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ADVANCED TECHNOLOGY FOR HIGH MODULARITY TWIN BREAKERS

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1. FOREWORD

Molded case circuit breakers (MCCB) and earth leakage circuit breaker (ELCB) have recently developed greatly and become popular as the main equipment for overcurrent protection and ground fault protection of low voltage power lines. In the advance of higher capacity and diversification of the electric facilities of factories, buildings, etc. in recent years, more advanced functions is demanded for this equipment.

Especially, regarding medium and low capacity MCCB and ELCB, there is a strong trend toward products that can improve ease of use and safety and expand the range of applications by modularization of the basic dimensions, rationalization of installation and connections, small size and high interrupting capacity, and make other contributions to total cost reduction at the consumer side aimed at economy.

Since conventional MCCB and ELCB were constructed by adding an earth leakage detection section including a zero current transformer (ZCT) to an MCCB, the dimensions of the ELCB became large.

This time, a new series of small high interruptingg capacity circuit breakers, TWIN BREAKERS, that completely modularize the Fuji Auto Breaker (FAB) and Fuji Earth Leakage Breaker (ELB) and which should contribute to simple consumer side system configuration, improvement of protection, etc. and lead the industry was developed.

The development of TWIN BREAKERS was realized by advanced design, evaluation, and manufacturing technology, for example, high current limiting technology, miniaturization technology for each component, etc.

Several new technologies for developing the new TWIN BREAKERS series are introduced.

2. REALIZATION OF HIGH CURRENT LIMITING INTERRUPTION

2.1 Necessity of current limiting interruption

The process by which an MCCB and ELCB interrupts a short circuit current is outlined in *Fig. 1*. That is, when a short circuit burrent flows, the MCCB or ELCB quickly detects it and an arc is generated by breaking of the contacts. This between-contacts are as on the short circuit as a counterelectromotive force and has an effect is called "current limiting effect" hereinafter.) The maximum peak let-through current is reduced substantially by increasing this current limiting effect.

Recently, the short-circuit capacity at fault generation at even low voltage circuits has increased and the responsibility placed on the MCCB and ELCB has become heavier. That is, to protect series equipment and wiring, they must have an ample current limiting effect and the mechanical and thermal stress on them must be reduced.

2.2 Theoretical analysis of current limitings interruption characteristic

The circuit configuration at short circuit generation can be represented as shown in *Fig. 2*. The following basic expression is established.

$$E_m \sin(\omega t + \theta) = L \cdot di/dt + R_i + V_a \quad \ldots\ldots\ldots \quad (1)$$

At this expression, the short circuit current when there is so are ($V_a = 0$) is given by the following expression:

Fig. 1 Short circuit current interruption process

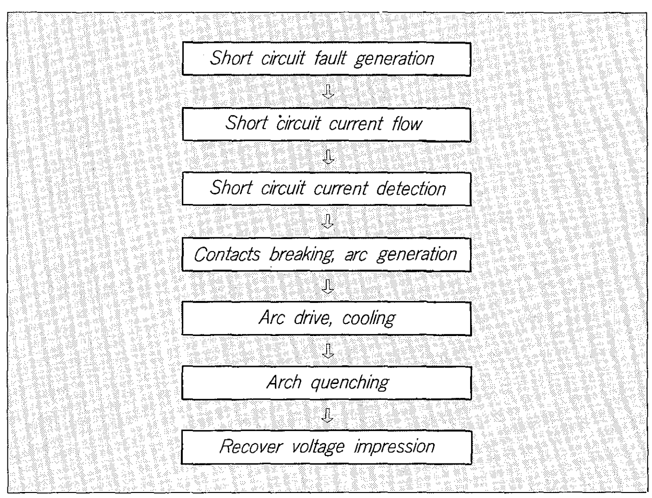


Fig. 2 Circuit configuration at short circuit generation

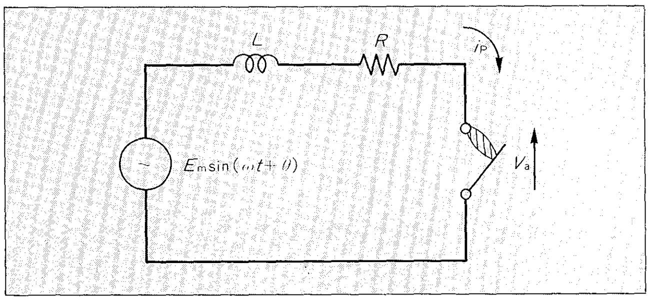
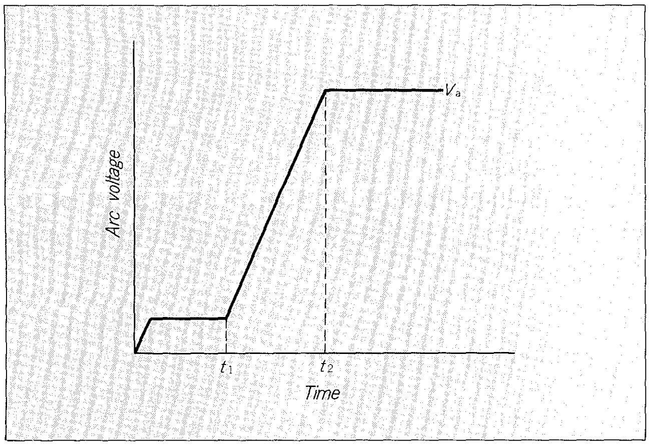


Fig. 3 Arc voltage waveform



$$i = \frac{E_m}{\sqrt{R^2 + (\omega L)^2}} \left\{ \sin(\omega t + \theta - \varphi) - \sin(\theta - \varphi) e^{\frac{-R}{L} t} \right\}$$

. . . . (2)

Where, φ : Power factor angle

However, when there is an arc ($V_a \neq 0$), except for special cases, numeric solution by computer is necessary. Therefore, the arc voltage was input in a form near that of the actual waveform as shown in *Fig. 3* and interrupting peak current, interrupting time, etc. simulation was performed. The results are shown in *Figs. 4* and *5*.

