Chapter 2

Hardware Components for Automation and Process Control

Actuators

- An actuator is a device that uses some type of energy and produces the required force
- It provide a motion to an object or actuating something.
- Actuators can be categorized based on the operation principle, such as:
  - Thermal
  - Electric
  - Hydraulic
  - Pneumatic
  - Micro-electro-mechanical (MEMS) ones.

The figure below illustrates a number of different types of actuators.

(a) servo motor (b) DC motor (c) stepper motor

(d) linear motor (e) pneumatic cylinder (f) solenoid actuator

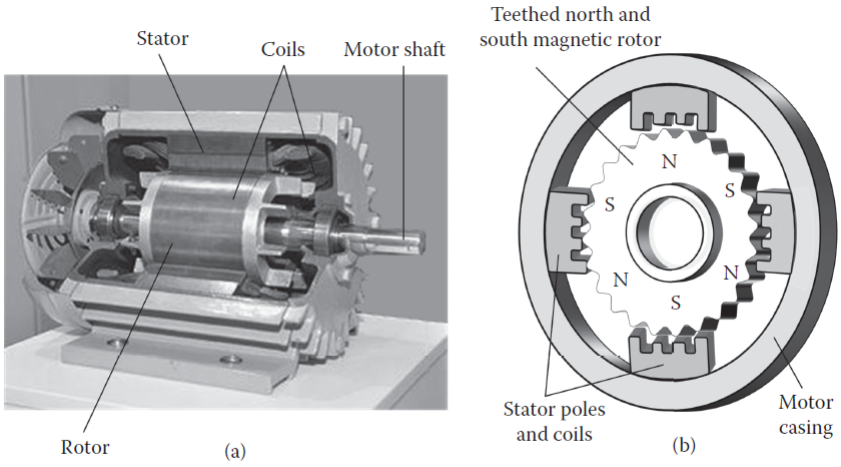
Various types of actuators in industrial automation

Electric motors

- Electric actuators include the category of electric motors of all kinds, such as the stepper motors, servomotors, linear motors, and solenoids.
- The term "actuator" is usually connected to low-power actuating devices and not to high-power electric motors.
- For an industrial engineer, the motor is a separate category itself and is not always straightforwardly connected to the actuators, although its definition includes them.
- All electric motors, AC or DC, use the principle of electromagnetic induction and the subsequent interaction of two magnetic fields to generate torque on a rotational element called a "rotor" inside a stationary housing called a "stator".

3

In the figure shown below, an indicative internal construction for the case of AC and step motors is provided, where the existence of the coils gives a first impression of the generated magnetic forces that are responsible for achieving motor rotation.



Internal view of an AC motor (a) and step motor (b).

4

- The AC motors are widely used in the automation industry compared with the DC ones, mainly because of their efficiency and less maintenance required.
- It is the simpler solution in applications such as machine tools, fans, pumps, compressors, conveyors, extruders, and other complex machines.
- Stepper motors base their operation on a working principle similar to that of DC motors and can rotate in very small discrete steps.
- The steps of a stepper motor represent discrete angular movements in the vicinity of 2° or 1° or even less, which are performed due to a series of digital impulses.
- It is obvious that a stepper motor can perform any number of rotation steps with the same precision by applying an equal number of electrical pulses to its phases. Regarding their internal structure, there are many types of stepper motors (such as unipolar, bipolar, single-phase, two-phase, multi-phase, etc.)

5

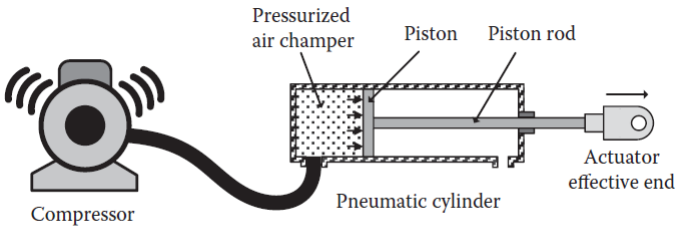
- When higher torque demands precise control, servomotors are then the best solution to be used.
- A servomotor consists of an **AC or DC electric motor**, a **feedback device**, and an **electronic controller**.
- In the case of a DC motor, this can be either a brushed or brushless type.
- Typically, the feedback device of a servomotor is some type of encoder built into the motor frame to provide position and speed feedback of the angular or linear motion.
- The electronic controller is a driver, supplying only the required power to the motor, in the simplest case.

6

Pneumatic Actuators

- A pneumatic actuator converts and transmits pneumatic energy derived from a central, pressurized air source into mechanical movement energy.
- The most common type of pneumatic actuator is the simple piston-cylinder assembly connected to a supply tube of compressed air, as shown in the figure below.
- The air pressure acts on the piston producing a direct linear motion of the piston rod's free end. Since air is highly compressible, pneumatic actuators are usually used for the movement of small and lights objects and are not suitable for accurate position control.

