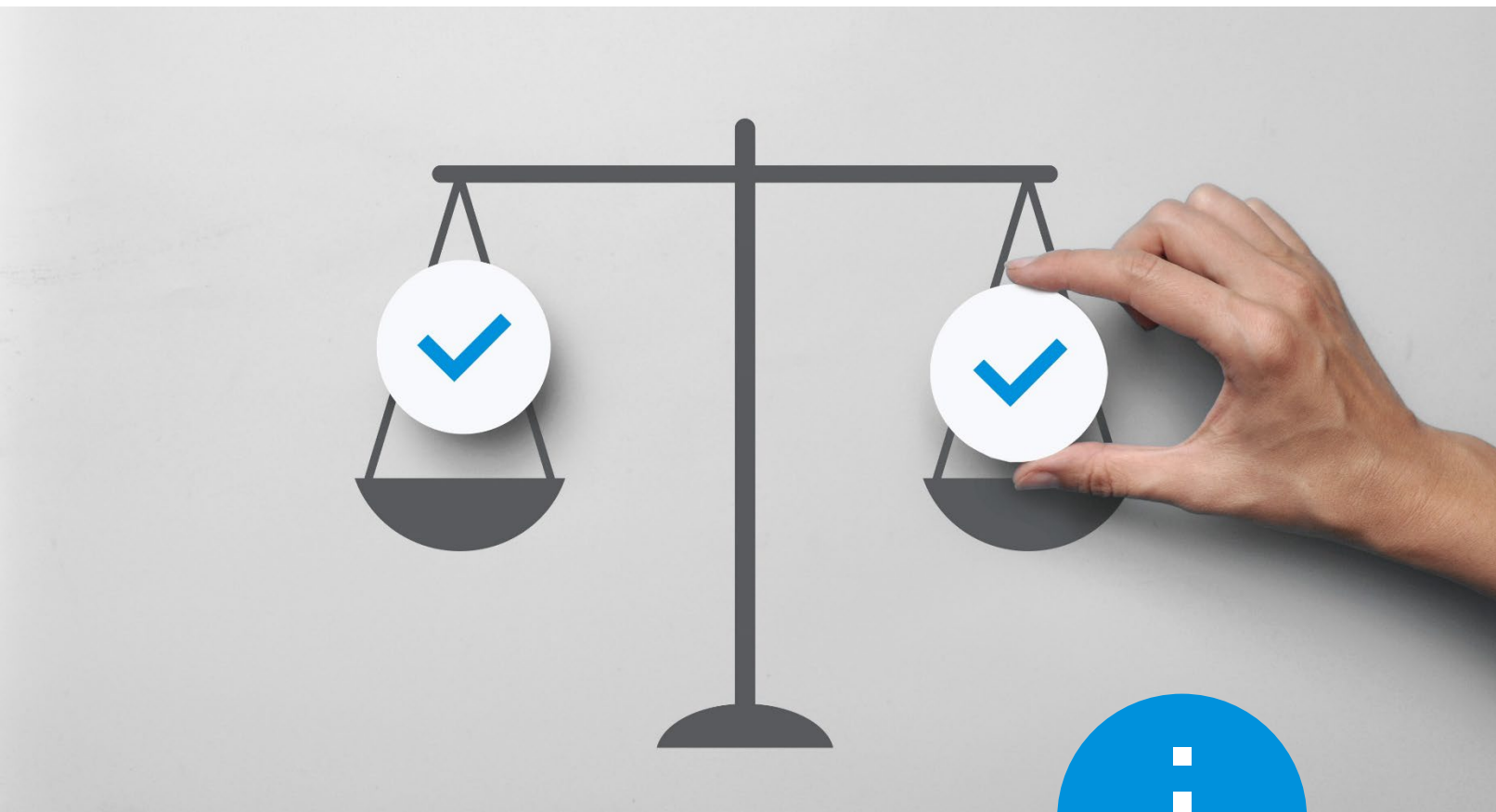
Electric actuators

Electric actuators traditionally require more expertise for installation and commissioning, for example for wiring, parameterization, and control system integration. In recent years, digital tools have improved significantly, greatly simplifying selection and configuration. Modern interfaces such as IO-Link allow straightforward integration and diagnostics, even for users who do not have in-depth knowledge of servo technology. Systems the Simplified Motion Series from Festo combine the advantages of pneumatics (simple design, rapid commissioning) with the precision of electric drives.

The components are low maintenance. Mechanical upkeep, such as lubrication, is usually unnecessary, as lifetime lubrication is common in industrial environments. However, specific spare parts may be required in case of failures. Thanks to integrated monitoring, fault diagnostics are often more precise but technical expertise is required to interpret the messages correctly.

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Costs – Purchase, operating expenses, and TCO

Economic considerations often determine the choice of a technology and they are not confined to operation. Even in the planning phase, it is worthwhile to be realistic when assessing all the cost components, from purchasing and installation to energy consumption, maintenance, and servicing. A total cost of ownership (TCO) analysis helps identify the most economical system.

Pneumatic actuators

Pneumatic components are usually significantly cheaper in purchase. A simple cylinder with a valve and some peripheral components often costs only a fraction of the price of an electric system – great for straightforward applications. In addition, pneumatic solutions can typically be integrated quickly into existing compressed air infrastructures. Installation is simple, and engineering effort is low.

The biggest cost driver is energy consumption. Generating compressed air is energy-intensive and comparatively expensive. Operating costs for large components (long cylinders with large diameters) and high cycle rates can end up being quite substantial.

In addition, maintenance needs to be carried out regularly, for example to replace filters, check for leakages, and service the compressor. Individual components are inexpensive to replace, but in practice leaks can go undetected for extended periods leading to continuous energy losses.

Overall, despite higher operating costs, pneumatics is often still the more economical option for applications with smaller components or low cycle rates, mainly because of the low initial investment. When used intensively, however, it can become significantly more expensive over the system's lifetime.

Electric actuators

Electric actuators need motors, gearboxes or ball screws, power electronics, and cabling. This typically results in significantly higher investment costs, with the initial investment being five to ten times greater than for pneumatic solutions. In return, they offer higher precision and flexibility. Installation effort is also greater, although synergies can be achieved in larger or modular machines, for example by having shared control systems.