It is no exaggeration to say that minimizing t_1 and t_2 and increasing the arc voltage is important. However, *Figs. 4* and *5* shows that when t_1 is large, even if the arc voltage is increased, the current limiting effect is not only noticeable, but conversely, the arc power is increased.

That is, reduction of t_1 is a keypoint in current limiting improvement.

2.3 Establishment of Active-Arc driving technique at current limiting interruption

Various experiments were conducted with a model as shown in *Fig. 6*. With this model, the moving contact arm weight, moving contact arm speed, and contact distance can be changed. The behavior of the generated arc is observed by high-speed camera and oscillogram.

Fig. 4 Arc voltage vs maximum peak let-through current

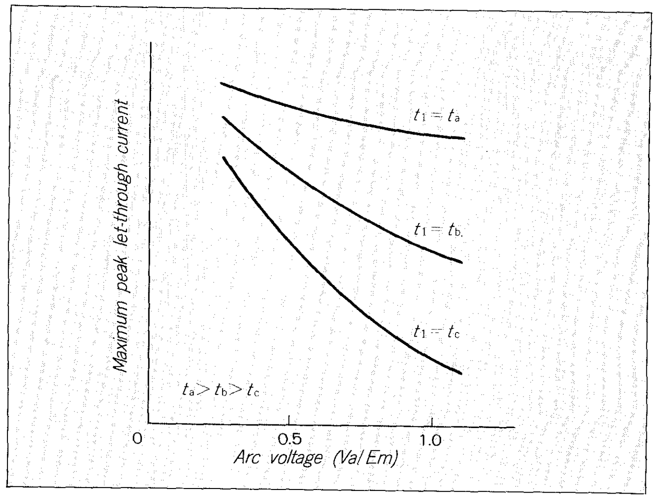


Fig. 5 Arc voltage vs arc power

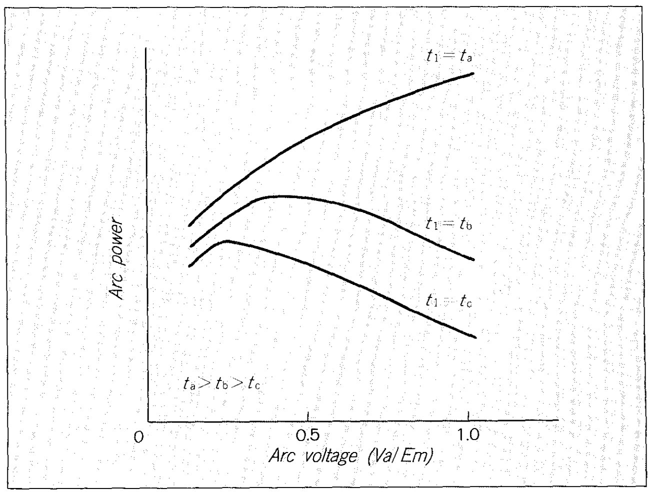


Fig. 6 Model during experiment

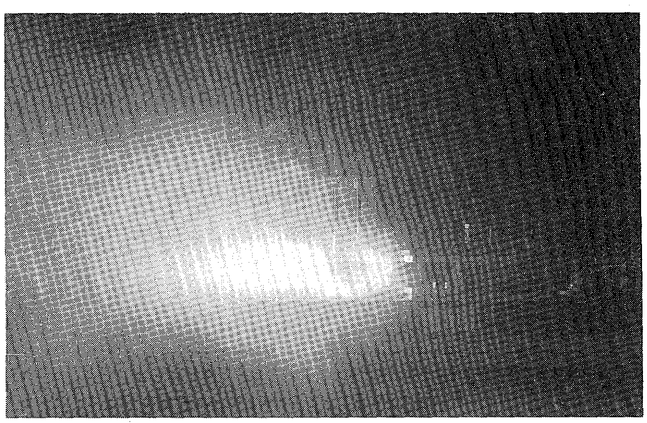


Fig. 7 shows the actual relationship between the static contact arm arc position and arc voltage. Moving the arc from on the static contacts to the static arc runner raises the arc voltage abruptly. In other words, it was found that during the period in which the arc does not

Fig. 7 Change of arc voltage by arc position

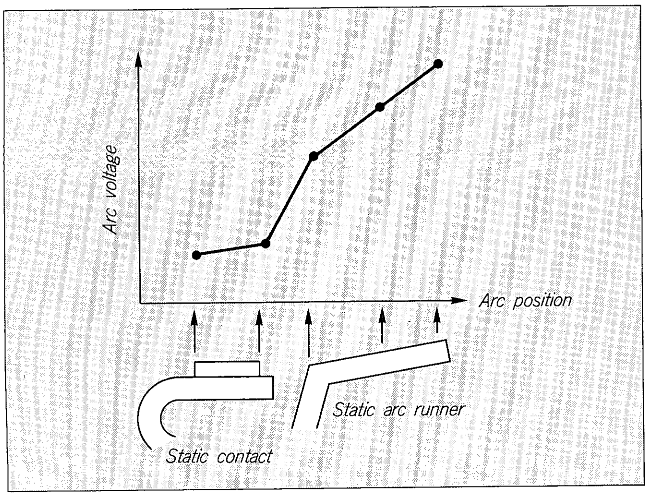
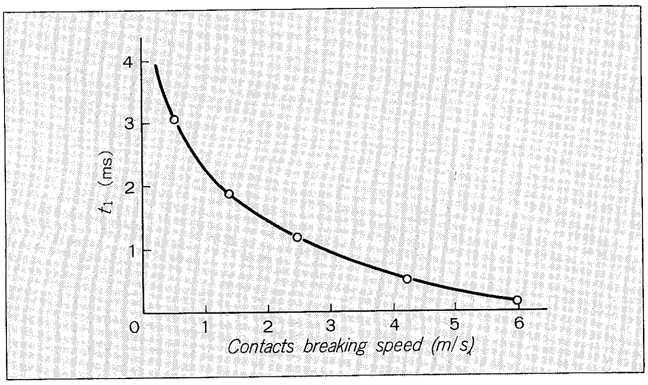


Fig. 8 Contacts breaking speed vs t_1



move on the contacts, the arc voltage does not rise very much and corresponds to period t_1 on the oscillogram (*Fig. 3*).

