Miniaturization Technology in the “TK12” Thermal Overload Relay

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ABSTRACT

As resource and energy saving continue to progress, there are demands to reduce the size and improve the energy efficiency of the control panels and machinery used in production facilities and other industries. There is also a higher demand to reduce the size and power consumption of the thermal relays which are the components in such equipment. Applying ever accumulated technology, Fuji Electric has developed the “TK12” thermal relay pursuing miniaturization with reduction of part quantity, implementation of thermoplastic material for the housing, and improvement of the heating section design. The relays also meet global demands for safety and operability, and are equipped with terminal covers that conform to IEC 60529 as standard.

1. Introduction

Thermal type, electromagnetic type, induction type and static type are available to apply overload relays for low-voltage induction motors. As in recent years, the electronic control of motors using inverters and the like has become popular, electronic technology for overcurrent protection has also become progressed.

Thermal type overload relays are not only more economical than other methods but they also facilitate harmonization with motors in thermal characteristics since they utilize the heat generated by the input current. Accordingly, thermal overload relays, in combination with magnetic contactors, are still essential devices for automation and labor-saving in various facilities and equipment.

A thermal relay converts the input current of an internal heater of each phase into heat, and detects the warp of the metal heated. Thermal relays consist of 2-element type having a heater only in phases R and T of three poles and 3-element type having a heater in all three phases R, S and T. Since low voltage of 200 V is used for industrial applications and the use of earth leakage breakers has become widespread, 2-element thermal relays have been popular in Japan. With the globalization of Japan domestic manufacturing industry, industrial machinery and manufacturing equipment are increasingly placed overseas, thermal relays are, therefore, requested to support high safety requirement, usage environment compatibility applicable to various situations, and high usability.

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2. Development Goals and Product Features

2.1 Development goals

The “TK12” thermal relay can be combined with the “SK Series” miniature contactor to configure electromagnetic switches. Amidst the recent trends toward resource and energy savings, the machinery and control panels used in manufacturing equipment and the like become smaller in size and more energy efficient. Miniaturization and lower power loss from the heater are required for the electromagnetic switches and also the thermal relays that configure the electromagnetic switches used in the equipment. Additionally, since there is growing awareness of motor protection safety and motors are increasingly operated with higher load factors in order to drive equipment more efficiently, improved detection accuracy of

Fig.1 “TK12” thermal overload relay

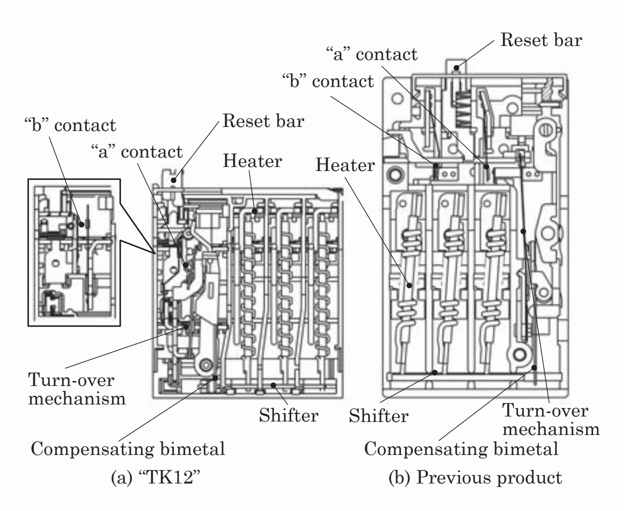

Fig.2 Overview of product structure

the thermal relay is highly anticipated.

In response to these requests, the TK12 was developed to have the world's smallest size, enhanced operating characteristics and accuracy, low power loss, improved safety functionality and ease of use. Figure 1 shows the appearance of the TK12 and Fig. 2 shows an overview of the product structure.

