

Safety Devices that Support the Reliability of Machinery and Equipment

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ABSTRACT

Against a backdrop of frequently occurring accidents at factories, railways and the like, interest in the safety of machinery and equipment is increasing. A newly developed short interruption restart relay combines the three functions of instantaneous restart, timed restart and prohibited restart in response to a power failure, and makes possible the safe implementation of the motor restart control. Also, a variety of safety standard-compliant devices such as emergency switches, trip wire switches, safety door switches, light curtains, safety mats, two-hand control stations and safety relay units are provided and help to reduce the risk associated with machinery and equipment.

1. Introduction

In recent years, concern for the reliability and safety of machinery and equipment has heightened as a result of the occurrence of accidents at public facilities such as railways and elevators and of large-scale industrial accidents at factories and manufacturing plants. This paper describes the roles and presents application examples of a “short interruption restart relay” for safely controlling the restarting of a motor after a power outage and “safety standard-compliant devices,” which are key components used in the construction of a safety system.

2. Short Interruption Restart Relay

Short interruption restart relays are used in factories or manufacturing plants, in which multiple motors have been installed, to restart the motors automatically after a short-time power outage has occurred in the main circuit. In addition to preventing the loss of time and the like involved in recovery work, system crashes due to insufficient capacity can be prevented even when using small-size power source equipment since the inrush current is distributed over time when restarting and the maximum current flow into the main circuit is reduced, and as a result, lower investment costs and energy savings are anticipated.

Fuji Electric’s newly developed “MB4” is shown in Fig. 1, and details of its specifications are described below.

2.1 Improvements in the MB4 Short interruption restart relay

(1) Adjustable prohibited restart function

The previous model (MB2) had a fixed setting for determining whether restarting would be allowed or disallowed according to the time duration of the power outage. With the MB4, the user is able to adjust the time setting so as to improve the ease of use.

(2) Small size and common sockets

The MB2 previous model had a large external shape, and used a custom ATX1PS socket for installation and wiring. In contrast, the MB4 has a smaller size that occupies only 65% of the volume of the previous model and uses common TP48X sockets, which are used with the MS4S series of general-purpose timers. As a result, unlike the previous model, the MB4 can be mounted on a DIN rail.

Fig.1 Short interruption restart relay “MB4”



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2.2 Operation of short interrupt restart relay

Figure 2 shows a connection diagram for the short interrupt restart relay. The operation when the power has been restored will differ according to the duration of the power outage and this difference is explained below using the operating pattern shown in Fig. 3.

(1) Instantaneous restart

In the event of a power outage, first, the self-holding function of a magnetic contactor (MC) is released. Then, if the power is restored within an instantaneous restart time t_1 , the output contact T_a turns ON in a pulse form. As a result, the magnetic contactor MC again implements its self-holding function and the motor restarts automatically.

(2) Time delayed restart

If the time duration of the power outage exceeds the abovementioned instantaneous restart time t_1 , the output contact T_a will turn ON after a timed delay restart interval t_d has elapsed following the restoration of power. In the case where multiple restart relays are

being used, by setting the time delay t_d to the desired time lag, the restart timing can be shifted for each motor so as to restart the motors sequentially. Since the motor inrush current will be distributed, the maximum current flow to the main circuit will be lowered.

(3) Prohibited restart

If the duration of the power outage exceeds the t_2 time setting, then even if power has been restored, the output contact T_a will not turn ON, and restarting will be disallowed until the START switch is turned on manually.

Fuji Electric's instantaneous restart relay is equipped with the abovementioned three operating modes that correspond to the power outage duration, and as a result, enables highly reliable automated control can be implemented in unattended electrical equipment.

In the case where automatic restarting after the motive power has been interrupted could pose a danger to the operator of the machinery or equipment, a preventative measure must be implemented using the safety relay unit introduced in section 3.2 below, or the like.