Fig. 8 shows the relationship between contact breaking speed and t_1. It was found that t_1 is suppressed to the target value or less by making the contact breaking speed sufficiently high.

That is, the point is that breaking the contacts quickly and making their breaking speed as fast as possible raises the arc to the active state and increases the current limiting effect. Fuji Electric has named this the Active-Arc Driving Technique (AD technique) and planned to apply it to FAB and ELCB.

2.4 Application of AD technique to TWIN BREAKERS

Based on the foundamental studies up to here, various types which should apply this AD technique to the TWIN BREAKERS were test manufactured and performance certification proceeded. As a result, the conclusion was reached that the type with the construction shown in *Fig. 9* has the fastest moving contact arm breaking speed over a wide short circuit current area and the arc can quickly enter the active state.

This new current limiting mechanism has the following features:

(1) Conventional circuit breakers operate with the contact spring as the load for breaking of the moving contacts arm. Therefore, the breaking speed is reduced. However, with the TWIN BREAKERS, a mechanism such that the contact spring also becomes accelerating force was realized. This relationship is shown in *Fig. 10*.

(2) The mechanism was so constructed so that the magnetic force generated between the contacts and between the contact arms can be efficiently converted

Fig. 9 Construction of new current limiting mechanism

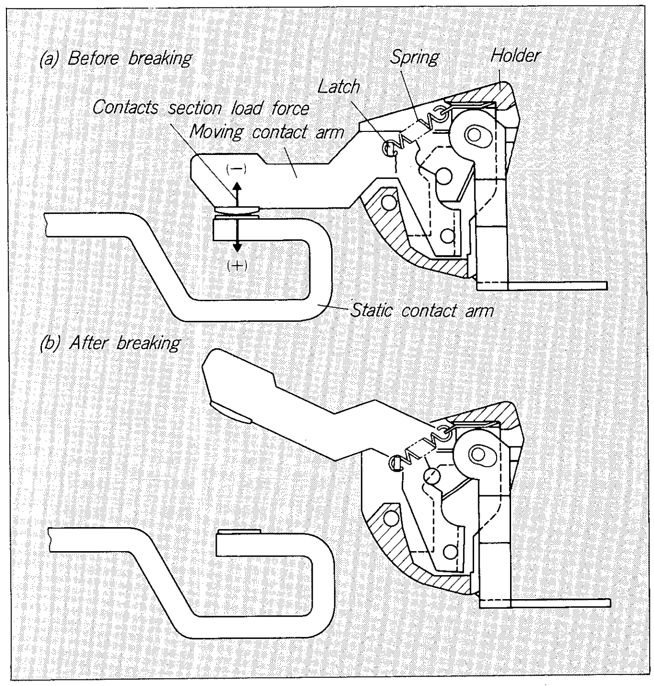


Fig. 10 Breaking distance vs contact arm load force

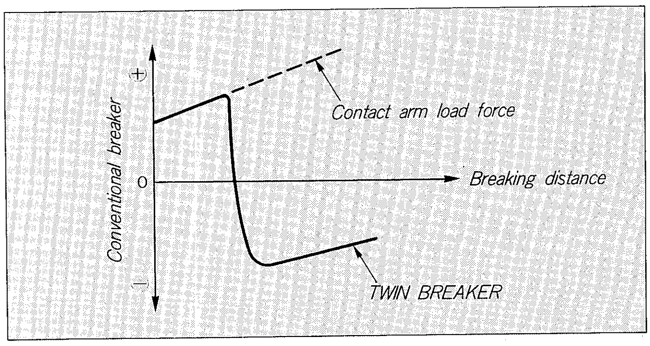


Fig. 11 Comparison of arc voltages

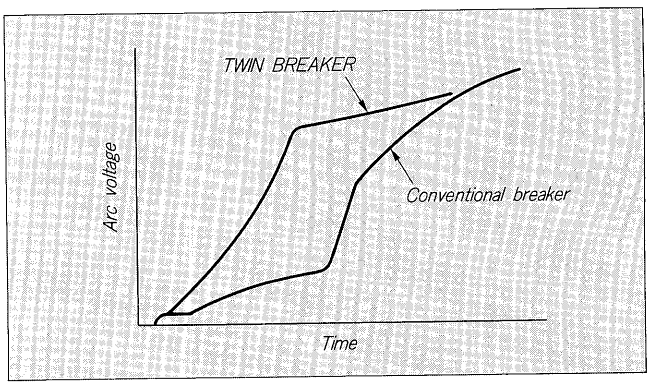


Fig. 12 Comparison of maximum peak let-through current

