Fundamentals of Electro-mechanical Relay Architecture

by Pan Yijun

Executive summary

Electro-mechanical relays are industrial control components equipped with electromechanical, magnetic, and thermal technology intelligence. They are widely deployed to support industrial control applications. Their structure varies depending upon the specific application. This white paper reviews the general working principle behind electro-mechanical relays and describes electro-mechanical relay architecture.

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Introduction

Electro-mechanical relays are one of the earliest forms of relay products. When a small current with the rated voltage is supplied as an input to the electromagnetic system of a relay, a magnetic force is generated that triggers a mechanical operation inside relay. That mechanical operation consists of contact switching. The electrical power circuit controlled by the relay contact system is switched either on or off in response to the input stimulus.

This paper will describe three main sub-systems of electro-mechanical relays. These sub-systems include the following:

- An electromagnet system, which converts electrical energy into mechanical power
- A contact system, which manages the mechanical switching of the electrical contact
- An auxiliary system, which acts as bridge between the magnetic and contact systems

This paper overviews electro-mechanical relay architecture in order to allow readers to understand the fundamentals of electro-mechanical relay products.

Working principles

Electro-mechanical relays use a small current that can be directly operated, to control a load that cannot be operated in a convenient or safe manner. The typical electro-mechanical relays consist of electromagnet system, contact system and auxiliary system. When an electro-mechanical relay is built, the electromagnet and contact systems are assembled together in the same base part. The auxiliary system, on the other hand, serves as a bridge between the electromagnet and contact system systems.

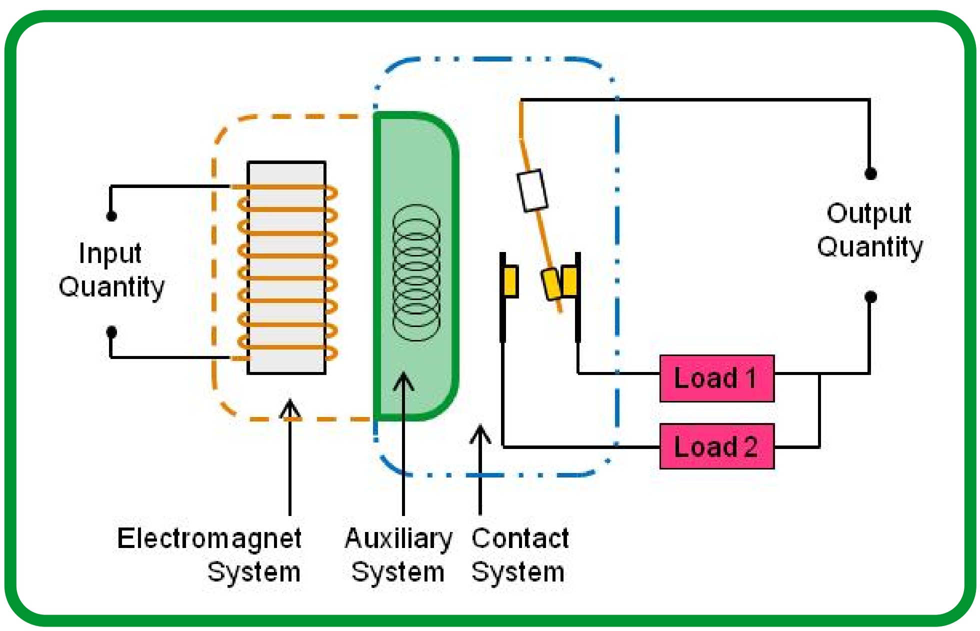


Figure 1
Electro-mechanical relay working principle

In **Figure 1**, the electromagnetic system is the sub-system inside the relay that receives the input quantity of current and voltage. When a voltage is supplied to it, the electrical current going through the coil generates the magnetic flow in the electromagnet system. The magnetic force, which is produced by magnetic field, stimulates the auxiliary system to drive the contact system.

When the supplied voltage increases, the current in coil and the generated magnetic force both increase at the same time. When the voltage increases to the rated value, which is referred to as the "pickup voltage", the electrical current in the coil generates sufficient magnetic force to overcome the mechanical reaction force (which comes from the contact system or auxiliary system or a combination of the two). This then causes the armature (the moving iron part of the relay) to move, which changes the contact system state from the load 1 position to the load 2 position (as illustrated in **Figure 1**).