Fig.2 Short interrupt restart relay connection diagram

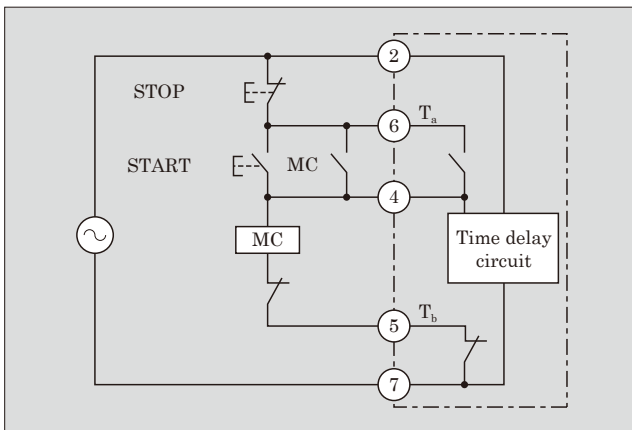
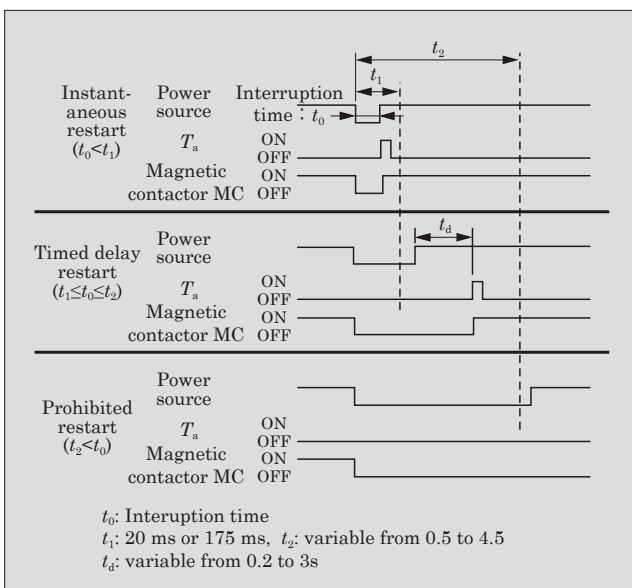


Fig.3 Operating pattern for restart



3. Standard-Compliant Devices

3.1 Market trends of safety devices

In Japan, with the adoption of international standards for machinery safety such as ISO 12100 (Safety of machinery: Basic concepts) and ISO 14121 (Principles of risk assessment), in order to ensure worker safety, safety measures for machinery and equipment are implemented in advance, and it is required the failure or misuse of such machinery and equipment will not harm people. Previously in Japan, the assurance of safety was highly dependent upon the skill of workers, and safety measures for machinery and equipment were not advanced. With the revision of the Japanese “Industrial Safety and Health Law” in 2006 and the “Guidelines for the Comprehensive Safety Standards of Machinery” in 2007, the concept of machinery safety in accordance with international standards began to gain ground in Japan.

Table 1 Functions and types of safety standard-compliant devices

Function	Type
Switch to stop machinery when dangerous situation arises	Emergency stop switch Trip wire switch
Sensor for notifying operator of the open or closed state of a guard that isolates dangerous locations	Safety door switch
Sensor for detecting the intrusion or presence of a person	Light curtain Safety mat
Switch for securing a person in a safe location while operating the machinery	Two-hand control station Foot switch
Device for safely controlling the abovementioned devices	Safety relay unit Safety controller

The devices used for safety have the following characteristics in order to improve the reliability of the safety functions. These devices are different from general-purpose devices.

- (a) Designed with redundancy
- (b) Designed with diagnostic functions and the like so as to be safe side even during a failure
- (c) Provided with a function for preventing defeat of the safety mechanism

The safety devices shown in Table 1 and Fig. 5 are individually described below.

3.2 Characteristics of Safety standard-compliant devices

(1) Emergency stop switch

Developed in 2007, Fuji Electric's "minico Series" of command switches help to achieve space savings in the control panel and have been well-received. As an expansion of this series, the "AR16 V" emergency stop switch was launched in October 2008 and its features are introduced below (see Fig. 4).

(a) Multi-contacts

Fuji Electric's conventional emergency stop switches were typically provided with 1 to 2 con-

tacts, but redundant circuitry is being required for electrical safety, and multiple contacts are desired. To meet these needs, the AR16 V is provided with up to 4 contacts.

The minico Series employs an integrated structure with built-in contacts; its body can be inserted directly into a $\phi 16$ mm mounting hole and is arranged so that 4 contacts can be efficiently arranged in the limited body space.