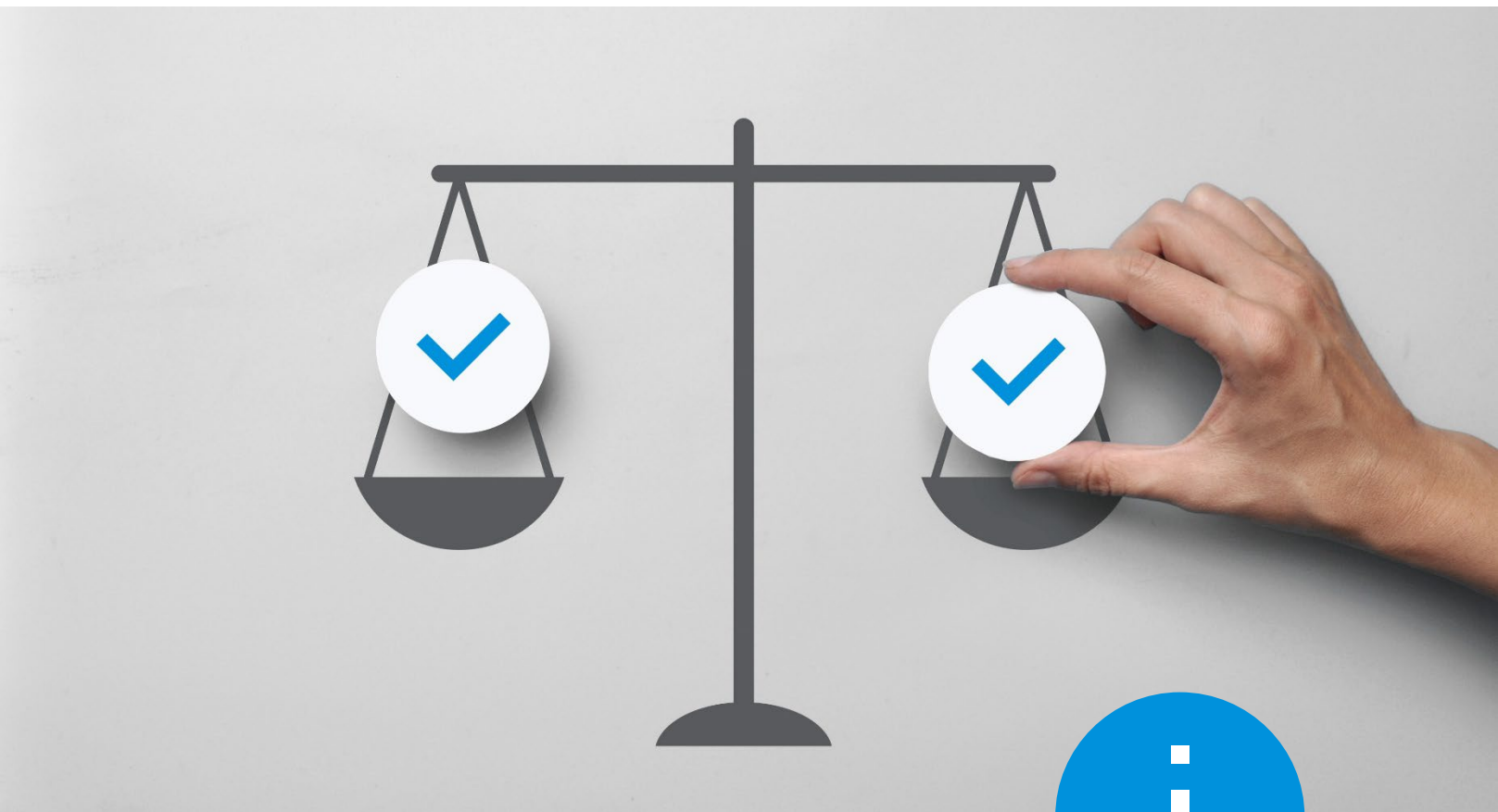
Electric systems are considerably more energy-efficient. They can achieve huge savings compared to pneumatics, especially in continuous operation, with high capacity utilization, and with "larger" components.

They also require less regular maintenance. Many systems are self-monitoring and enable quick fault diagnostics. However, spare parts can be more expensive and application-specific.

In energy-intensive applications, the higher acquisition costs are amortized within just a few years thanks to the reduced energy consumption. For reliable decision-making, a total cost of ownership (TCO) analysis is recommended, which many manufacturers now support with dedicated software tools.

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Safety behavior

Safety is a central criterion when selecting actuator systems, especially in applications involving human-machine interaction or significant forces. It is not just the behavior during normal operation that matters, but also how a system responds in the event of a fault.

Pneumatic actuators

Pneumatic actuators generally behave in a predictable and controllable manner when faults occur. In case of a power loss — for example, due to loss of compressed air — are usually safe as they behave passively: they either remain in position or move to a defined safe end position. Such mechanical reset mechanisms increase functional safety without requiring additional control technology.

An emergency stop can also be easily realized in pneumatic systems by simply cutting off the air supply.

In critical applications, safety zones can be defined in which groups of actuators are selectively shut down while other areas continue operating. This increases overall system availability while maintaining a high level of safety.