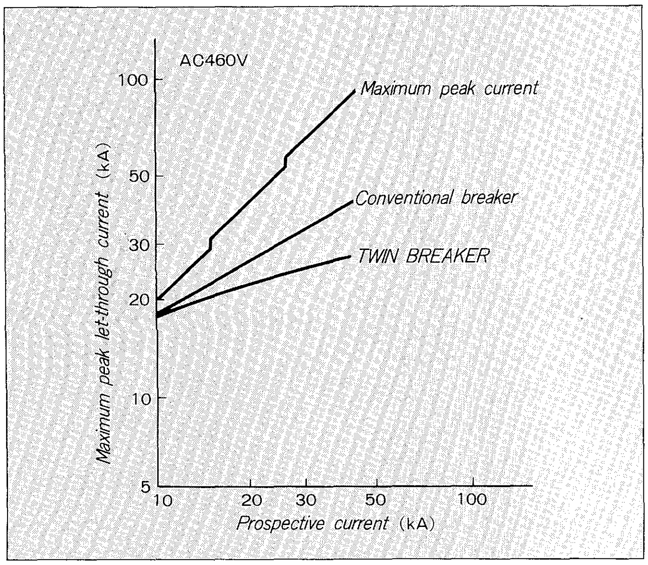
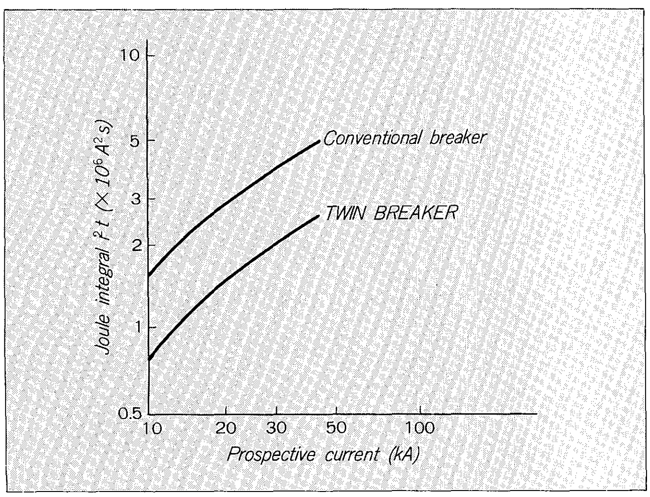


Fig. 13 Comparison of joule integral i^2t



to breaking speed by moving contact arm rotation supporting point position optimization, etc.

(3) The weight of the moving contact arm was lightened and high-speed breaking was realized while maintaining conduction performance by refinement of the contact material, rotary sliding contact, etc. By incorporating these features, the arc voltage at short time current became as shown in *Fig. 11* and both t_1 and t_2 were shortened considerably compared to those of conventional circuit breakers.

As result, we succeeded in suppressing the maximum peak let-through current and joule integral (i^2t) as shown in *Figs. 12* and *13*. For example, for 100A frame, the interrupting capacity could be increased 2.5 times with the same dimensions.

Fig. 14 shows the behavior of the arc of the TWIN BREAKER and conventional breaker observed with a high speed camera. For the TWIN BREAKER, the arc is already driven 2 ms after short generation and is almost extinguished in 5 ms. On the other hand, it is observed that with the conventional breaker, arc drive and quenching are comparatively slow.

Fig. 14 High speed photographs of interruption

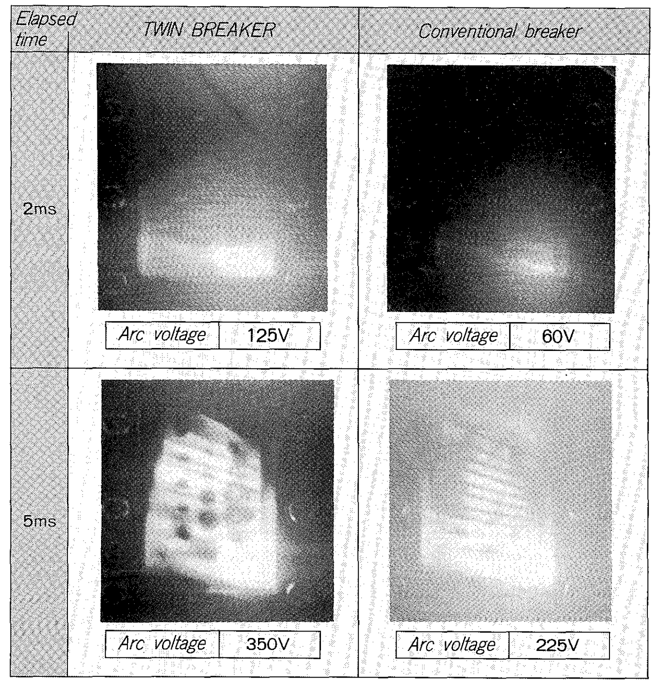
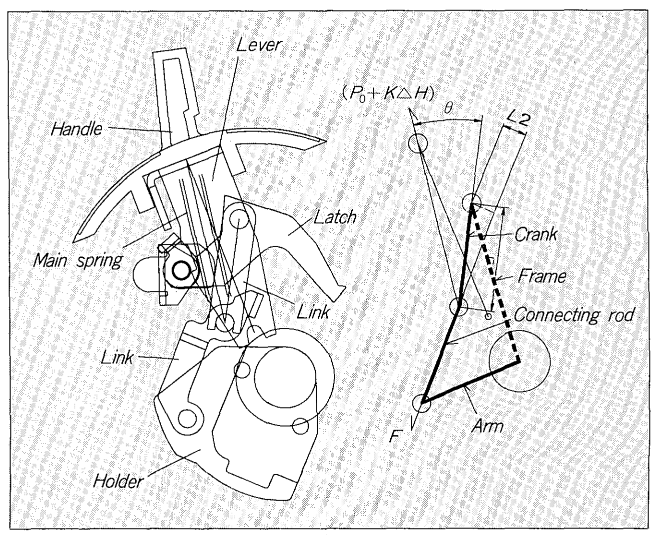


Fig. 15 Switching mechanism



3. DEVELOPMENT OF SMALL SWITCHING MECHANISM

As also described before, the TWIN BREAKERS developed this time are also said to be the concentration of miniaturization technology. Miniaturization of switching mechanism based on a certain target was also planned. When miniaturization is advanced by extending conventional technology, creation of the following problems is forecast:

(1) Insufficient switching force or degradation of operability to compensate for it.