When the armature moves to the final position from the initial position, and when the armature sticks to the core, the auxiliary system drives the contact system to complete the contact switching.

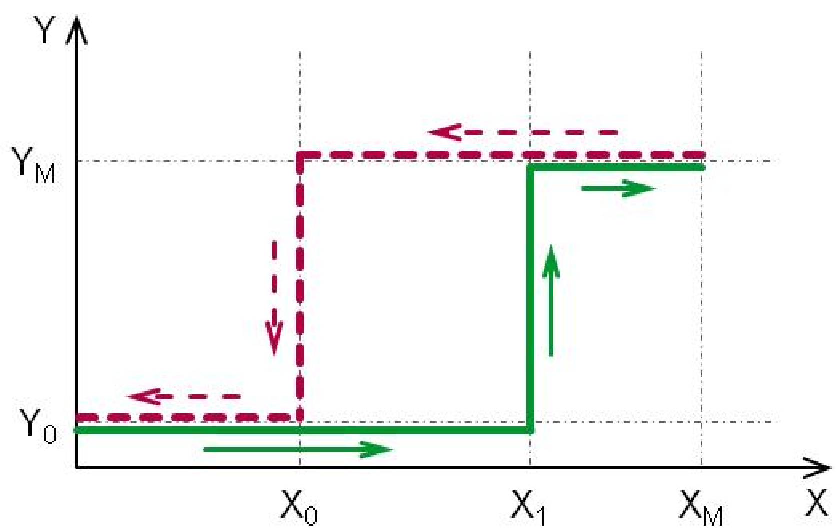
With a decrease of the supplied voltage, the current in the coil and the generated magnetic force both decrease at the same time. When the voltage drops to a rated value, which is referred to as "release voltage", the magnetic force generated by the current in coil is lower than the mechanical reaction force. When this happens, the auxiliary system forces the armature back to the initial position, and the contact system is driven to make the reverse contact switching.

Now, let's take a more detailed look at some characteristics of relays that help to shape the principles of a more robust and efficient relay technical design.

The instantaneous contact change principle

The contact system of electro-mechanical relays manages the function of the electrical contact. When it comes to managing contact state changes, there is no adjustment time required to initiate the change from ON to OFF (or from OFF to ON). It is an instantaneous change of contact switching. **Figure 2** illustrates the instantaneous contact change principle. In **Figure 2**, when input quantity X starts to increase along the direction of solid arrow from the 0, the output quantity does not change at Y=Y0 (the value is 0 in most cases). But when X quantity increases to X=X1, the output quantity Y jumps from Y0 to YM. After that, even if X quantity continues to increase to reach X=XM, the output quantity Y stays at the constant value of Y=YM.

Figure 2
Electro-mechanical relay product characteristics



X represents the input quantity, Y represents the output quantity

When the input quantity X starts to decrease along the dashed arrow direction from XM, the output quantity Y keeps the constant value Y=YM. But when the input quantity X decreases to X=X0, the output quantity Y jumps from YM to Y0.

The galvanic isolation principle

According to IEC 60664-1 (Insulation Coordination for Equipment within Low-voltage Systems, Part1: Principles, Requirements and Tests), the insulation coordination of electrical equipment is the mutual correlation of insulation characteristics taking into account the expected micro-environment and other influencing stresses. It implies the selection of the electric insulation characteristics of the equipment with regard to its application and in relation to its surroundings, which includes:

- Clearance, which is shortest distance in air between two conductive parts;
- Creepage, which is shortest distance along the surface of the insulating material between two conductive parts;
- Solid insulation, (solid insulating material interposed between two conductive parts)