2.2 Product features

As operation safety is considered deeply in recent years, requests concerning the reliability of protective functions for thermal relay to be applied globally have been increasing more than ever before in distribution circuit conditions in worldwide as well as in Japan. Fuji Electric's lineup of thermal relays previously included the three variations of 2-element device, 3-element device, and 3-element with phase-loss protection device for 3-pole main circuit. The TK12 aggregates all these variations into a single high-performance 3-element phase-loss protection device, enabling overload protection and phase-loss protection for motor circuits in any application throughout the world. The TK12 supports both global specifications and the major requirements of the Japanese market. For example, since the TK12 is provided with a terminal shape and terminal cover structure designed to facilitate wiring with the round-type crimped terminals that are commonly used in Japan, it must be easy-to-use products for Japanese users as well.

Furthermore, in terms of standards certification, since this series has acquired the world's leading cer-

Table 1 Operating characteristics in balanced circuit

Standard	Limit of operation		Overloaded operation (hot)	Constrained operation (cold)
	No-operation	Operation		
IEC 60947-4-1	105% I_e (less than 2 h)	120% I_e (within 2 h)	150% I_e less than 2 min	720% I_e 2 to 10 s
JIS C 8201-4-1				

Table 2 Operating characteristics in imbalanced circuit

Standard	No-operation	Operation (hot)
IEC 60947-4-1	2-phase: 100% I_e (less than 2 h) 1-phase: 90% I_e	2-phase: 115% I_e (less than 2 h) 1-phase: 0
JIS C 8201-4-1		

Table 3 Heating element rating in "TK12"

3-phase standard motor full load current (ref. value)				Heating element rating (A)		
4P 400 V 50 Hz		4P 200 V 50 Hz		Electromagnetic switch		
Capacity P (kW)	Current I_e (A)	Capacity P (kW)	Current I_e (A)	SK06*W	SK09*W	SK12*W
				0.1 to 0.15	0.1 to 0.15	0.1 to 0.15
				0.13 to 0.2	0.13 to 0.2	0.13 to 0.2
				0.18 to 0.27	0.18 to 0.27	0.18 to 0.27
0.1	0.34			0.24 to 0.36	0.24 to 0.36	0.24 to 0.36
				0.34 to 0.52	0.34 to 0.52	0.34 to 0.52
0.2	0.7	0.1	0.68	0.48 to 0.72	0.48 to 0.72	0.48 to 0.72
				0.64 to 0.96	0.64 to 0.96	0.64 to 0.96
0.4	1.2			0.8 to 1.2	0.8 to 1.2	0.8 to 1.2
		0.2	1.3	0.95 to 1.45	0.95 to 1.45	0.95 to 1.45
0.75	1.8			1.4 to 2.1	1.4 to 2.1	1.4 to 2.1
		0.4	2.3	1.7 to 2.6	1.7 to 2.6	1.7 to 2.6
				2.2 to 3.4	2.2 to 3.4	2.2 to 3.4
1.5	3.1	0.75	3.6	2.8 to 4.2	2.8 to 4.2	2.8 to 4.2
2.2	4.6			4 to 6	4 to 6	4 to 6
		1.5	6.1		5 to 7.5	5 to 7.5
3.7	7.5				6 to 9	6 to 9
		2.2	9.2			7 to 10.5
5.5	11					9 to 13

tifications such as UL, TÜV, CE and CCC, it must become a true global standard.

2.3 Specifications and ratings

Table 1 lists the operating characteristics in balanced circuit, and Table 2 lists the operating characteristics in imbalanced circuit.

Table 3 lists the heating element ratings in TK12, and the standard application of heating element ratings corresponding to 3-phase standard motor capacity.

3. Miniaturization Technology of the "TK12"

The thermal relays have been miniaturized in four ways: use of a new turn-over mechanism, improvement of part fixing method, use a thermoplastic housing and improvement of the heater design.

3.1 New turn over mechanism

In order to realize both miniaturization and stable high-performance operating characteristics, the TK12 uses a toggle turn-over mechanism configured with a tension spring for the turn-over mechanism as shown in Fig. 3. The existing leaf spring method has an advantage in which spring characteristics can be obtained with a single leaf; however, in miniaturizing the TK12, there was a limit to the size of the leaf spring to obtain the I/O characteristics. As a solution, a tension spring was adopted in the turn-over mechanism. In order to optimize load and displacement I/O characteristics and to optimize space efficiency, the dimensions, load and other parameters were analyzed at more than ten locations that form the turn-over mechanism so that it realized stabilized operating characteristics and space savings.