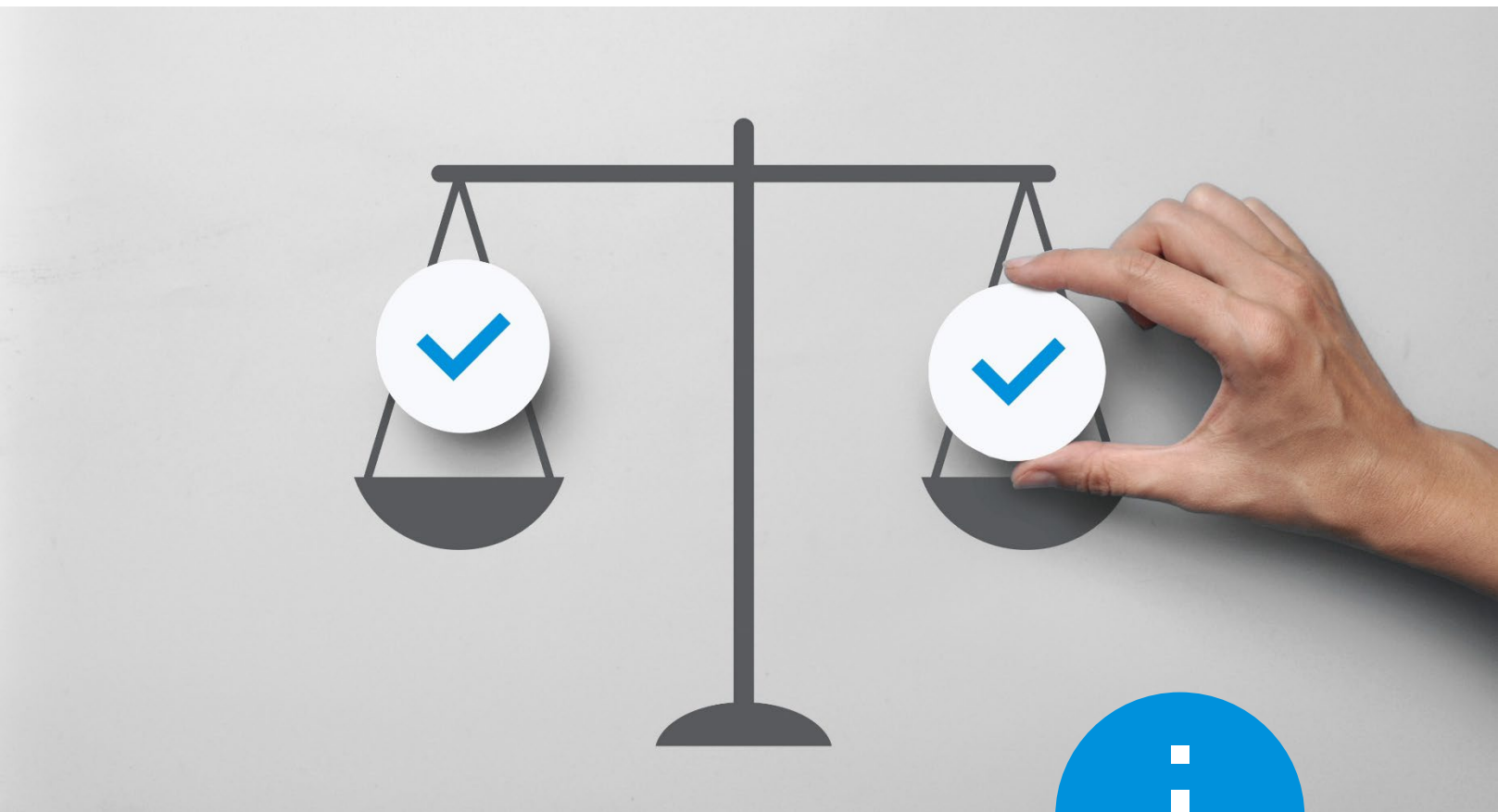
Electric actuators

The safety behavior of electric actuators varies depending on the type of actuator. Ball screw actuators have the advantage of self-locking: in the event of a power failure, they remain in position, which in most cases is considered safe. Other types, such as belt-driven systems, can continue moving uncontrollably without an active brake, which is a safety risk. A safe shutdown usually requires additional measures: brakes, safety relays, or integrated STO (Safe Torque Off) functions ensure that axes behave safely during an emergency stop or fault.

Unlike pneumatic systems, electric actuators generally require functional safety integration – that is, protection via control systems, sensors, and electronics. This also enables more sophisticated safety concepts, such as safely slowing down, selectively switching off individual axes, or a controlled return to a defined position.

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Environmental suitability

Most automation solutions do not in spotless conditions. Many machines are located in dusty production halls, cold storage rooms, areas with vibration, or even in potentially explosive environments. The surrounding conditions have a significant impact on the selection of the appropriate actuator technology. Pneumatic and electric systems each offer specific strengths and limitations in terms of environmental suitability.

Pneumatic actuators

Pneumatic systems operate within a wide temperature range (typically -20 to $+80$ °C). They do not generate significant heat themselves and therefore do not heat their surroundings – an advantage in hot environments or in tightly packed machines. Active cooling is generally not required. Humid, dusty, or vibrating environments are usually not a problem, as pneumatic components are extremely robust and can withstand external influences.

However, pneumatic systems can themselves have an impact on their surroundings: unfiltered compressed air can release small amounts of aerosols from fine particles or oil. Even air from oil-free compressors is not entirely free of oil, since the intake air can contain traces of oil and other hydrocarbons. In most industrial applications, this is not critical but in cleanrooms, proper exhaust and filtration is required. In the food industry, specially suited components are recommended, e.g., those without mineral-based lubricants.

Pneumatics is also well suited for potentially explosive environments, as pneumatic components contain no electrical ignition sources. The requirements for materials and temperature classes are relatively easy to meet.

Electric actuators

The typical operating temperature for electric components is between 0 and 40 °C. For motors, the upper limit is somewhat higher, around 60 to 70 °C.

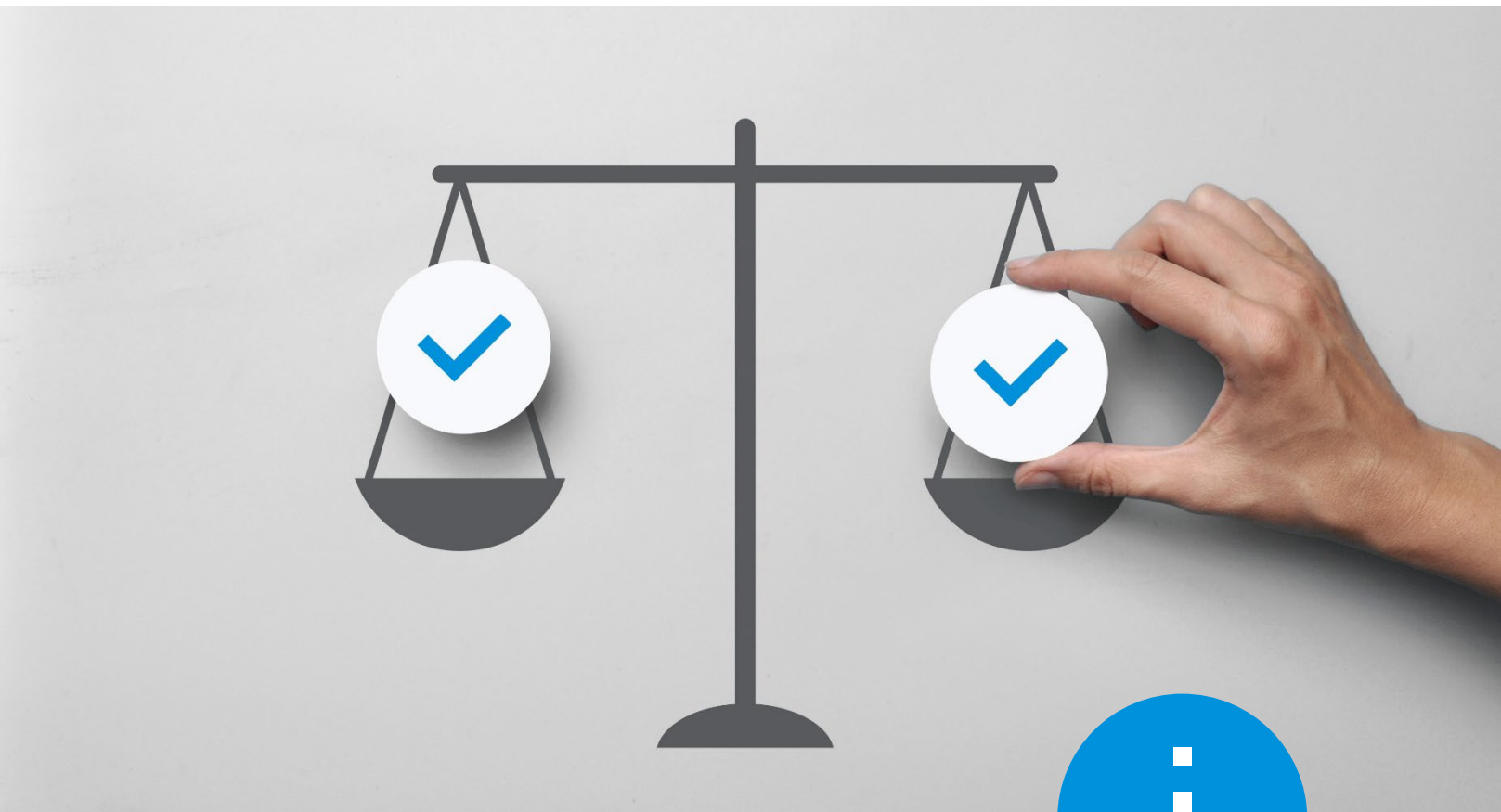
The heat losses from motors and electronics discharge a noticeable amount of heat into the environment. Additional cooling measures may be required, such as control cabinet air conditioning or motor fans.