7



The pneumatic cylinder as linear motion actuator.

- hydraulic actuators are operated by a pressurized fluid that usually is oil.
- Their operation logic is similar to that of the pneumatic ones, but different in terms of construction.
- Since fluids are non-compressible, hydraulic systems are generally used when high forces and accurate control are required.

8

Micro-Electro-Mechanical Systems (MEMS)

- (MEMS) are a process technology based on techniques of microfabrication and are used to create devices that have the ability to sense, control, and actuate on the micro scale, while generating effects on the macro scale.
- Over the past few decades various micromechanical actuators (or microactuators) began appearing in numerous industrial products and applications.
- These miniaturized actuators are MEMS devices, which range in size from a few micrometers to millimeters, that convert one form of signal or energy into another form.
- MEMS microactuators have a wide variety of actuation mechanisms producing very small forces or displacements and can be categorized in four basic groups: electrostatic, piezoelectric, magnetic, and thermal.

9

- MEMS microactuators are used in various industries, such as the automotive, electronics, medical, and communications.
- Some typical examples of microactuators are micro-valves for control of gas and liquid flows, micro-grippers for robotic surgery, and focusing micro-mechanisms for cameras in mobile devices.

Relays

- a relay is a binary actuator as it has two stable states, either energized and latched or de-energized and unlatched, while a servomotor, for example, is a continuous actuator because it can rotate through a full 360° of motion.
- A soft distinguishing between the terms “relay” and “contactor” is that the second one is used for powering large electric motors.

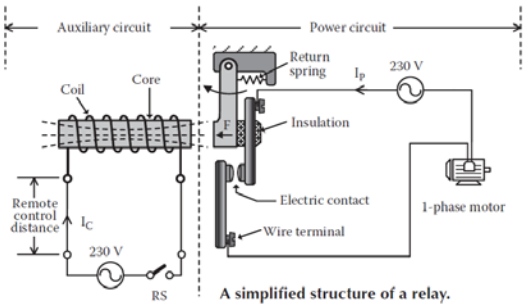
10

- From a construction point of view there are two types of relays, the power relays and the general purpose or control relays, both having the same principle of operation described below.

Relays' Operation Principle

- Relays consist of two parts; a first one containing the various main or auxiliary electric contacts, and a second one containing the electromagnet-based mechanism that creates the motion required for the operation of the electric contacts.
- The figure below shows a simplified form of a relay, including the coil-core electromagnet, the movable arm, the electric contact consisting of two parts (the fixed and the movable one), and the return spring.

11



A simplified structure of a relay.

- The relay's contacts are electrically conductive pieces of metal, when contacted together, complete a circuit and allow the current to flow, just like a switch.
- The operation of the relay is achieved by forming two independent and isolated circuits, the power circuit and the auxiliary or the control one.
- The power circuit refers always to the electrical device usually called "load", which is powered through the relay contact, while the auxiliary circuit refers always to the coil of the relay.

12

Standardized Values for Nominal Voltage Selection of a Relay Coil

Values of Relay Coil Nominal Voltage	
AC 50 HZ	24, 42, 48, 60, 110, 230, 380 V
DC	12, 24, 36, 48, 110, 230 V

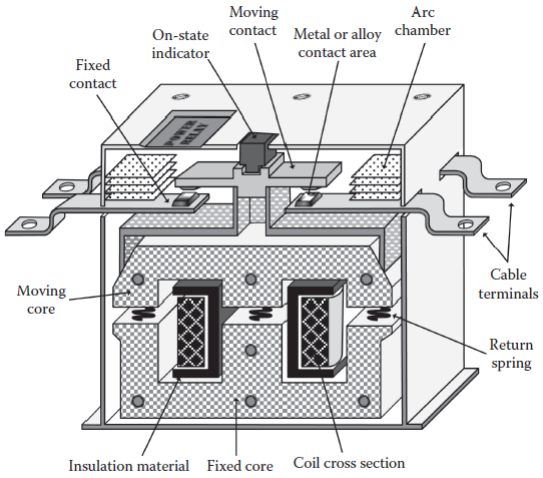
- The time required for the activation and deactivation phases of the relay depends on the type of relay and is usually rated up to 10–50 msec.
- Since the described relays include mechanical and electrical components, they are also called "electromechanical relays" in order to be distinguished from the "solid state relays" consisting only of electronic and semiconductor components (transistors, thyristors, and triacs) and circuits.