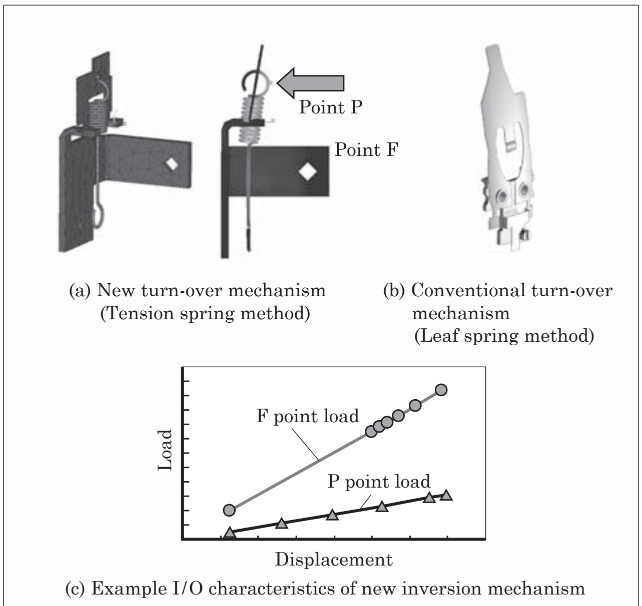

Fig.3 Turn-over mechanism

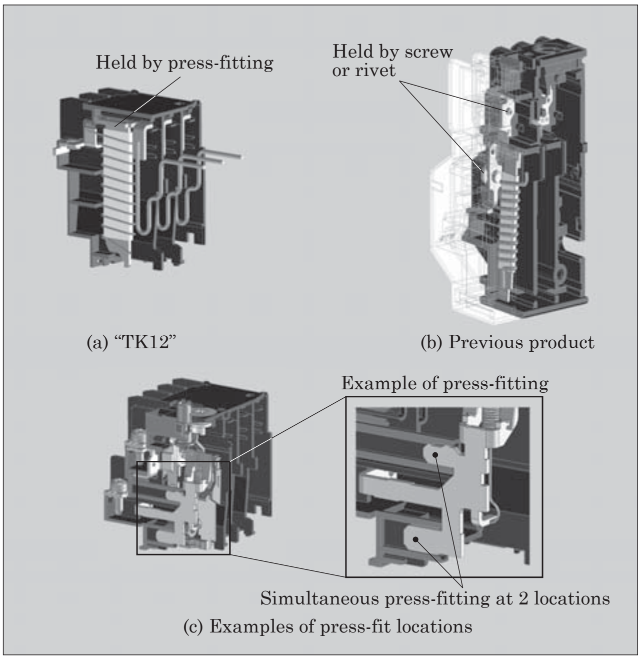

Fig.4 Example of press-fit parts

3.2 Parts fixing method

To realize minimum external dimensions, the size and number of individual parts must be reduced.

To minimize all the parts used, a method was adopted in which the metal parts were fixed by press-fitting them into a mold. When using a press-fit structure, however, ensuring the positional accuracy of each fixing part was a subject. As shown in Fig. 4, this was solved by optimizing the press-fit location of each part. Additionally, miniaturization was realized by providing metal parts with only the essential functional shape, and without extra locations for fixing to the mold, thereby significantly reducing the number of steps essential for assembly. The part count was reduced by 25% compared to existing products of the same type.

3.3 Use of thermoplastic material for the housing

In order to utilize a press-fit structure, the selection of materials for the housing is critical. To ensure sufficient holding strength after press-fitting, a thermoplastic material with fracture toughness was used for the housing. Conventional heat-curing material has not enough fracture toughness, and therefore press-fit structure had not been applicable. To fix the parts, additional parts such as rivets and screw fasteners increased the number of parts, and the space required for fixing parts with them led an increase in the external dimensions of the product. Farther-more, since thermoplastic material is renewable, it was used for all other molded parts in consideration of the environmental performance. Consequently, as shown in Fig. 5, the housing volume was reduced to 55% compared to that of an existing product of the same type. It was the first time in Japan that thermoplastic material had been used in the housing of a thermal relay.