In harsh industrial environments — e.g., with dust, humidity, or vibration — electric systems must be properly enclosed and protected. Modern systems are designed for these conditions, but the engineering effort is often greater than for pneumatics. On the other hand, electric systems are often cleaner in terms of emissions. Particle emissions from mechanical wear (e.g., on ball screws) can be effectively controlled using enclosures, lubrication, or specialized guides. Electric actuators are well suited for applications with high cleanliness requirements.

Electric systems can be used in potentially explosive environments, though they tend to be more complex. They require specially certified components (e.g., pressure-resistant encapsulated ATEX motors), which are heavier, more expensive, and need more maintenance.

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Energy efficiency

As energy costs are rising and environmental regulations are increasing, it is ever more important to ensure that technical systems are energy efficient — right from when the most suitable actuator technology is selected.

Pneumatic actuators

Pneumatic systems are generally considered comparatively energy-intensive. There are several reasons for this: compressing air generates a large amount of heat that cannot be used pneumatically. In addition, many systems are oversized, operate at unnecessarily high pressures, or lose energy continuously through leakages that often go unnoticed over long periods.

However, modern technology can overcome these drawbacks. When pneumatic systems are designed and sized according to actual demand, energy consumption drops considerably. With intelligent control, such as servo-pneumatic valves, the air supply can be precisely regulated to match the system's needs, thus avoiding unnecessary consumption. In many plants, the heat generated during compression is also used for heating or process purposes, further improving overall energy efficiency.

In certain applications, though, energy efficiency only plays a minor role. When using short strokes, small piston diameters, or low cycle rates, the absolute air consumption is so low that efficiency is practically negligible. In such scenarios, pneumatics often provides a simple, cost-effective, and practical solution.

Electric actuators

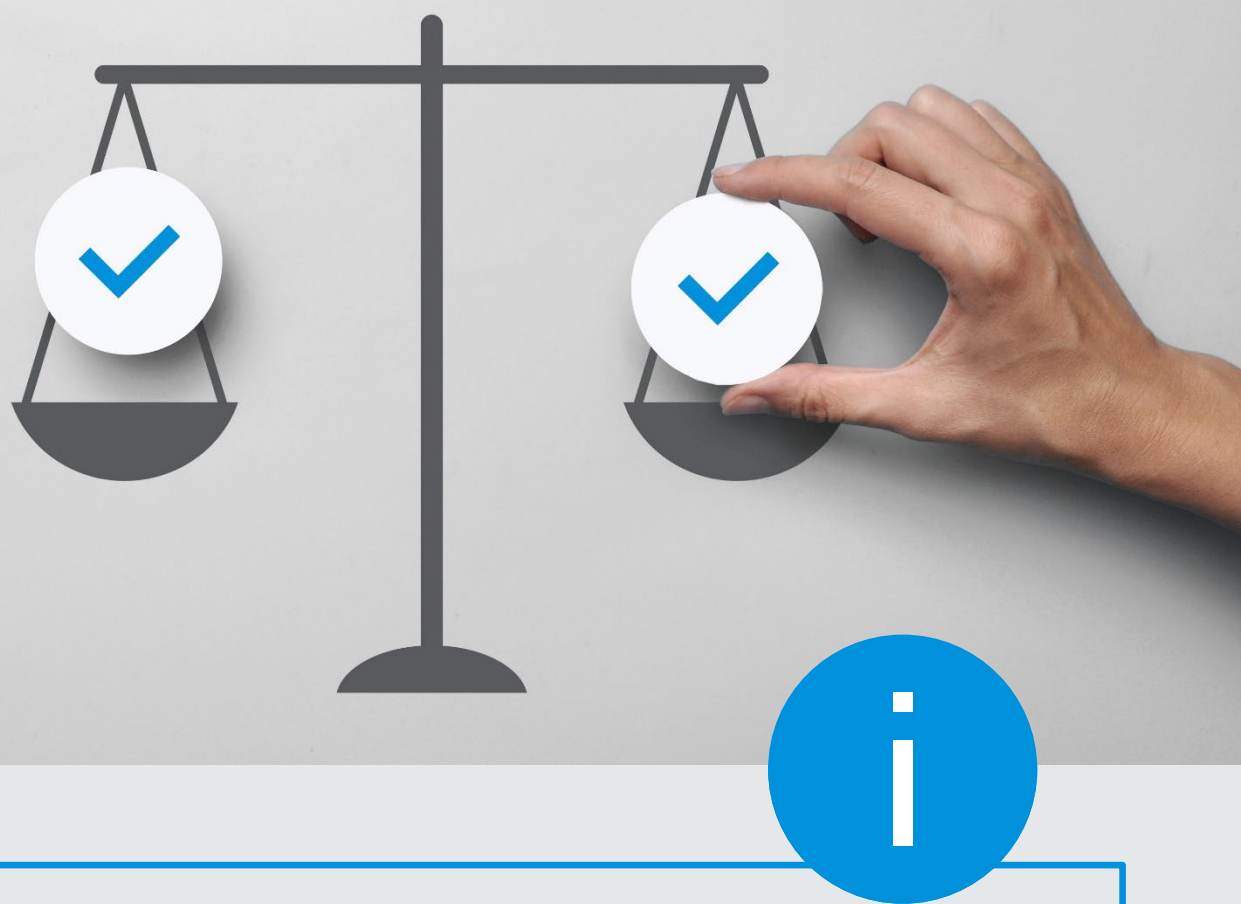
Electric actuators extremely energy efficient. Even when accounting for quiescent current (e.g., from inverters) and active position holding, their energy consumption is generally significantly lower than that of comparable pneumatic components.

These characteristics are especially advantageous for long strokes or high cycle rates. This is where savings accumulate over many movements and electric actuators provide a noticeable reduction in operating costs. Additionally, motion profiles can be precisely tailored to the application, for example using smooth acceleration and deceleration ramps, which not only saves energy but also reduces mechanical wear.

Energy efficiency is not quite as essential for short strokes or infrequent actuation, as the absolute energy demand is low anyway. Yet electric actuators also excel in such applications due to their precision and controllability. Overall, electric actuators are particularly well suited for highly automated applications, even if the control technology is more complex and the initial investment is higher.

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Sustainability and carbon footprint

Sustainability has become a key criterion when selecting actuator technologies. In addition to energy efficiency, factors such as manufacturing effort, resource consumption, and the carbon footprint over the entire lifecycle play an important role.

Pneumatic actuators

Pneumatic drives have a relatively simple with a limited range of materials. As a result, their environmental footprint during manufacturing is generally lower than that of complex electric systems. Many components are made from metals such as aluminum or steel, which are highly recyclable. In addition, pneumatic systems are robust and durable, further contributing to their long-term resource efficiency.

Depending on the application, energy consumption during operation can become the dominant factor in the CO₂ footprint. Large actuators or high cycle rates, in particular, lead to increased energy demand. The overall environmental impact also strongly depends on the energy mix used; a bigger share of renewable energy improves the sustainability of pneumatic systems. Overall, the CO₂ footprint of conventional pneumatic systems is often higher than that of electric drives, but they still provide a practical and economical solution in certain applications, such as with smaller strokes or lower cycle rates.