(b) Improved operability

According to IEC 60947-5-5 (Electrical emergency stop device with mechanical latching function), a safety device is required to be able to withstand an operating force of five times the mounting hole diameter. In the case of a $\phi 16$ mm mounting hole, the corresponding required force withstand capability is 80 N, but during an emergency, it would be difficult to adjust the operating force according to the switch diameter. The AR16V has a structure capable of easily withstanding 150 N, which corresponds to a standard maximum diameter of $\phi 30$ mm. Also, the two release methods of turn-reset and pull-reset exist in the market, as consequently, the operation will vary depending on the machine, and this may invite confusion. Turn-reset and pull-reset structures are both capable of implementing the release with the AR16V, and as a result, safety is ensured and the customer's ease-of-use is improved.

(c) Lineup of illuminated-type products

Particularly for large-size machinery, there is a need to improve the visibility of emergency stop switches so that they can be located quickly. Emergency stop switches compatible with $\phi 16$ mm mounting holes have been added to Fuji's lineup as the first illuminated-type products. In addition, LEDs are used as the light source, helping to reduce power consumption and CO₂ emissions.

(2) Trip wire switch

If an emergency stop system is needed along a long conveying line or the like, a trip wire system that activates a stop function when a wire is pulled is well suited for this purpose. As shown in Fig. 6, a trip wire switch can be operated from anywhere within the workspace so that workers are able to avoid the direct

Fig.4 Appearance of "AR16 V" emergency stop switch



Fig.5 Example installation of safety standard-compliant devices

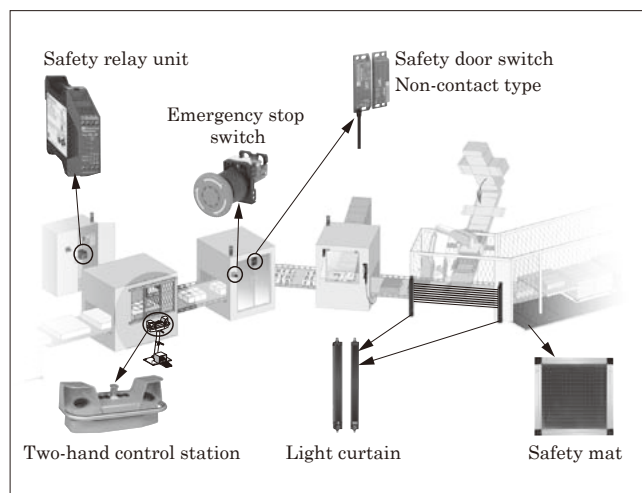
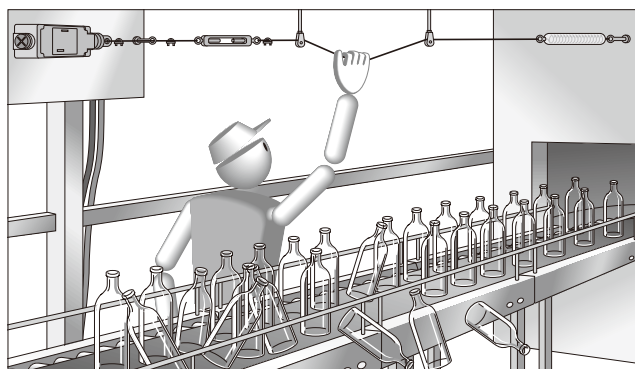


Fig.6 Trip wire switch



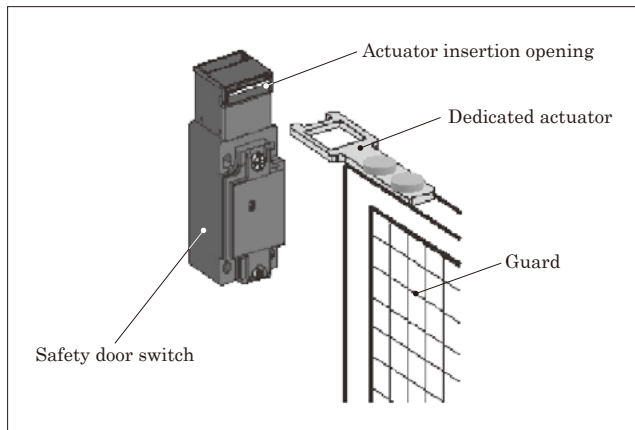
risk of danger. Compared to the case in which multiple emergency stop switches are installed, the implementation of a trip wire switch enables a significant reduction in the time required for wiring.