Because thermoplastic material is susceptible to deformation by thermal stress, the wall thickness of the molding material was made uniform and the location of the mold gate was optimized so that the molded parts would not become deformed or warped. Moreover, creep deformation in the vicinity of the self-heating heater must also be considered. Thus, in the TK12, by the deformation analysis as shown in Fig. 6 at the time of injection molding, the optimization of the gate location and minimization of the amount of deformation was verified in advance, as well as the stress analysis performed during the design stage.

3.4 Heater design

To improve the miniaturization of thermal relays, reducing the size and increasing the efficiency of the heater, as an output engine, and reducing thermal interference between phases by facilitating the dissipation of heat to the exterior in consideration of the small housing are challenges.

To realize this miniaturization, the amount of heat generated by the heater was minimized by using coupled analysis of the current, electric heating, and bimetal curvature as shown in Fig. 7, and a structure was adopted to ensure the amount of curvature by heating the bimetal efficiently.

Additionally, to miniaturize the bimetal and maximize the amount of curvature, the heater structure was formed by laser-welding with the bimetal and the retaining parts (see Fig. 8). As a result, compared to the effective length of the bimetal of the existing structure, a 7% increase was achieved.

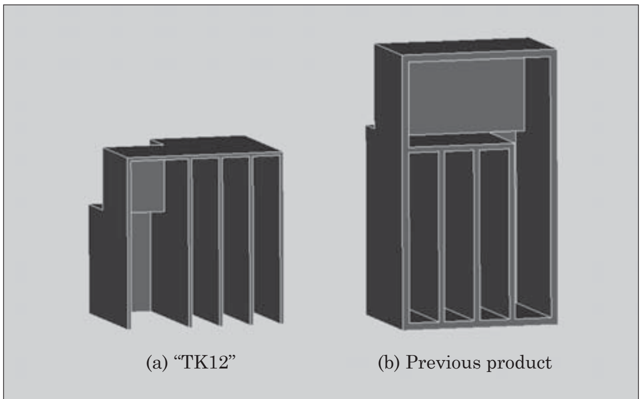

Fig.5 Comparison of housing volume ratios

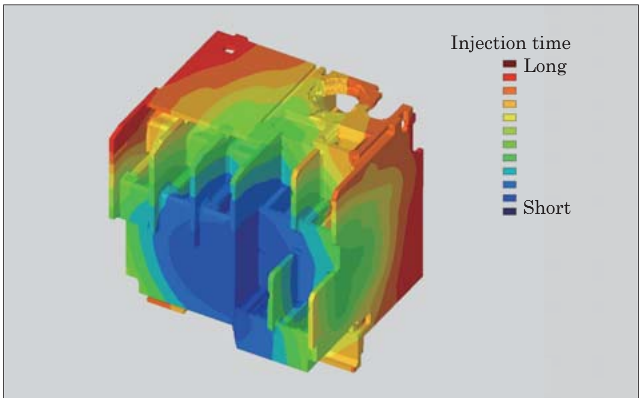

Fig.6 Example of molding flow analysis of housing

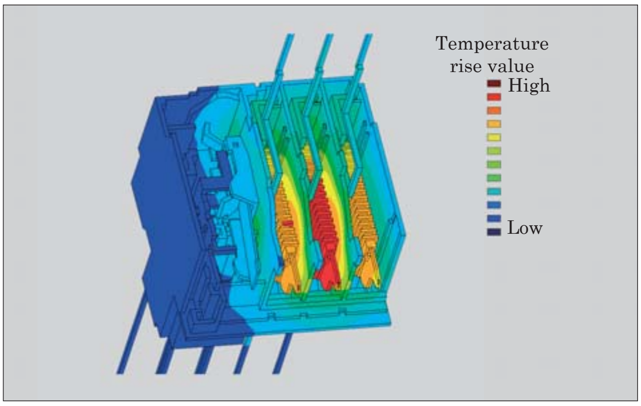