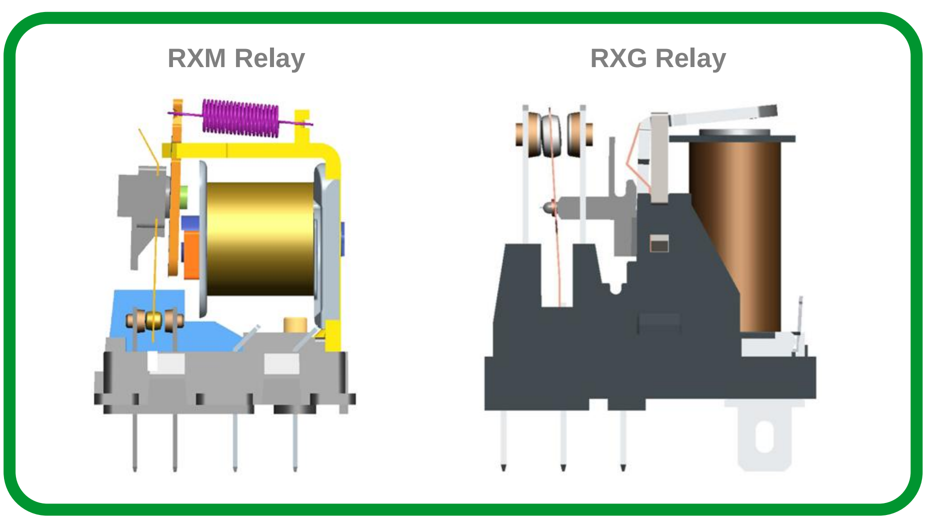
For electro-mechanical relays, the electromagnet system which receives the input quantity from the control circuit and the contact system which sends output quantity to the electrical power circuit are isolated from each other in two separated circuits. The auxiliary system is the only bridge that transfers mechanical power between the electromagnet system and contact system. There is no direct electrical connection between these two circuits. The insulation design of electro-mechanical relays can be enhanced easily by improving clearance, creepage and solid insulation. So electro-mechanical relays can achieve good performance on galvanic isolation.

The instantaneous contact change makes electro-mechanical relays respond very quickly and transmits information very clearly when the input quantity reaches the rated value, which is either pickup voltage or release voltage. The galvanic isolation makes electro-mechanical relays an attractive solution for applications where higher galvanic isolation is required (for safety or reliability reasons). Electro-mechanical relays also can support a wide range of input and output quantities in a separate fashion (can range from low voltage/current to high voltage/current and from DC to GHz frequencies). Therefore a suitable electro-mechanical relay can be always found or designed to match the specific requirements of the various industrial applications. As a result, electro-mechanical relays are widely used in industrial automation control, protection and information delivery applications.

Architecture

Electro-mechanical relays applications vary depending upon the requirements of the industrial control area in question. The product structure design is different in each case.

Figure 3
Visual comparison of relay with horizontal coil (RXM) and relay with vertical coil (RXG)



Take an example of two typical electro-mechanical relay products. One product type is equipped with a horizontal coil, which is characteristic of a general purpose relay (see the Schneider Electric RXM relay example in **Figure 3**. A second product type is equipped with a vertical coil, which is typical of most interface relays (see the Schneider Electric RXG relay example in **Figure 3**). Both relay product types have similar functions. However their structure is not the same because each needs to be adapted to its particular technical environment.

Although these types of differences are commonplace, electro-mechanical relays have the same core architecture which consists of an electromagnet system, a contact system and an auxiliary system. Electromagnet system and contact systems are mounted together. Auxiliary systems will transfer mechanical power from the electromagnet system to the contact system when a product is powered on, and force the contact system back to initial position when the product is powered off.

Electromagnetic System

The electromagnet system converts the input quantity of electrical energy into mechanical power. Electromagnet systems include a coil, a core, a yoke and an armature. If the input is AC, a copper ring is also included (see **Figure 4a** for an RXM example and **Figure 4b** for an RXG example)