(3) Safety door switches

With ISO 14119 (Interlocking devices associated with guards), safety door switches are required to have a function for preventing the safety interlocking mechanism from being defeated. As shown in Fig. 7, the “XCS Series” has a functional structure only when a dedicated actuator has been inserted. This prevents workers from using wire and common tools to defeat the switch and operate the machinery in a dangerous state. In cases where the machinery does not stop immediately by inertia after the issuance of a stop command, an “XCSE,” having a function for locking the opening and closing of doors, is used together with a stop detection unit, which will be described later.

With the “XCSDM” non-contact type safety door switch,

Fig.7 Safety door switch “XCS Series”



switch, there is no mechanical contact between a magnetic actuator and sensor unit. Therefore no particulate debris is generated as a result of abrasive wear. In addition, these “XCS Series” safety door switches are provided with an IP67 protective structure and are well suited for use in semiconductor manufacturing equipment and in food machines that use water.

(4) Light curtain, safety mat

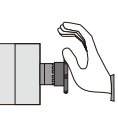
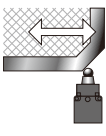
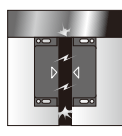
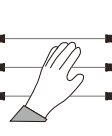
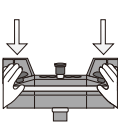
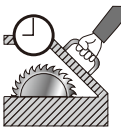
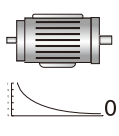
The “XU Series” of light curtains are sensors for detecting the intrusion of a person and comply with IEC 61496 (Electro-sensitive protective equipment). Various models are available for finger detection, hand detection and human body detection and the sensor transmitter and receiver can be separated by a long distance of up to 20 m. These light curtains can also be used as a substitute for a safety fence.

Since a light curtain is installed in the periphery of a hazardous area, it is difficult to distinguish between the presence of a person or machine inside the hazardous area. In such a case, a “XY2TP” safety mat spread out on the floor is well suited for detecting the presence of a person. This safety mat has a relatively large detectable weight capability of 20 kg or more, and is resistant to mis-operation due to the dropping of tools or the like.

(5) Two-hand control station

The “XY2SB” two-hand control station requires the use of both hands to press switches to start the machinery, and consists of two mushroom-shaped push-button switches and an emergency stop switch integrated into a single unit. To ensure safety during operation, the two-hand control station complies with the requirements of ISO 13851 (Two-hand control devices). When used in conjunction with a custom stand, the height, direction and tilt of the switch installation

Table 2 Safety relay unit, safety controller and applications

Safety relay unit, safety controller model	Safety application								Compliance category *1
	Emergency stop switch	Safety door switch	Non-contact door switch	Light curtain	Safety mat	Two-hand control station	Safety time delay	Zero speed detection	
									
XPS AF	○	○							4
XPS ATE	○	○					○		3
XPS AV	○	○					○		4
XPS VNE								○	3
XPS AK	○	○		○	○				4
XPS DMB			○						4
XPS BF						○			4
XPS MC	○	○	○	○	○	○	○		4
XPS MP	○	○	○	○	○				4

*1 : ISO 13849-1 (Safety related parts of control systems)

can be adjusted freely according to the physique and posture of the operator.

(6) Safety relay unit, safety controller

By combining safety relays equipped with forcibly guided contact mechanisms, a redundant safety circuit can be configured with diagnostic functions such as redundancy and welding detection, but the time and investment required for the development, design and standard certification of such circuits is a problem.

In the “XPS Series” of safety relay units, the safety controller is integrated into a single unit, enabling safety systems to be realized easily. Table 2 shows the suitability of each model of this series according to the applications and categories prescribed by ISO 13849-1 (Safety related parts of control systems). Each unit in “XPS Series” supports category 3 (design such that the safety function is always retained when a single fault occurs) or category 4 (design such that an accumulation of faults shall not lead to the loss of the safety function).