Electric actuators

Electric actuators, with their copper windings, magnets, and electronic control components, generally require more materials and resources during manufacturing. Critical raw materials, such as rare earths, can also play a role depending on the motor design. At the same time, electric drives offer high precision, low mechanical wear, and a long service life, which improves resource efficiency over the entire lifecycle.

Their main advantage is in operation. Thanks to high efficiencies and individually adjustable motion profiles, energy consumption remains comparatively low even during prolonged movements or high cycle rates. Overall, this results in a favorable CO₂ balance. Having said that, the actual environmental impact of electric actuators depends on the energy mix: the greater the share of renewable energy used, the greater their sustainability. The specific carbon footprint varies depending on the application and usage scenario.

Pneumatics or Electrics

Both technologies in direct comparison

Criteria	Pneumatics - Standard	Pneumatics - Servo	Elektrics - Ball screw	Elektrics - Belt drive
Dynamics and motion quality	★★★ Quick switching, but limited controllability, damping required.	★★★★ High motion quality, good damping characteristics	★★★★ Precise and smooth motion	★★★★ Excellent acceleration
Force	★★★★ High durable force possible	★★★★★ High prolonged force possible	★★★★★ High force as self-locking	★★ Limited suitability for high holding forces
Power density	★★★★ Particularly suitable for short strokes	★★★★ Particularly suitable for short strokes	★★ Large installation space needed for motor, ball screw, guide	★★ Relatively long overall lengths
Holding forces	★★★★★ Force maintained by pressure without energy input	★★★★ Slightly higher air consumption due to control	★★★★★ Self-locking, no energy required to hold a position	★ Motor remains active, high energy consumption
Stiffness	★ Compressibility of compressed air	★★★ Slightly better, position can be controlled	★★★★★ Mechanical self-locking	★★★★ Some flexibility with elastic belt
Flexibility	★★★★★ Compressibility of compressed air	★★★★ Adjustable via control	★ Mechanical self-locking	★★ Some flexibility with elastic belt
Adaptability	★ Changes require mechanical intervention	★★★★ Behavior adjustable via software	★★★★ Parameter selection via software	★★★★ Parameter selection via software



The choice of the appropriate actuator technology

Ultimately depends on many factors: the technical requirements, the economic framework, and, not least, the specific circumstances in every industry sector. Both technologies have their strengths and their optimal application areas. To provide a clear overview, the table below presents a concise comparison of the most important differences:

Pneumatics or Electrics

Both technologies in direct comparison

Criteria	Pneumatics - Standard	Pneumatics - Servo	Elektrics - Ball screw	Elektrics - Belt drive
Simplicity	★★★★★ Easy to commission and operate	★★★ Complex engineering, controller adjustment	★★★ Wiring, parameterization, protection	★★★ Wiring, parameterization, protection
Purchase costs	★★★★★ Low-cost components and peripherals	★★★ More complex valves, controllers, software	★ Generally more expensive components	★★★ Relatively expensive components
Operating costs	★★ High energy consumption	★★★★ Consumption adjustable depending on application	★★★★★ High efficiency, possible friction losses	★★★★★ High efficiency
Safety behavior	★★★★★ Defined states achievable in case of failure	★★★★★ Component behavior can be monitored	★★ Mechanical self-locking, possibly no emergency release	★★★ No self-locking in case of power failure
Environmental suitability	★★★★★ Withstands heat, moisture, dirt, but exhaust air may be an issue	★★★★ Slightly more sensitive because of electronic components, watch exhaust air	★★ Sensitive to dust, moisture, high temperatures	★★ Sensitive to dust, moisture, high temperatures
Energy efficiency	★★ Low efficiency, often oversized	★★★★ Energy demand adapted to the application	★★★★★ Hardly any losses, especially at low speeds	★★★★★ Good efficiency at high motion dynamics
Sustainability	★★★ Low manufacturing effort, but high energy consumption	★★★ Energy-saving, but complex components	★★★★★ High manufacturing effort, but efficient and durable	★★★★★ High manufacturing effort, but efficient and durable



The choice of the appropriate actuator technology

Ultimately depends on many factors: the technical requirements, the economic framework, and, not least, the specific circumstances in every industry sector. Both technologies have their strengths and their optimal application areas. To provide a clear overview, the table below presents a concise comparison of the most important differences:

Industries in Focus

Application-oriented assessment for various industrial sectors

It becomes clear that, in practice, the requirements for actuator solutions vary considerably from one industry to another. While hygiene, ease of cleaning, and certification are essential in the food and pharmaceutical industries, the focus in traditional machine and plant building is often on flexibility, modularity, and high availability. In automotive production, energy efficiency, cycle time, process reliability, and robustness tend to dominate. Meanwhile, in intralogistics or packaging technology, the priorities are often lightweight design, speed, and easy scalability.

It is therefore worthwhile to take a closer look at typical industry scenarios. The focus on specific selection criteria can change significantly depending on the environment and the application. The following sections highlight which requirements are particularly relevant in various industries and how these can influence the choice of the most suitable actuator technology.



Industries in Focus

Automotive industry

In automotive production, cycle time, durability, and energy efficiency are especially important. As production volumes are high, the production lines often run in three shifts, so even small savings per cycle add up to significant cost and energy benefits. The benefits of electric actuators are their high efficiency and precise controllability, especially for frequent movements or complex motion profiles. Their diagnostic capabilities and seamless integration into higher-level systems also make electric actuator technology a real favorite.

Nevertheless, pneumatic systems are still widely used, especially for simple pick-and-place tasks, clamping functions, or in safety-critical areas, such as crash cells or welding stations. Here, robustness, simplicity, and inherent protection against ignition hazards are essential. Pneumatic systems can also be replaced quickly or efficiently controlled via standardized valve manifolds.

Modern production lines often use a mix of both technologies: Pneumatics for robust, clearly defined movements or tasks requiring high holding forces, and electric actuators for complex, difficult to control, flexible, or energy-optimized processes.