Fig. 16 Example of operation analysis at closing

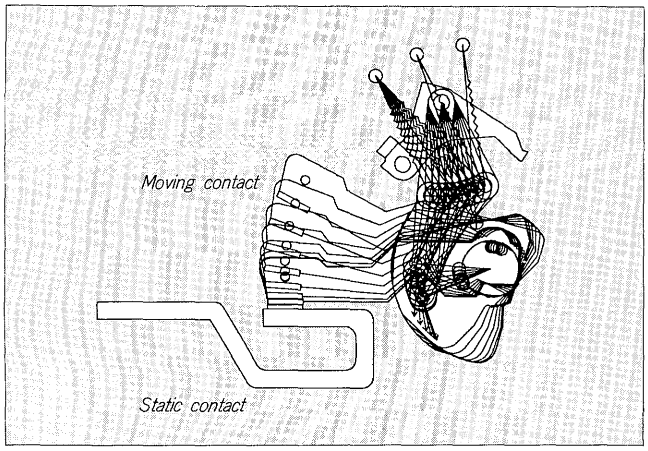
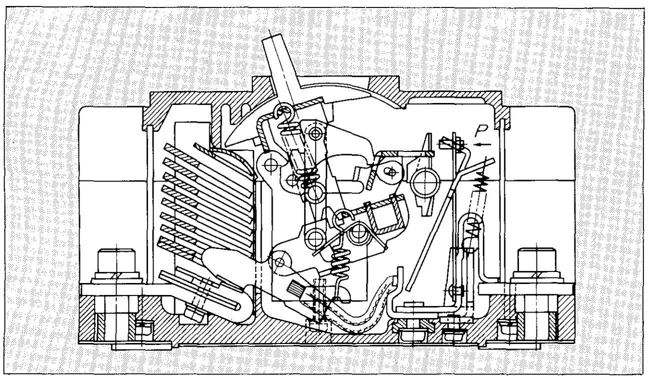


Fig. 17 Conventional FAB



(2) Degradation of durability by increased stress of each part of the switching mechanism.

To solve such problems, development of a switching mechanism by which a large switching force is obtained by small operating force is necessary. However, operation of the switching mechanism of MCCB and ELCB changes complexly with the relationship between the distance between the rotating axis pin joints of each component element part and shaft position combination. Therefore, link design was difficult in that repetitive studies were performed while changing each parameter.

Therefore, a switching mechanism analysis program by CAD use was developed before design study. This program finds the optimum position and dimensions combination relationship by input/output load and dynamic simulation synchronized with it while changing the position of pin joint quantitatively.

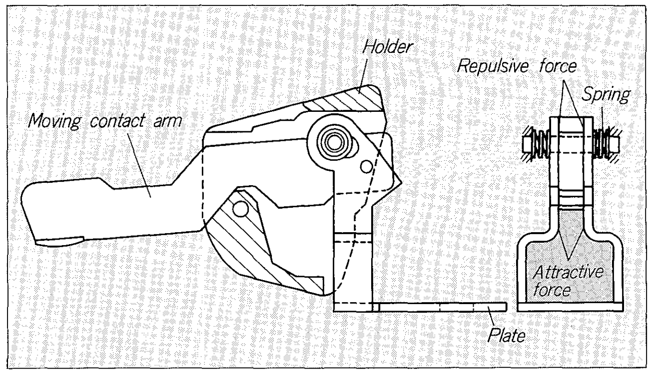
Switching force F in *Fig. 15* is the force which is generated by the main spring which is the link driving force.

$$F = (P_0 + K\Delta H) \times \sin\theta \times L_1/L_2 \quad \ldots\ldots\ldots\ldots (3)$$

P_0 : Spring initial tension
ΔH : Spring displacement
L_1 :
L_2 :

The program above was used in selecting the relationship between the link ratio at which transmission efficiency $\eta\,(=F/P_0)$ becomes highest under various restrictions

Fig. 18 Basic construction of rotary sliding contacts



and the pin joint position and a new toggle joint mechanism which obtains a large closing force by small operating force was developed. An example of analysis of operation at switching is shown in *Fig. 16*. The new toggle joint mechanism developed based on these analyses and studies realized an approximately 30% space-saving miniaturization for each frame.

4. ROTARY SLIDING CONTACT

4.1 Pursuit of miniaturization and necessity for rotating sliding contacts

Fig. 17 shows the construction of the existing 225A frame FAB. It was found that the holder, braids, and main shaft parts occupied an equivalent space overall. With the TWIN BREAKERS, in the pursuit of miniaturization, the holder and main shaft were integrated and the current limiting mechanism was built into it. Therefore, if securing of the sectional area necessary area at 225A conduction is attempted with braids, the FAB becomes as shown in *Fig. 17* and building in is difficult.

Fig. 18 is the basic construction of the rotary sliding contact with braids removed. There are the following technical problems with this rotary sliding contact construction:

(1) Contact area and contact pressure sufficient for passing a wide range of current from the rated current to short circuit current is secured in a small space.
(2) Does not load the movement of the moving contact arm.
(3) There is no adverse affect by surface wear after several thousand switchings.
(4) Stable contact state is maintained even after long use.

4.2 Rotary sliding contact construction and surface treatment

To solve these problems, studies were conducted from the two standpoints of construction and rotary sliding part surface treatment.