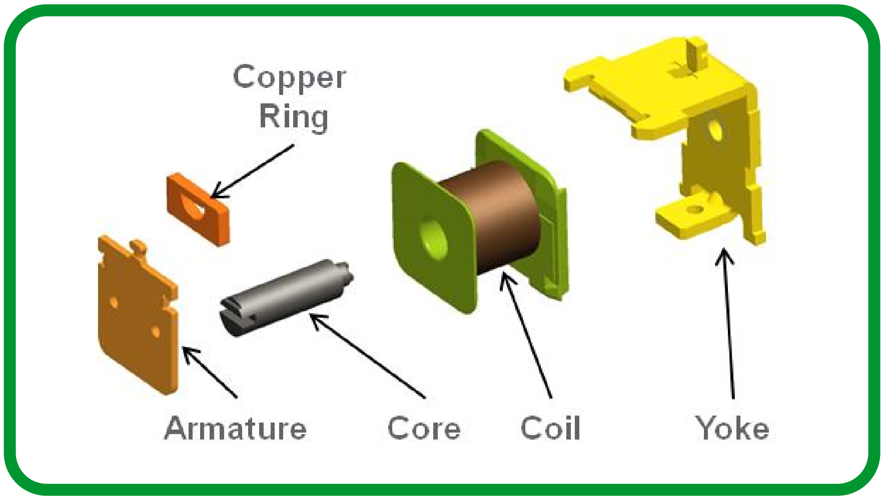


Figure 4a
RXM Electromagnetic System

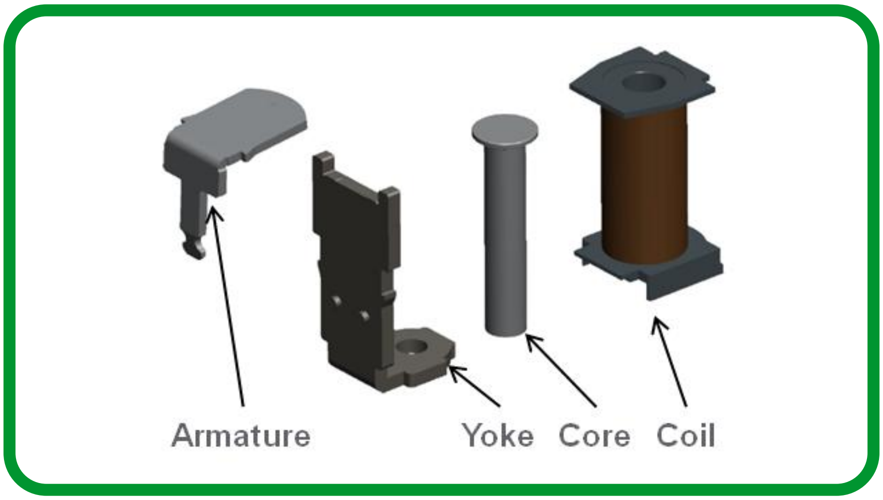


Figure 4b
RXG Electromagnetic System

Coil

A coil consists of an enamel insulation wire wound around a coil bobbin frame. The enamel wire selection, coil size and shape will be configured according to the required magnetic force and specific product structure. When the power on, a current will go through enamel insulation wire to generate a magnetic field. The coil is the engine of electro-mechanical relay.

Core

A core is placed in the center of coil and is made up of ferromagnetic materials. This material can significantly amplify a magnetic field when an external magnetic field is applied.

The ferromagnetic material is made up of many small magnetic domains. Each magnetic domain can be an individual magnetic dipole with a random direction. The material as a whole body does not perform as one magnetic dipole and does not have any magnetism. When an external magnetic field is applied on the ferromagnetic material, the magnetic dipoles of each magnetic domain line up parallel to the external field. Because there is a strong interaction between the neighboring atomic dipoles, the magnetic dipoles alignment will be much stronger with this material as opposed to other materials. After enhancement from the external magnetic field, the total magnetic field inside a ferromagnetic material will be 10^3 or 10^4 times stronger than the external magnetic field.

The relay core can help to improve magnetic field strength, improve coil magnetic permeability, and concentrate magnetic flux.

Armature

The armature is the moving part that drives the contact system. It is one of the parts in the magnetic circuit and is composed of ferromagnetic material. When the magnetic field is generated by the coil, it exerts a mechanical force on the armature. The armature then moves along the magnetic field direction due to the air gap between armature and core. It is quite similar the way a permanent magnet attracts any magnetic objects. The polarity of the magnetic field is irrelevant to the armature attraction.

Yoke

The yoke is a stationary part inside the relay which is used to support or fix other parts like coil, core, armature, or returning spring. A high level of mechanical strength is required for the yoke to function properly.

The yoke is one of the parts in magnetic circuit inside a relay and need to provide a closed low magnetic circuit with minimum remanence. (Remanence is the magnetization left behind in a ferromagnetic material after an external magnetic field is removed). The yoke is made of ferromagnetic material.

Copper ring

Alternation current (AC) power has a waveform characterized by voltage increases at the peak and a drop to zero voltage every half cycle. As a result, the magnetic field, which is influenced by the coil powered by the AC power supply, also varies. The magnetic force on the armature changes between peak and zero every half cycle as does the frequency of the AC power supply. The armature needs to be shielded from this effect if it is to work properly.

In order to address this issue, a copper ring (or shading ring) is mounted at the top of the core. It is similar as a transformer with two coils around a common core (where the magnetic energy is transferred from a primary coil to a secondary coil. In a relay, the copper ring acts as a secondary coil, and it also generates a magnetic field. There is a phase displacement between the magnetic fields of the coil and of the copper ring. When the magnetic field from coil drops to zero, the magnetic field from the copper ring with phase displacement will attract the armature.