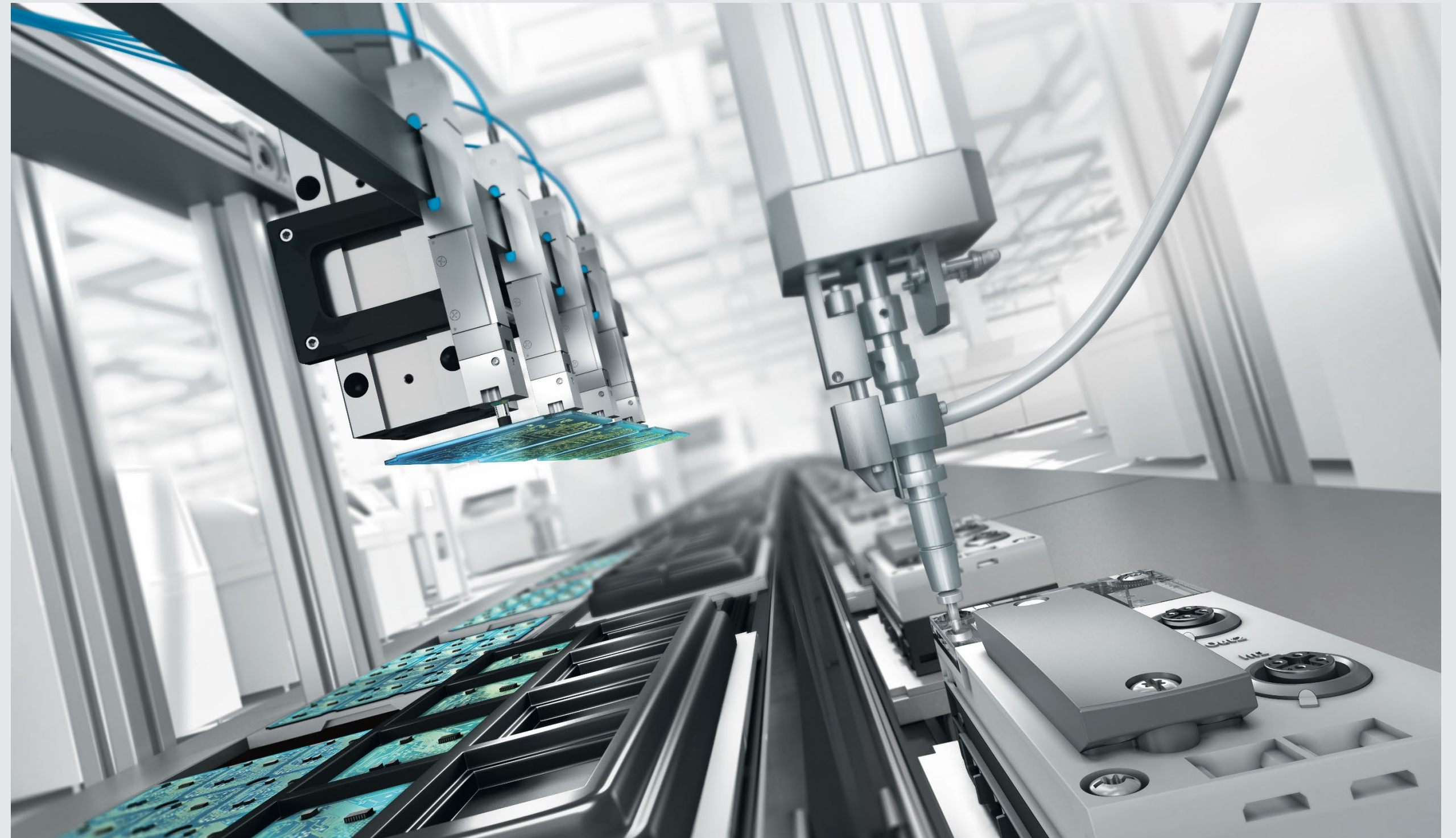


Industries in Focus

Electronics and semiconductor industry

In this sector, electric are mostly used. The decisive factors are the extremely high demands on speed and precision: applications such as pick-and-place machines, wafer handling, or micro-assembly require micrometer-level positioning accuracy at very high speeds, along with precise spatial coordination of multiple axes.

Pneumatic actuators, on the other hand, are mainly used for secondary functions. These include operating shut-off valves in wafer production, where smooth acceleration and jerk-free end positioning are more important than high precision. They also provide a robust and cost-effective solution for other simple point-to-point auxiliary motions within complex systems.



Industries in Focus

Food and packaging

These sectors have traditionally relied heavily on pneumatics, mainly for their high cycle rates, simple design, and the wide availability of hygienic components (e.g., stainless steel cylinders or IP69k-rated actuators). Precision is often less critical, and pneumatic systems are easy to clean and inexpensive to maintain.

However, electric actuators are increasingly used in these industries as well. This trend is driven by rising demands for format flexibility (e.g., in packaging machines), improved controllability (e.g., for smoother filling operations), and the goal of reducing energy consumption. Pneumatic actuators are still considered to be suitable, though, for example, in grippers for pick-and-place tasks, air-jet ejection systems, or simple auxiliary functions.

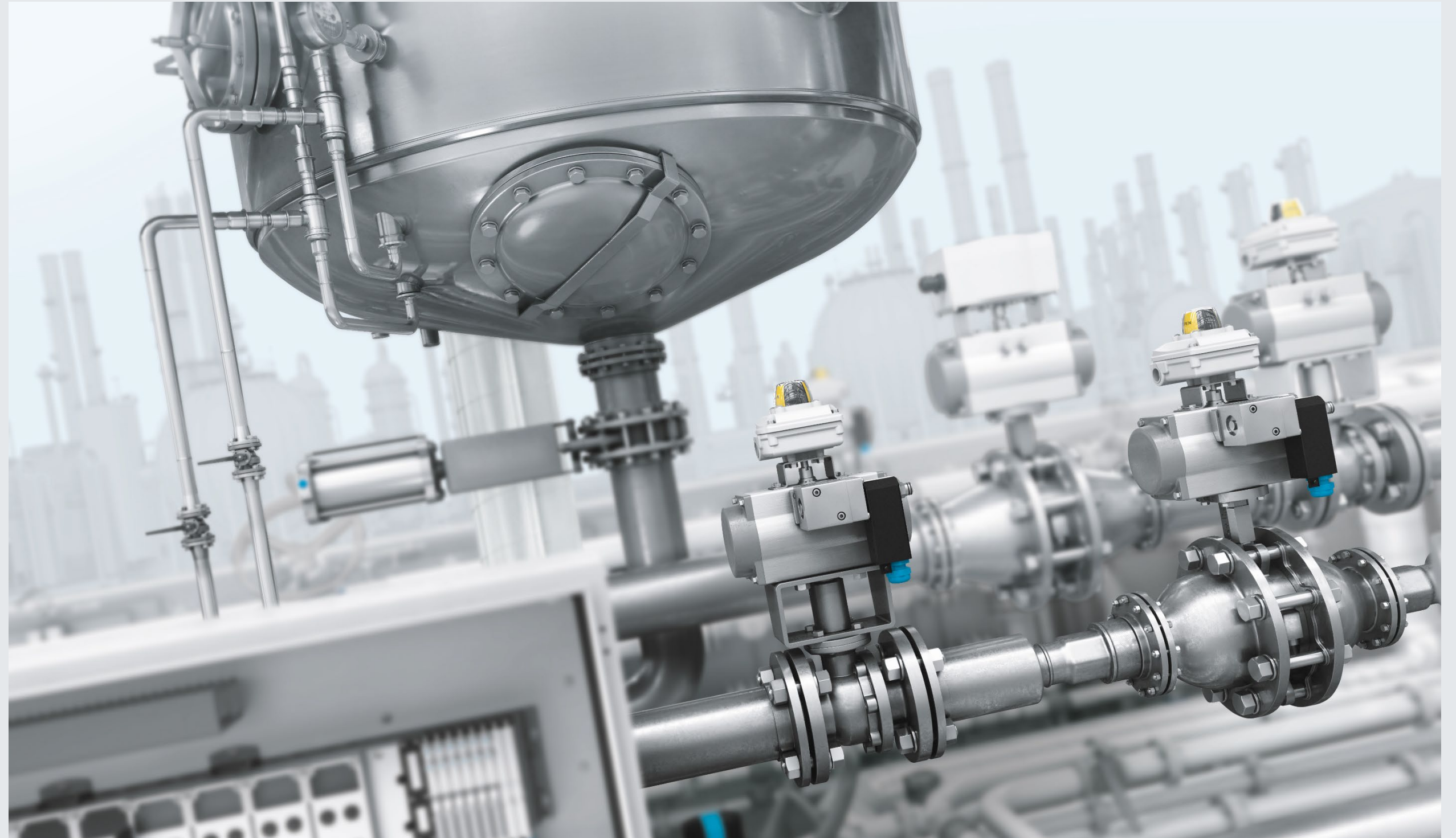


Industries in Focus

Chemical and process industry

In the chemical and process industry, pneumatic systems have traditionally been widely used, primarily because of their explosion safety and robustness. Typical applications include simple valve actuators, vibrators, or flap actuators in the field, often under harsh environmental conditions. Pneumatic actuators have proven themselves since they not generate any ignition sources and are less sensitive than electric systems to dust, moisture, and temperature fluctuations.