First is refinement from the standpoint of construction. A construction which secures the minimum contact pressure necessary for conduction by means of a com-

Fig. 19 Magnetic force which acts on rotary sliding contact

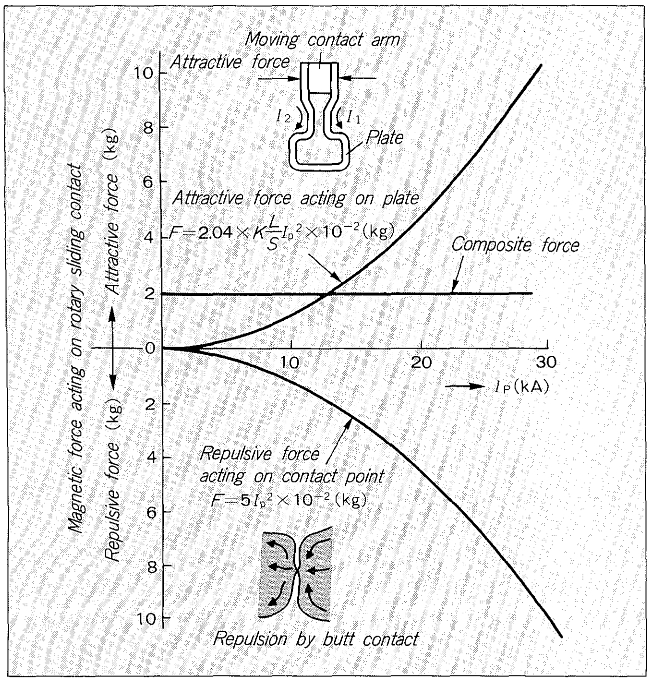
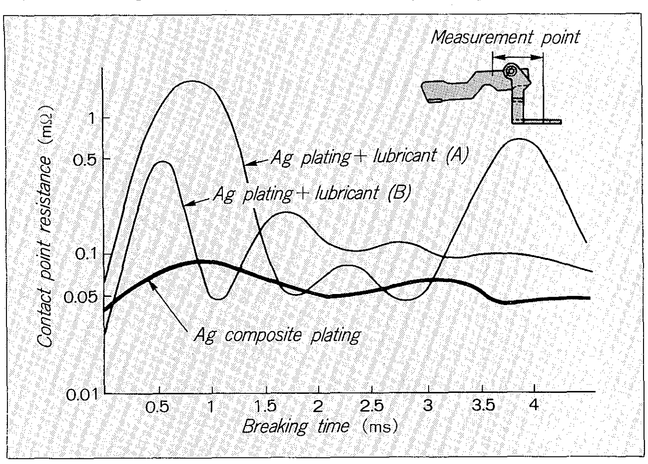


Fig. 20 Change of contact resistance during sliding



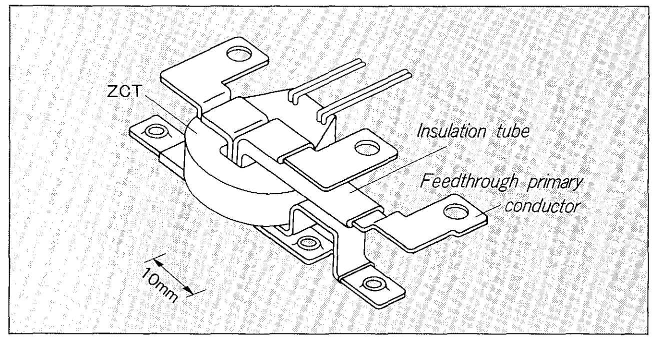
pression spring and cancels the magnetic repulsive force generated at short current conduction by means of the magnetic attractive force between parallel conductors as shown in *Fig. 18* was used. This relation is shown in *Fig. 19*. However, the composite force is constant in all current regions.

With this construction, the load at moving contact switching is only the friction of the compression spring. The load could be made amply smaller than the load generated by the rigidity of the braids.

Contact point surface treatment is described next. In the past, the contact point was coated with various lubricants to improve slideability. With the TWIN BREAKERS also it was found that switching durability could be amply satisfied by coating with lubricant. However, the contact point this time not only simply slides, but also have a heavy duty of passing short circuit current while sliding.

Fig. 20 shows an example of the change of sliding

Fig. 21 Construction of ZCT



part contact resistance during sliding. This figure shows that the coating with lubricant causes the contact resistance to become unstable during sliding and may reach arcing of the contact point at short circuit current interruption. Therefore, Ag composite plating, which mixes lubricant granules in gold plating, was introduced.

This Ag composite plating has an extremely contact resistance even after severe and long use. At the same time, it was also confirmed with an amply unit that it has sufficient switching durability.

5. DEVELOPMENT OF THIN ZERO PHASE CURRENT TRANSFORMER AND SPACE-SAVING PRIMARY CONDUCTOR

In the development of the TWIN BREAKER ELCB series, the space occupied by the ZCT and primary conductor was restricted because of the space configuration of each circuit breaker. Development of a thin ZCT and space-saving primary conductor was demanded as its solution. *Fig. 21* is an example of the configuration of the ZCT and primary conductor of the 100A frame ELCB developed this time. From *Fig. 21*, it should be understood that space saving and assembly to the circuit breaker body are easy. From the standpoint that the ZCT and its primary conductor detect the earth-leakage current, which is the main function of an ELCB, good results were obtained in making the ZCT thin and saving primary conductor space by emphasizing the following evaluation tests, not to mention basic characteristics and performed.

(1) Improvement of ZCT efficiency

The secondary output was made a suitable value for the ZCT primary input and evaluation tests were conducted for making the ZCT thinner with improvement of efficiency as the point. At efficiency improvement, how to reduce the iron loss at conversion was the point and a high permeability ACT core material and a suitable shape and thickness were used. As a result, efficiency could be improved 60% above that of conventional products. The complete ZCT could be made approximately 30% thinner than conventional products.