Fig.7 Coupled analysis example of current–electric heating–bimetal curvature

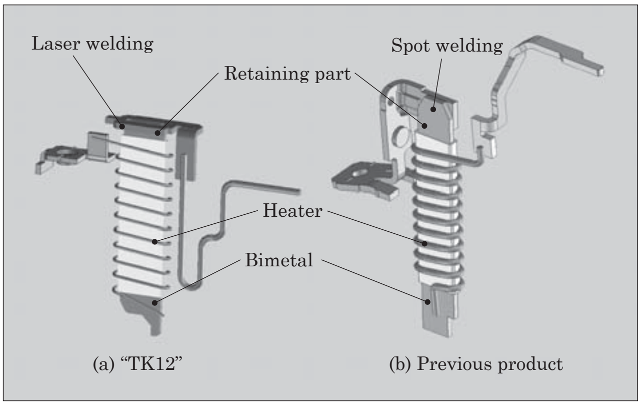

Fig.8 Laser welding method

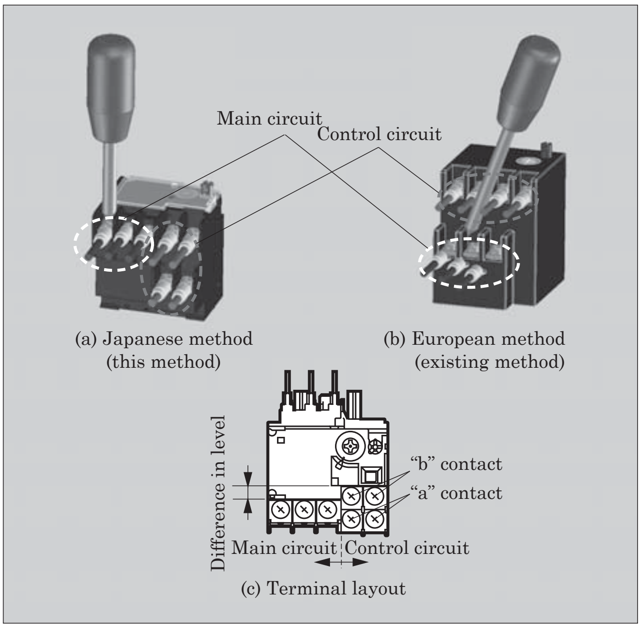

Fig.9 Diagram of the main circuit wiring

4. User Interface

4.1 Customer installation and wiring

In a typical thermal relay, auxiliary circuit terminals are located at the front and the main circuit terminals are located at the back of the control panel. The terminals are arranged in either Japanese-style or European-style layouts, and the wiring view of the main circuit is shown in Fig. 9.

Overseas, the main circuit is typically wired first, followed by the wiring of the auxiliary terminals of the control circuit. In Japan, however, it is often the case that wiring of the control circuit is performed by the panel manufacturers, and the wiring of the main circuit is performed onsite. Therefore, with a European-style terminal layout such as described above, the main circuit terminal is situated behind the control circuit wiring and is therefore difficult to reach with tools, and if the thermal relay is positioned near a wiring duct, the wiring work would be difficult to carry out. To resolve these problems, in the TK12, the main circuit and auxiliary circuit are positioned side-by-side, and a structure was adopted that facilitates the wiring work, for either type of wiring arrangement. Additionally, the main circuit and the control circuit are set at different levels in order to prevent incorrect wiring between the main circuit and the control circuit.

As for the arrangement of control circuit terminals, since the "*b*" contacts (NC contacts) are typically required as self-holding circuits for magnetic contactors, they are located on the panel face.