However, electric alternatives are increasingly being considered: ATEX-certified actuators with integrated monitoring and optional fail-safe mechanisms (e.g., spring return or battery backup) are seen as lower-maintenance solutions. These are still more expensive and tend to be used only in specific cases. Pneumatic actuators therefore remain the preferred solution in many standard applications within the process industry.

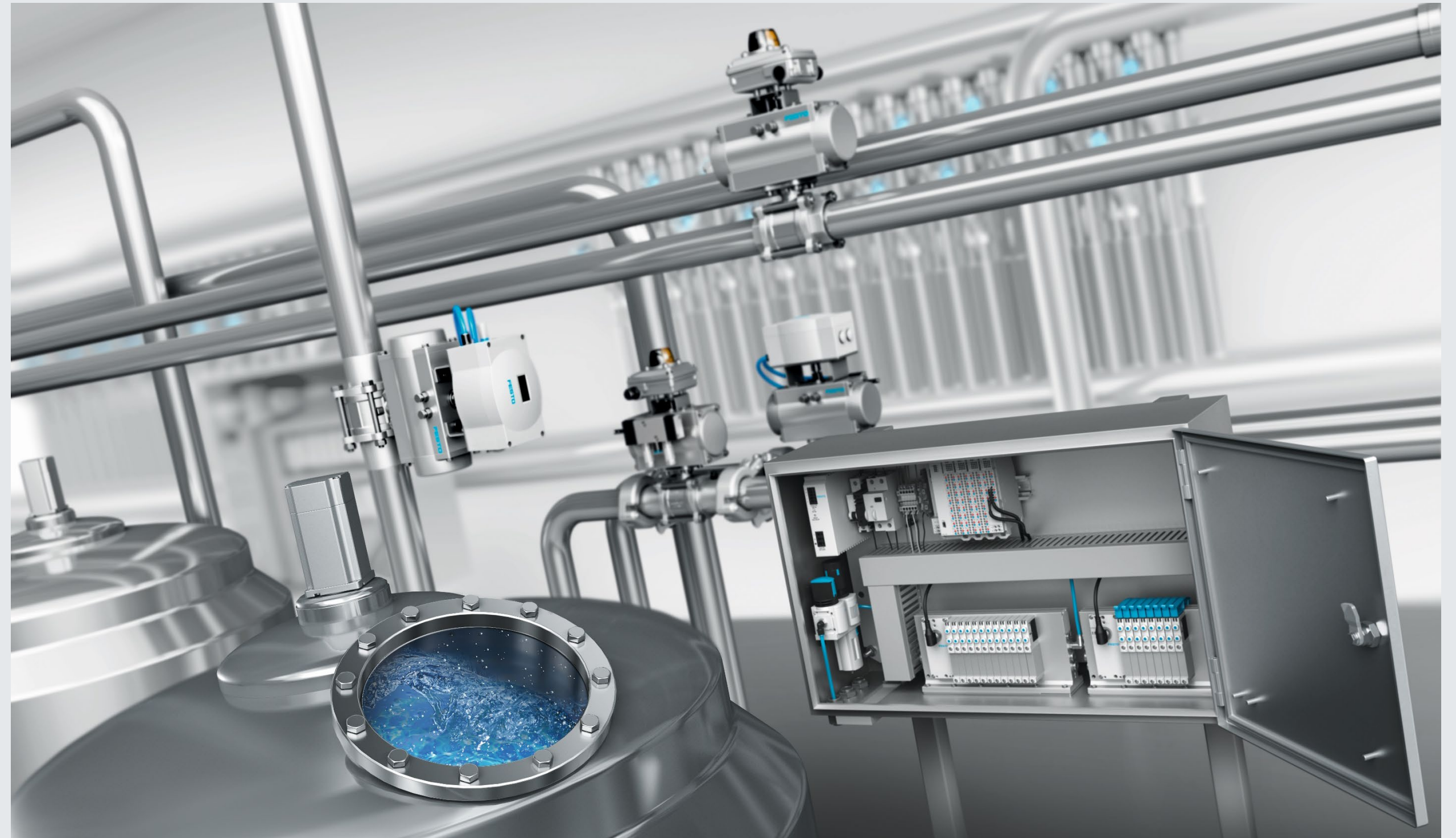


Industries in Focus

Pharmaceutical industry

In pharmaceutical production, product purity, process safety, and traceability are top priorities. This means that the demands on actuator systems are high: they must be easy to clean, verifiable (functionally and in terms of documentation), and as particle-free as possible. Electric actuators offer many advantages; for example, enclosed designs, precise controllability, and the ability to record and document movements consistently.

Pneumatics is still widely used, especially in simple applications with fixed cycles such as lifting, gripping, or sorting processes. Stainless steel cylinders with high protection ratings (e.g., IP69K) are efficient when hygiene requirements need to be met. However, exhaust air critical: it must be reliably removed or filtered in cleanroom or aseptic applications.