13

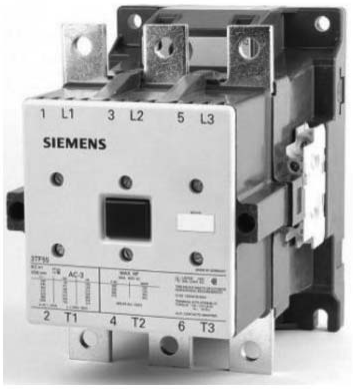
Power Relays: are made in order to feed the various kinds of electric motors with the required electric power.

- In proportion to the typical motors' powers, these power relays are made in several sizes, from the smallest of nominal power 5.5 KW, to the largest of 500 KW under 660 V, while it is obvious that the power relays and particularly their electric contacts must withstand a "switching under load".
- This means that an electric contact of a power relay should have the mechanical strength required in order to open while the nominal current is passing through it.
- The reason that causes damage to the contact material is that an electric arc is created during the opening or closing of the electric contact. Therefore, the construction of a power relay leads to the increase of the contact surface and subsequently to larger dimensions of the metallic plates as shown below.

14



Typical internal structure of power relay.



Typical external view of a power relay by Siemens.

15

General purpose relays:

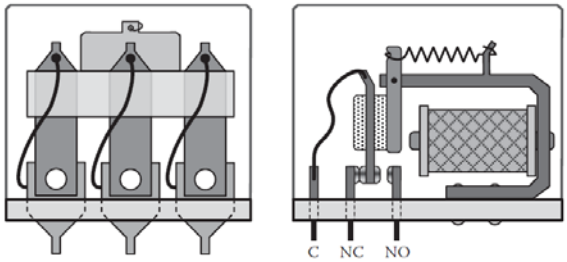
- are usually miniature relays, used either as auxiliary components for automation circuits, or as switches for supplying very small electric loads, such as electric valves, micromotors, small fans, alarm sirens, etc.
- Their use as auxiliary relays or as auxiliary contacts of a power relay means they are necessary for the Boolean logic functions described in the automation circuit.
- These relays are mounted on a base for accepting electric wires (easy replacement), or directly on a PCB board as a part of an electronic circuit.
- The movable contact arm, called common terminal (C), has two contact tips and it is located between two fixed contacts, which forms a normally closed contact (NC) and a normally open one (NO). This type of electric contact is usually called "changeover two-way contact",

16

- The electric contacts of a general-purpose relay are passing a current rated up to 15 A approximately, except from the very small ones (with dimensions of 1 . 1 . 2 cm for PCB boards) that have a nominal current of 1 A.

(a) (b)

general purpose relay without (a) and with (b) a mounting base.



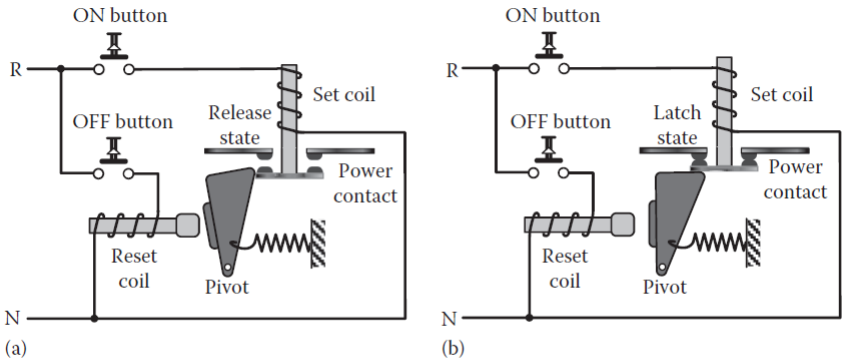
Two internal side views of a general purpose relay.

17

Latching Relays

- A latching relay, after its activation, maintains its contact position although the coil power supply has been removed, and therefore has two relaxed states as an electronic, bistable flip-flop.
- The classical relay should have a coil voltage applied to it at all times that it is required to stay energized.
- Such a situation is not necessary in latching relays, where their contacts are mechanically or magnetically locked in the ON state until the relay is reset manually or electrically.
- Mechanical latching relays use a locking mechanism to hold their contacts in their last set position until commanded to change state, usually by means of energizing a second coil.

18



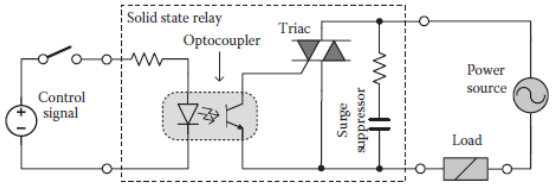
Schematic diagram of latching relay: (a) relay tripped and power circuit open, and (b) relay set-latched and power circuit closed.