4.2 Safety and operability

In order to ensure globally-acceptable safety, the TK12 is equipped with a terminal cover that conforms to IEC 60529 (see Fig. 10). Additionally, since a transparent cover that can be opened and closed is mounted on the front of the product, close of the cover can prevent improper operation of the current setting value of the adjustment dial, and improper operation of the manual and automated switching of the reset bar. Moreover, the transparent cover is provided with a sealing hole so that the cover does not open and close unintentionally.

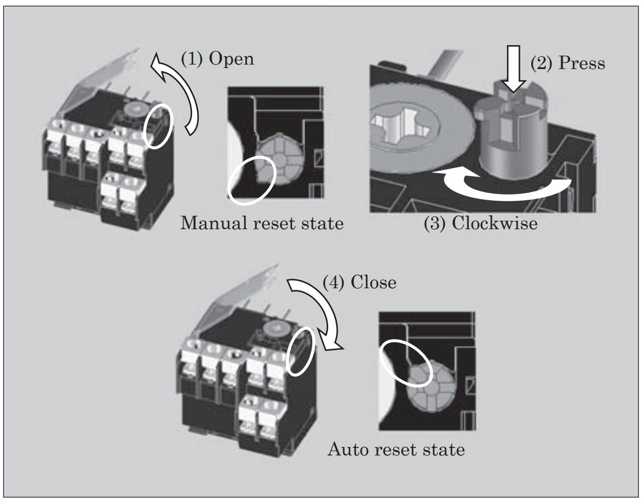

Fig.10 Automatic reset mode switching method

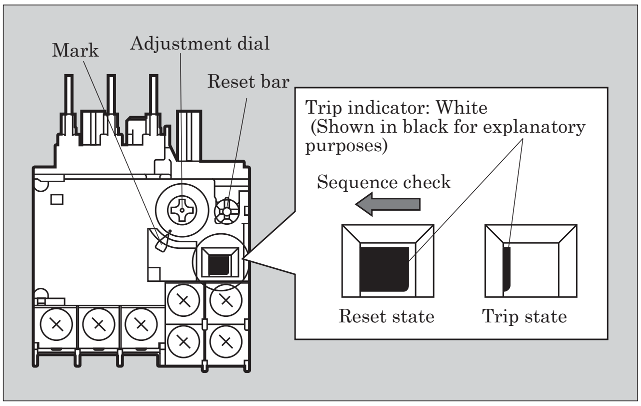

Fig.11 Sequence check

As shown in Fig. 11, the operating state can be identified from the front view of the main body, and this display can be used to check the operating sequence.

5. Product Traceability

In the production of the TK12 of relays, in order to manage production traceability, a system that uses a QR code on a nameplate has been introduced to record the production history for each individual device (see Fig. 12).

○ Production lot, individual number
○ Daily production status, defect rate
○ Individual device adjustment history

This information is centrally managed in the factory, and therefore when a product problem occurs and its production history must be investigated, the QR code can be used to confirm the individual device adjustment history immediately, thereby enabling a quick response to our customers.

6. Postscript

In the industrial equipment sector of the globalized market, as a means of differentiation from competitors,

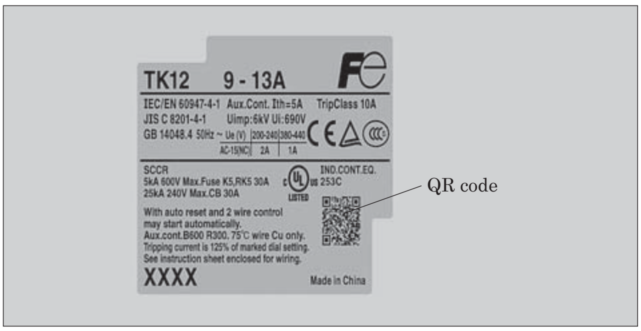

Fig.12 Faceplate

the trends toward miniaturization and higher level performance of equipment are increasing more and more. The thermal relays used to configure electromagnetic switches are no exception. Against this background, an overview of the miniaturization technology incorporated into Fuji Electric's newly developed thermal relays has been presented herein.

In the future, Fuji Electric will continue to develop technology that meets the needs of the market, and aims to develop products that will meet the requirements of customers.

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