(2) Balance of ZCT

To reduce the temperature rise of the ZCT primary conductor and secure a suitable arrange state of the primary conductor to the ZCT, a static conductor was used as the primary conductor. Unification of the conductor layout was planned and multiple iron alloy materials with different permeability were suitable combined as magnetic shield plates at the ZCT and it was certified that it has the target balance.

(3) Impulse withstand voltage test

At the ZCT primary conductor, impulse withstand voltage performance was secured by tough interphase insulation matched to the space-saving shape.

(4) Working voltage continuous impression test

ELB interior heating at load current conduction and ambient temperature fluctuations were taken into account and a working voltage continuous impression test was performed at high temperature and long-term reliability was secured.

6. SIMPLIFICATION OF EARTH LEAKAGE DETECTION CIRCUIT

Conventional 200-415V circuit use ELCB used a system which, when an earth leakage occurred at the secondary side dropped by power transformer, turned on a thyristor that entergized a small built-in relay whose contacts drove an apply voltage type trip coil. This time, to minimize the dimensions of the ELCB, an earth leakage detection circuit that omits the power transformer and small relay and can be used for 100-200-415V was developed.

The conventional earth leakage detection circuit and the earth leakage detection circuit developed this time are shown in *Fig. 21*. At the new circuit, a current limiting circuit is connected at the stage after the power supply circuit, then a trip coil, charging capacitor, and magnetic hold type trip coil are connected. The features of the new circuit and evaluation test results are outlined below while comparing them with the conventional circuit.

(1) Earth leakage detection circuit input current suppression

To guarantee 100-200-415V use, considering power supply voltage fluctuations, stable earth leakage detection operation over the 84V to 484V voltage region is desirable. It is desirable that at 80V, the earth leakage detection circuit operate positively and at 484V, the heat generated by the earth leakage detection circuit be limited by suppressing the input current of the earth leakage detection circuit at the earth leakage monitoring state. As a result of continuing use of an amplifier (dedicated IC) with ample market achievements and accumulated studies for satisfying the previously mentioned restriction conditions, the problem has been solved already by connecting a current limiting circuit.

(2) Realization of 100-200-415V common use

The power supply voltage E and input current I relationship at the earth leakage detection circuit developed this time is shown in *Fig. 23*. The minimum required current of the amplifier at 80V is made I_{s1} and the upper limit of the input current which is determined from the

Fig. 22 Earth leakage detection circuit

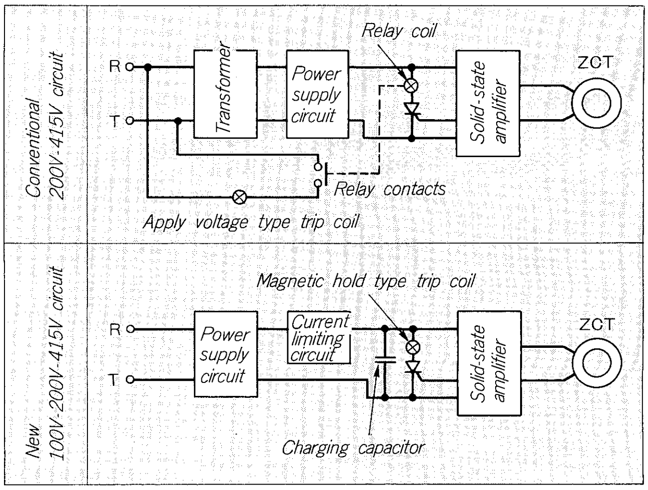
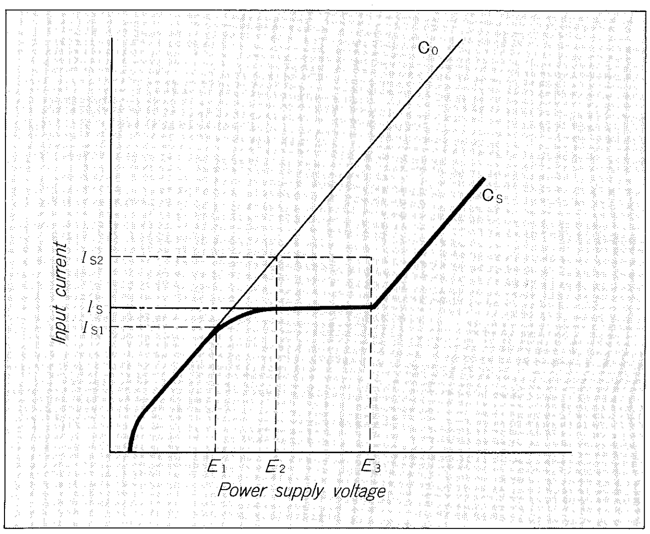