A safety relay unit supports a single safety function, and the realization of multiple safety functions for large-scale machinery results an increase in the number of installed units and complicated wiring. With the “XPS MC” safety controller, up to 32 devices can be monitored from a single controller, resulting in a smaller footprint and requiring less wiring time. This product is equipped with both solid-state and relay outputs and can handle loads of up to 4 A, and is also capable of driving a magnetic contactor directly. In addition, because the software is constructed from certified function blocks, safety functions can be real-

ized with simple programming techniques, and the monitoring of individual safety devices makes it possible to assess the status quickly when a failure occurs.

3.3 Example application of motor rotation stop detection

The “XPS VNE” is a safety relay unit for detecting the rotational inertia of a motor, and utilizes a method for detecting the back electromotive force of the motor. Since rotation sensors such as proximity switches are unnecessary, use of the XPS VNE enables a reduction in the amount of work required for sensor installation and adjustment. The circuit configuration is described with reference to the typical application example shown in Fig. 8.

(1) Detection of rotation stop

Each U, V and W motor phase is connected to an input pin Z1, Z2 and Z3, respectively, of the XPS VNE, which detects and monitors the voltage between each phase. When the power to the motor is interrupted, a back electromotive force is generated in the stator windings. This back electromotive force is proportional to the rotational speed of the motor. Therefore, a determination to stop the rotation is made if the voltage being monitored drops below a certain threshold value.

(2) Failure diagnosis

If a difference in the voltages between pins Z1 and Z2 and between Z2 and Z3 is detected, a wiring abnormality is determined to exist between the motor and the XPS VNE, and mis-operation due to a broken wire or failure is prevented.

(3) Movable guards and control of magnetic contactors

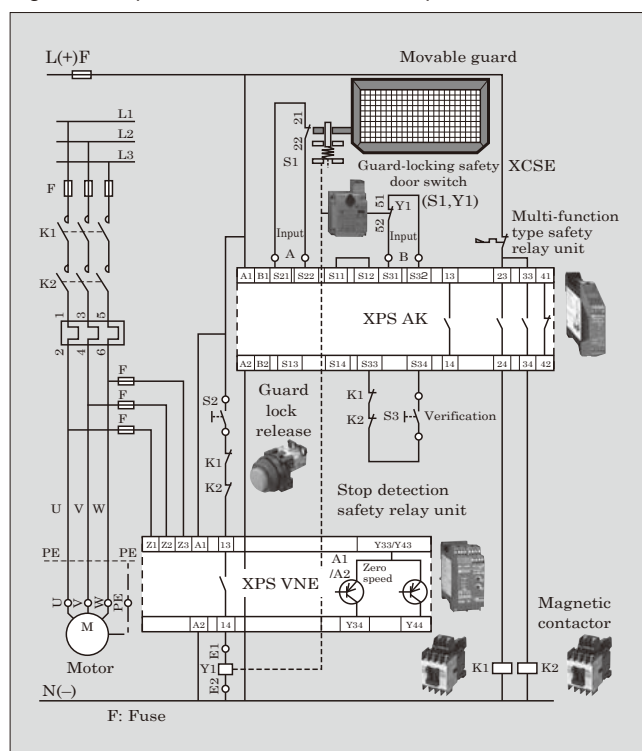
The “XPS AK” safety relay unit monitors whether movable guards are closed and also the welding status of contacts for mirror contact-type magnetic contactors. In the case of occurring abnormalities such as contacts welding, for example, the output contacts 23-24 and 33-34 are turned off, and control is implemented to inhibit the motor from starting. Additionally, the “XCSE” interlocking safety door switch immobilizes the movable guards while the motor is rotating, but after confirmation that the rotation has stopped, in response to a command from the XPS VNE, drives a solenoid incorporated into the door switch to release the guard lock.

The configuration described above is able to ensure safety in an inertial system.

4. Postscript

In this paper, in addition to safety devices for unmanned equipment, characteristics of new safety standard-compliant devices that support the changing tide of the concept of global safety have been introduced. By offering a combination of safety devices and detection equipment and providing technical know-how, Fuji Electric will endeavor to promote safety solutions that contribute to society.

Fig.8 Example connection of rotation stop detection unit





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