The purpose of copper ring is to ensure that some magnetic energy remains in core when AC voltage drops to zero. Then armature can have a stable attraction throughout the entire AC power supply cycle.

Contact system

The contact system executes the contact switching of the electrical power circuit. The system includes one moving contact and one fixed contact. Each contact connects to a terminal for connection to an external electrical power circuit. Normally one set of contacts is referred to as one contact "pole".

Electro-mechanical relays usually consist of one or more contact poles. For example, there could be four contact poles in an RXM relay product, and could be only one contact pole in RXG relay (see **Figures 5a and 5b**). The solid insulation is in place to separate poles if the creepage and clearances need to be adjusted.

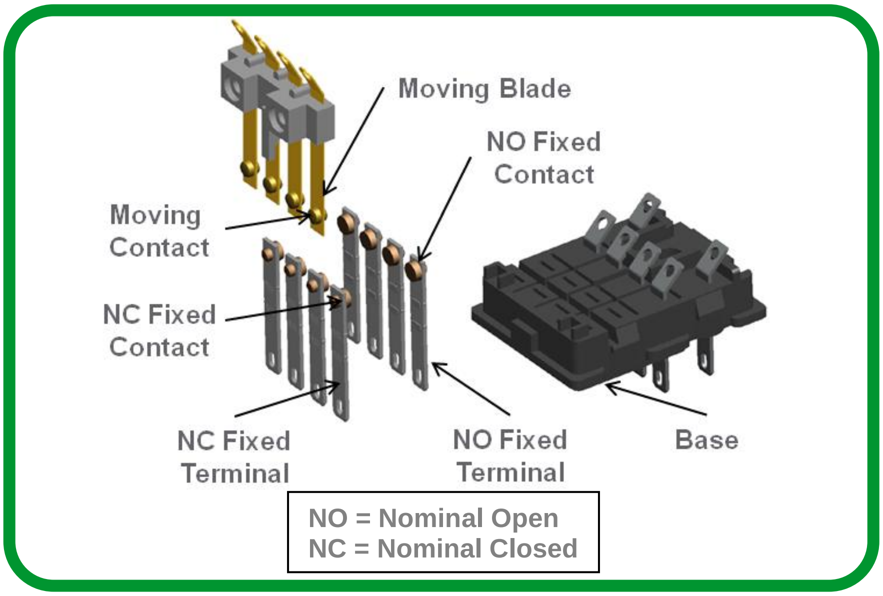


Figure 5a
RXM Contact System

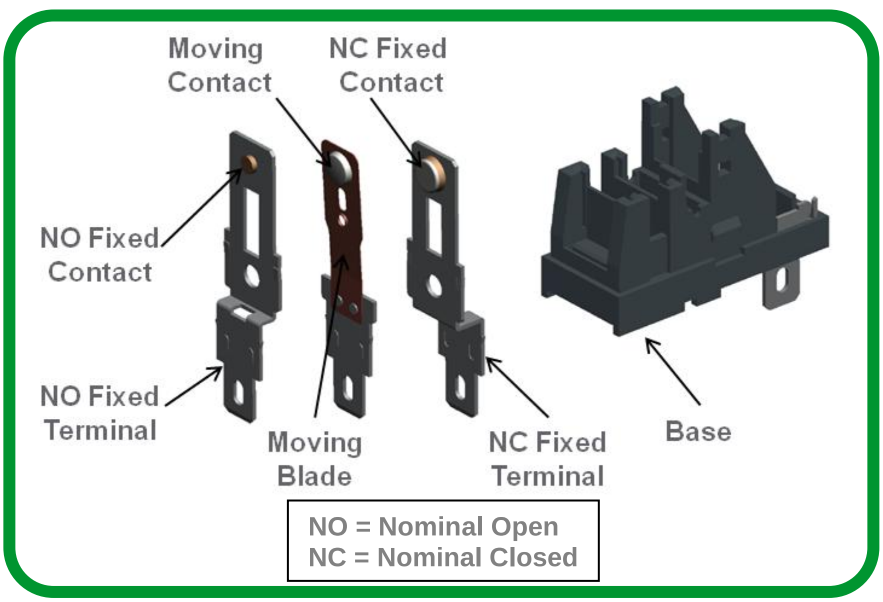


Figure 5b
RXG Contact System

Moving contact

The moving contact is a moving part within a contact set. It is directly riveted in the moving blade. It moves toward the fixed contact in order to close the contact. Or, it moves away the fixed contact in order to open the contact. The external electrical power circuit is switched on or off accordingly.