19

Solid state relays (SSRs):

- are electronic devices with no mechanical contacts capable of switching various AC or DC loads, such as heating elements, motors, and transformers.
- SSRs perform the same switching function as the electromechanical relays, however their structure is quite different, consisting of semiconductor switching elements, such as thyristors, triacs, transistors, and diodes.
- SSRs include a semiconductor-type optocoupler to separate the input circuit from the output circuit, offering complete isolation of the input and output signals.
- The control signal (which corresponds to the coil voltage of the electromechanical relays) is applied to a light-emitting diode (LED).
- The light, or infrared radiation, is detected from a phototransistor that triggers the triac, which switches on the load current supplied from an external source.

20



Simplified circuit of a photo-coupled solid-state relay.

- SSRs provide high-speed or high-frequency ON-OFF switching operations and generate low noise.
- Due to the absence of movable contacts, they do not produce electric arcs and hence are suitable for use in hazardous areas. In chemical, petrochemical, mining, and many other industries where combustible materials are transported, stored, or processed, potentially explosive atmospheres are inevitable.
- In such cases, the use of SSRs as load switches is mandatory, according to national laws and regulations, since they ensure reliable operation and safety for personnel and machinery, even in extremely explosive environments.

21

Electric Contact Classification

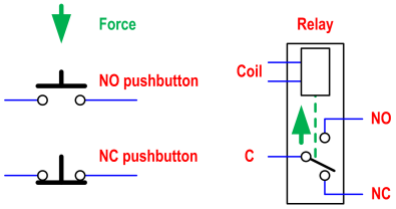
- An electric contact of a relay may be open or closed when the relay is de-energized, i.e., no supply voltage connected to the relay coil.
- Such a status of an electric contact, when the relay is not energized, is called “normal” and hence may be “normally open” or “normally closed”, abbreviated as NO or NC correspondingly.
- The same relay of any kind may contain NO and NC contacts simultaneously, independent of one another.
- When the relay is energized, all the NC contacts open and all the NO contacts close.

22

The table below shows the possible states of an electric contact in relation to the energized or NO state of the relay and the corresponding possible current flow.

Contact States and Current Flow with Regard to Relay State

Relay / Contact	Non-Energized	Energized
Normally closed (NC)	NC 	
Normally open (NO)	NO 	

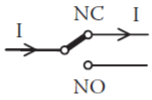
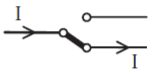
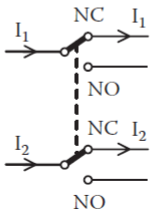
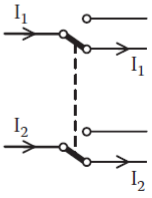


23

- The electric contacts permit the current to flow only one way or "**throw**".
- An electric contact of a relay or switch may have one or more throws.
- In other words, the number of throws indicates how many different output connections each electric contact can connect its input to, which is called a "common terminal".
- The two most common types are the single-throw and the double-throw contacts.
- Relays can be made up of one or more individual electric contacts with each "contact" being referred to as a "pole".
- The table below shows the possible states of the simplest changeover contacts (SPDT and DPDT).

24

Possible States of Two Simple Changeover Two-Way Contacts

Relay / Contact	Non-Energized	Energized
SPDT		
DPDT		

25

- The figure shown below is presenting the most basic electric contacts and their abbreviations.
- The electric contacts of the relays are numbered on convenient locations of the relay body, according to a standard numbering system, the basic rules of which are:

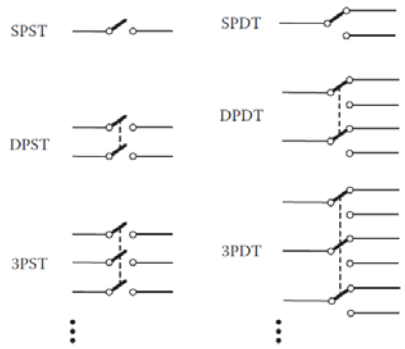
1. The power contacts are numbered with one-digit numbers (1, 2), (3, 4), and (5, 6) for the three phases R, S, and T, respectively.

2. The auxiliary NC contacts are numbered with two-digit numbers (X1, X2), where X=0–9.

3. The auxiliary NO contacts are numbered with two-digit numbers (X3, X4) where X=0–9.

26

The issue of selecting the suitable relay for an application depends on many parameters that concern the kind of construction; operation principle; size; and electrical characteristics, such as coil nominal voltage, the contact's rated current, the number of contacts, and many others.



Single-throw and double-throw electric contacts for several numbers of poles.

27

General conclusions on relays :

1. Relays are used either as power switches or as auxiliary logic components.
2. Relays permit a low-voltage circuit to control another high one or in general different voltage one.
3. Relays can be used as current "amplifiers".
4. Relays provide complete electric isolation between the control signal and the power signal, that is between the auxiliary control circuit and the power circuit.
5. By using relays with multiple poles of contacts, it is possible with one low-voltage signal to control the operation of many loads, each one with a different voltage.

28