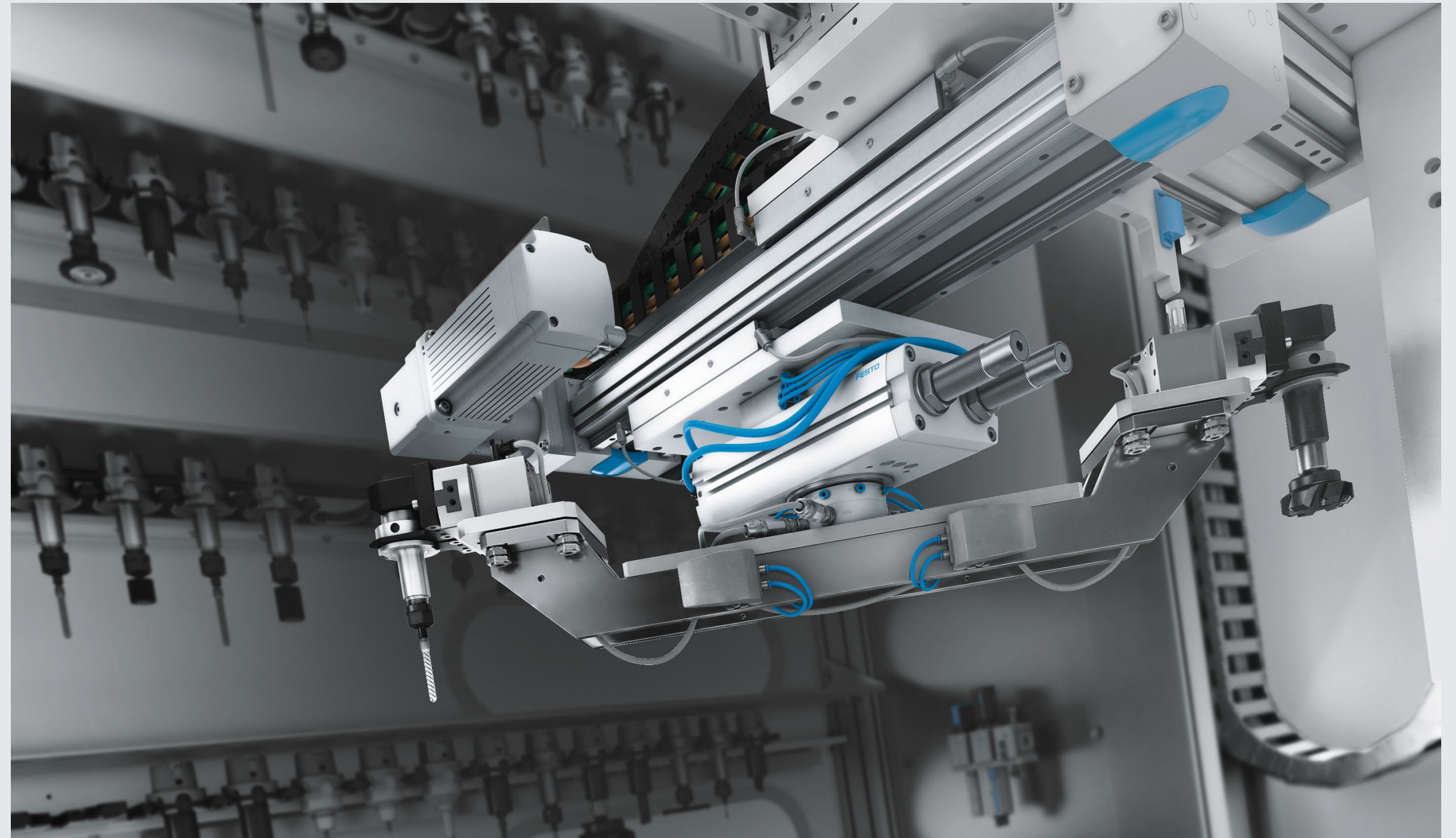
Industries in Focus

Machine tools

The machine building sector has extremely diverse requirements, from highly dynamic production modules to slow-moving custom machines. As a result, both electric and pneumatic actuators are used, often in combination.

Electric actuators stand out thanks to their flexibility, precise motion control, and easy integration into modern automation systems. They facilitate complex motion profiles, quick format changes, and connectivity to digital engineering tools. This is especially useful for variant-rich machines or adaptive processes, such as in special machinery or customer-specific batch sizes.

Pneumatic actuators are preferred when simple, robust, and cost-effective solutions are needed; for example in cyclic operations, clamping, or blowing functions. Their standardization, ease of replacement, and excellent availability are crucial in many systems. And thanks to their robustness and reliability, pneumatic actuators are also the product of choice for use in harsh environments or during long periods of inactivity.



Industries in Focus

Intralogistics

In intralogistics, speed, energy efficiency, and minimal downtime are the primary concerns. This is why electric actuators are being used more and more here, for example in diverters, lifting modules, shuttles, or roller conveyors. They enable precise control, smooth movements, and offer great energy efficiency.

Pneumatic systems, though, are still much used for pick-and-place tasks, sorting arms, or grippers, where simple motions at very high cycle rates are required. Their simple design and low mass are often advantageous, as long as energy consumption remains manageable.



The Right Choice

Technically, Economically, and Sustainably

Which technology is better: Pneumatics Electrics?

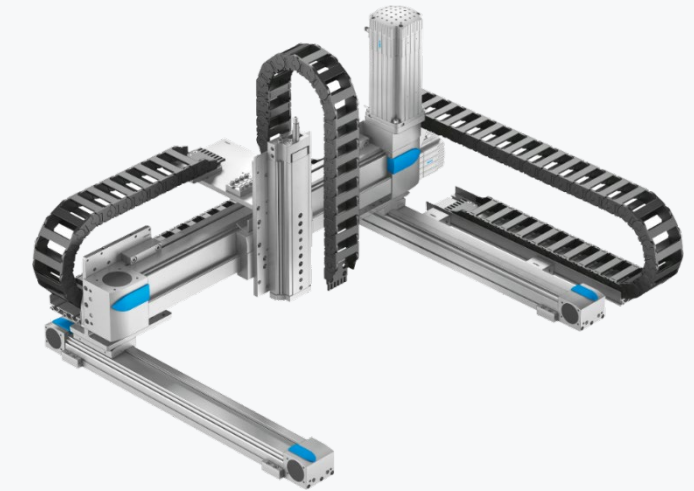
There's no simple answer. Choosing the right technology always involves balancing multiple factors: mechanical requirements, energy efficiency, costs, environmental conditions, and maintenance effort. Both technologies have their place, and often the optimal solution consists of an intelligent combination.

The strengths of electric actuators manifest themselves primarily where precision, flexibility, and energy efficiency are paramount. Pneumatic systems excel through simplicity, robustness, and low initial costs, especially for well-defined tasks in harsh environments. Servo-pneumatics combines specific controllability with the robust, cost-effective world of compressed air. This makes it an attractive solution when variable motion profiles, moderate precision requirements, and economical implementation are needed. Examples include cycle rates that demand a certain level of dynamics but do not justify a fully electric axis.

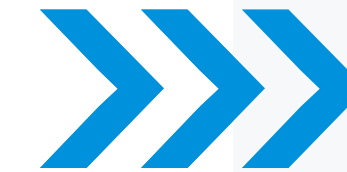
In many cases, a sensible combination of both technologies can also provide the optimal solution. Especially in more complex or modular machines, it becomes clear that electric and pneumatic actuators can complement each other very well.

A typical example of this is so-called gantry systems for positioning in X, Y, and Z directions. While X and Y movements require flexible positioning – making electric drives ideal – the Z axis can fully leverage the strengths of pneumatics, such as low weight, high power density, and compact design.

In the end, what matters most is that the solution best fits the specific task. When requirements are thoroughly analyzed and the decision criteria for the application are correctly prioritized, this creates the basis for well-engineered, economically viable, and sustainable automation solutions.



05 "Best of both worlds" — flexible electric positioning actuators for X and Y movements, compact pneumatic actuators with high power density for the Z-axis



From an efficiency perspective, the summary provides a rough guide:

Pneumatic actuators

The shorter the stroke, the higher the end-position force, the longer the holding duration, the more efficient pneumatic actuator technology is.

Electric actuators

The longer the stroke, the lower the end-position force, the shorter the holding duration, the more efficient electric actuator technology is.

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Daniel Ditterich is a Technology Expert for sustainable automation at Festo SE & Co. KG and brings extensive experience in choosing the optimal drive solution. His expertise includes the design of automation systems, energy efficiency, and the conception and introduction of innovative products.