A material of high electrical conductivity and low environmental sensitivity, like silver and / or silver alloy, is chosen for a contact rivet. Gold plating is sometimes applied to prevent oxidation.

Fixed contact

The fixed contact is a stationary part in one contact set. It is directly riveted to the fixed terminal. It remains static and either maintains contact close or break contact open conditions vis-à-vis the moving contact.

Normally the fixed contact material is the same as the moving contact material.

Moving blade

The moving blade is a flexible moving part, which is driven by the auxiliary system. When the moving contact rivet touches the fixed contact rivet, the shape of the flexible moving blade is distorted by the auxiliary system. The purpose of this intervention is to generate a spring force, so that the proper contact force can be maintained to ensure contact reliability.

Fixed terminal

The fixed terminal is a rigid and stationary part, which is fixed into the relay base. A design with a fixed terminal produces the contact pressure and is optimized for contact force control. It can be adjusted during the manufacturing process.

Contact Arrangement

The contact arrangement is defined by the form factor and the contact pole number. It can vary depending up the specific requirements of the industrial application. **Table 1** illustrates some examples of some common contact arrangements.

Table 1
Contact arrangements

Contact Arrangement	Description
1A	1 pole of NO contacts
1B	1 pole of NC contacts
1C	1 pole of Change-Over contacts
2A	2 poles of NO contacts
2B	2 poles of NC contacts
2C	2 poles of Change-Over contacts
1A1B	Total 2 poles, 1 pole of NO contacts and 1 pole of NC contacts
2A2B	Total 4 poles, 2 poles of NO contacts and 2 poles of NC contacts
3A1B	Total 4 poles, 3 poles of NO contacts and 1 pole of NC contacts

Below are examples of common form factors

- **Form A contact** – In this design, the contact set is initially set at the nominal open (NO) position. When the relay is powered on, the moving contact rivet and fixed contact rivet achieve contact closed status and switch on the external electrical power circuit. However, when the relay is powered off, these components break contact open status and switch off the external electrical power circuit. This form factor is called as "Form

A" contact. Form A contact is useful in applications that need to switch on a single power source from a remote location.

- **Form B contact** – In this design, the contact set is initially set at nominal closed (NC) status. When the relay is powered on, the moving contact rivet and fixed contact rivet will break contact open and switch off the external electrical power circuit. When the relay is powered off, these components achieve contact closed status and switch on the external electrical power circuit. This form factor is called as "Form B" contact. Form B contacts are useful in applications where the circuit is required to remain closed before the relay is powered on, but the circuit must be shut down after the relay is powered on.

- **Form factor C** - Change-Over (CO) contacts are a combination of Form A and Form B. In this design, the moving contact is common and can control the switch of two electrical circuits. It is also called as "Form C" contact. In most relay products, one contact rivet makes or breaks contact with another contact rivet. This is called a single contact. If two contact rivets are used to make or break contact with other contacts in the same pole, it is called as bifurcated contact.

According to the contact system structure, Form A or Form B can be called "Single Throw" relay contact. Form C can be called a "Double throw" relay contact. **Table 2** illustrates common examples of contact designations.

Table 2
Contact designations

Contact Arrangement		Description
SPST	Single Pole Single Throw	One pole relay has either NO contacts or NC contacts. The terminology "SP_NO" or "SP_NC" is used.
SPDT	Single Pole Double Throw	One pole relay has both NO contacts and NC contacts.
DPST	Double Pole Single Throw	Two pole relay has either NO contacts or NC contacts. The terminology "DP_NO" or "DP_NC" is used.
DPDT	Double Pole Double Throw	One pole relay has both NO contacts and NC contacts.

In the **Table 2** example, The "S" or "D" may be replaced with a number to indicate a multiple pole relay product. For example, "4PDT" indicates a four-pole relay that has both NO contacts and NC contacts.

Auxiliary system

Auxiliary systems work as a bridge between the electromagnetic system and the contact system. When the relay product is power on, the auxiliary system transfers mechanical power generated by the electromagnetic system to the contact system and changes contact status. When the relay product is power off the auxiliary system also forces the contact system and electromagnetic system back to their initial positions and changes contact status.

The auxiliary system normally consists of a driving part and a returning part. These components can be configured either as separate parts or as a common part with the required functions. For example, a Schneider RXM relay has a separated returning part, but it uses a moving blade holder as the driving part (see **Figure 6**). But a Schneider RXG relay has a separate driving part, and it uses the moving blade as a returning part (see **Figure 6**).

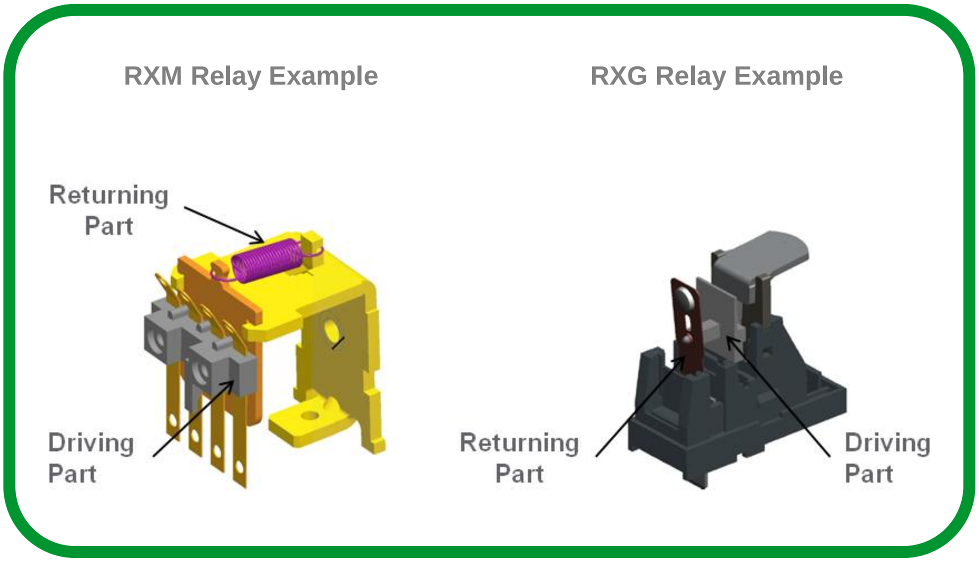


Figure 6
RXM (left) and RXG (right) auxiliary systems

Driving part

There are two major types of driving part structures between the electromagnetic system and contact system in most relay products.

When the driving part is a common part that shares other functions, for example, RXM relay illustrated in **Figure 6**, the contact holder, which is a fixed on the armature, transfers mechanical force between the contact system and the electromagnetic system. At the same time, the contact holder also functions to hold all the moving blades. This kind of structured design is simple, it is highly efficient, and is reliable for transferring mechanical force. It does require, however, an additional soft cable to connect between the moving blade and the output common terminal. This soft cable is one of the weaknesses of this configuration from an electrical performance and manufacturing productivity perspective.

When the driving part is a separate part, for example, RXG relay illustrated in **Figure 6**, a specific card part made of insulating material is used to transfer mechanical force between the contact system and the electromagnetic system. The efficiency and reliability of the transfer mechanical force is impacted by the insulating part, but this structure design removes the need for a soft cable and the associated disadvantages.

Returning part

The returning part generates a force to drag the armature back to the initial position. The force values will change with armature moving. The returning force always works together with the magnetic force to change the contact status of contact system when the relay is power on or power off.

The returning part can be a separated part or a shared part. For example, the returning part is a separate spring part in an RXM relay, as illustrated in **Figure 6,** but it is a shared part, which is the moving blade, in the RXG relay, as illustrated in **Figure 6**.

The structure design with the spring returning force is simple and easy. The returning force is adjustable during the manufacturing process. It is the most widely applied system among the electro-mechanical relay products.

Electro-mechanical relay application

There are two areas where electro-mechanical relays are commonly used. One area is a signal transmission application. In this case, electro-mechanical relays act as interface relays. They transfer the control signal to the end products. The interface relays need to have low level signal adaption ability, medium sensitivity, fast action, and high switching reliability.

Another application area is electrical power control. In this case, the electro-mechanical relay acts as an electrical power relay. They work to control the heavy electrical load, which cannot be directly operated. For example, they are used for control of a lamp, motor, electromagnetic clutch, electromagnetic valve, or solenoid means.

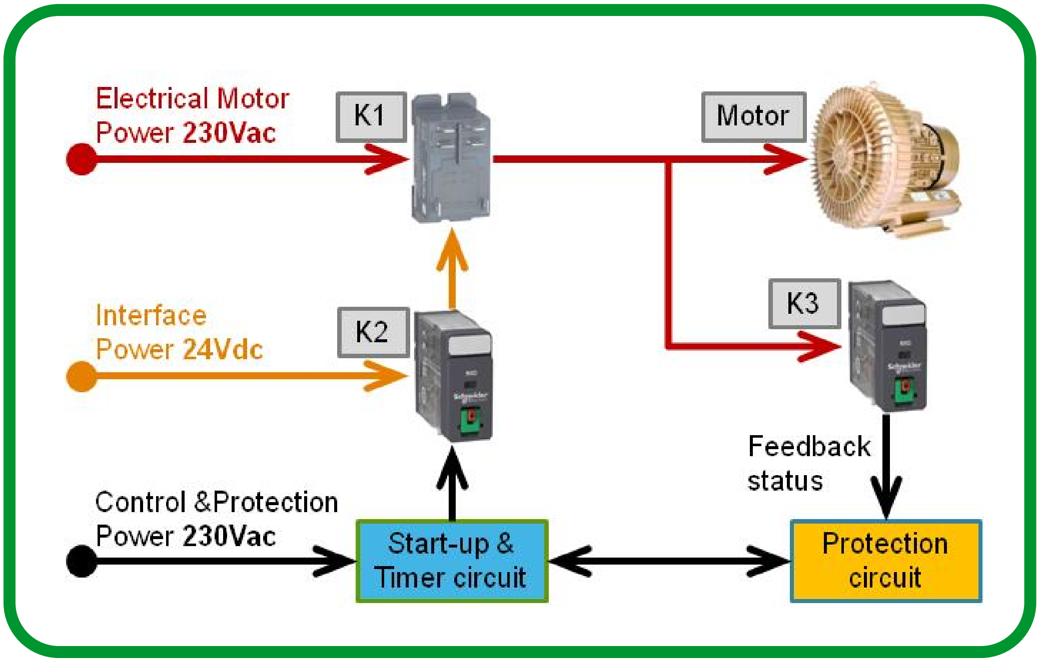


Figure 7
Electro-Mechanical Relay Application Example

Figure 7 provides an example of relays in an industrial application. In Figure 7, K1 represents an electrical power relay, and K2 and K3 represent interface relays. When the Start-up and Timer circuit is power on, the protection circuit is activated at the same time. The control signal of activation is sent to K2, and it is then converted to an interface signal and transmitted to K1 via interface relay K2. Then the electrical power relay K1 start to work and directly controls the electrical motor with high rated current. The interface relay K3 is controlled in parallel with the motor and communicates the motor's running status to the protection circuit.

If any abnormal operation condition manifests itself on the motor, the protection circuit receives an abnormal status from the interface relay K3 and sends the signal to the Start-up and Timer circuit (which sends out the control signal of deactivation to K2).

Environmental conditions must be considered during industrial relay installation and operation. The industrial machinery and equipment always will transmit the shock and vibration to the control cabinet where the electro-mechanical relay is installed. Such conditions will impact relay performance and reliability. There are also some gaseous fumes or particulates containing chemicals such as sulphur, phosphorus that can impact performance. The amount of heat generated is also a performance factor to consider. Such conditions accelerate organic contact contamination, which will impact the product life of the electro-mechanical relay.

Conclusion

Due to the variety of industrial control applications, relay structures may differ and require different product types. Overall, core electro-mechanical relay architecture is basically the same.

The instantaneous contact change in response to a stimulus and galvanic isolation between the input and output circuit are two characteristics that offer a technical advantage. Electro-mechanical relays offer an excellent solution for separating the input of an electronic control circuit from the output in an industrial application with leap change requirement.

Electro-mechanical relays are simple, cost effective, and provide reliable performance. They are also flexible enough to address the requirements of a wide variety of industrial control applications.

About the author

PAN Yijun is a Senior R&D Electromechanical Engineer and EDISON Group Expert Level 1 within the Relay Business at Schneider Electric. He holds bachelor's degrees of Mechatronics Engineering from XIDIAN University, China. He has focused on R&D of electro-mechanical products including relays, socket and accessories for about 10 years.