Fig. 23 Input current characteristics of earth leakage detection circuit



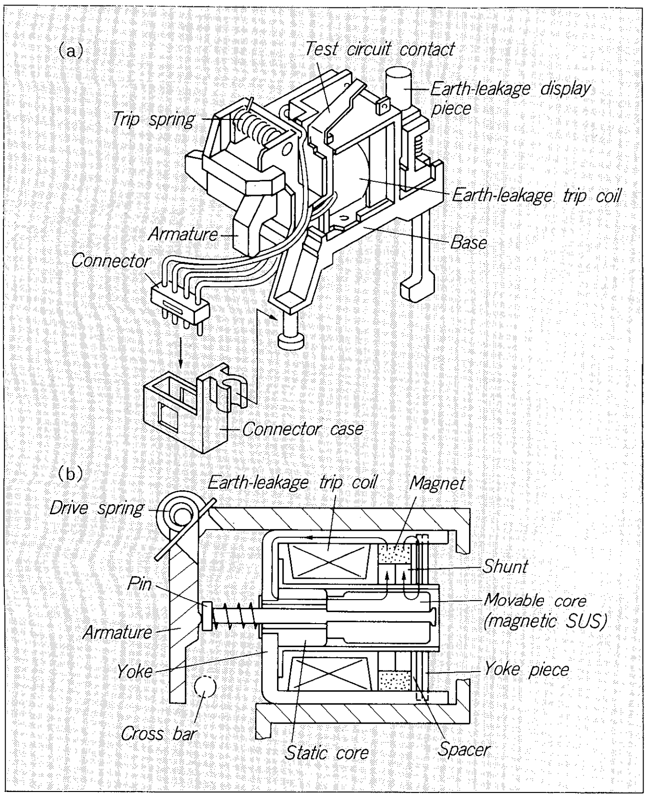
restriction of the calorific value of the entire earth leakage circuit is made I_{s2}. Curve C_0 shows the case when there is no current limiting circuit. The usable voltage range is from E_1 to E_2. On the other hand, curve C_s shows the case when a current limiting circuit was connected. The input current is suppressed to the value shown by I_s until the power supply voltage reaches E_3 by suitably selecting the circuit constants of the current limiting circuit described previously. That is, 100-200-415V common use was realized by expanding the usage voltage range from E_1 to E_3. It also became possible to provide a margin at the calorific value of the entire earth leakage detection circuit by making input current I_s when the power supply voltage is E_3 such that $I_s < I_{s2}$.

(3) Earth detection circuit space-saving

The overall space of the earth detection circuit developed this time could be reduced to approximately 1/4 that of the conventional 200-415V circuit with power transformer and small relay. As a result, it had a large effect for miniaturization of the ELB dimensions.

(4) Evaluation test results

Fig. 24 Construction of trip coil unit



In addition to confirmation of the earth leakage detection performance at high temperature, high humidity, vibration, shock, and other environmental conditions, electromagnetic test radiation and noise test these assumed a surge that entered from the system were performed and the target performance were secured.

7. DEVELOPMENT OF SMALL HIGH EFFICIENCY TRIP COIL

A new magnetic hold trip coil was developed in place of the conventional apply voltage operation trip coil. The features and evaluation test results of the developed trip coil are outlined below.

(1) Low consumption VA

The development process was backed by magnetic circuit design technology accumulated with the proven magnetic tripping type ELCB and finite elements analysis. The result was that a low consumption VA high efficiency magnetic hold type trip coil that can be driven positively by the charging capacitor of the earth leakage detection circuit previously described could be developed.

(2) Spacing saving

The sectional view of the trip coil developed this time and the trip coil unit are shown in *Fig. 24*. By planning low consumption VA and high efficiency, space saving became possible and the test circuit unit, which is an essential element of the ELCB, and earth-leakage indicator unit could be integrated as a trip coil unit. The result was that stabilization of the earth-leakage operation characteristic

Fig. 25 Impact strength (Charpy) of molding compound

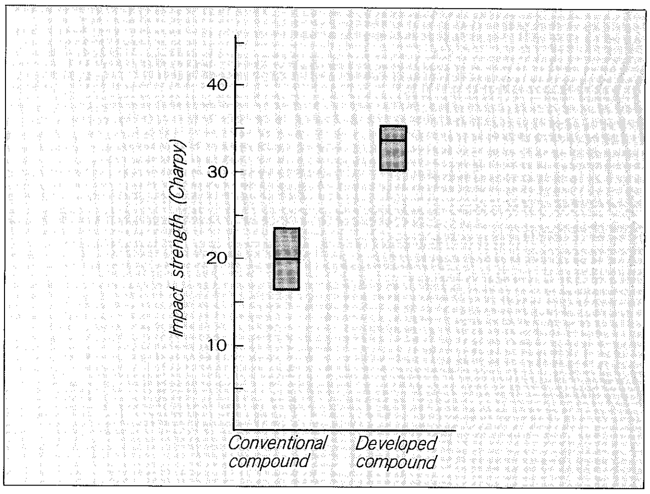
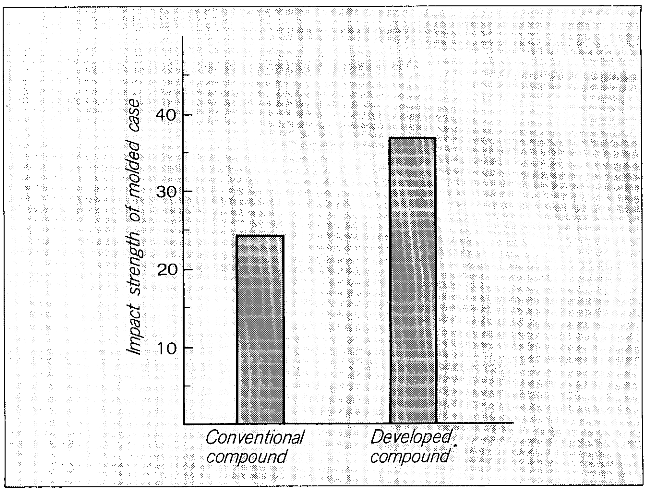


Fig. 26 Comparison of characteristics with molded case



and improvement of assemble-ability to the circuit breaker were planned.

(3) Evaluation test results

Besides confirming the earth-leakage protection durability at high temperature, high humidity, vibration, shock, and other environmental conditions, high magnetic field test and erosion test, etc. were performed with the actual product and the target performances were secured.

8. DEVELOPMENT OF HIGH-STRENGTH MOLDING COMPOUND

Up to here, studies proceeded from various directions for miniaturization and its realization was planned. Finally, the molded case and cover that house these are described.

The molded case and cover have important roles of (1) holding each mechanism part, (2) securing insulation performance, etc. However, regarding miniaturization, they strength is especially important.

When an MCCB or ELCB interrupts a short circuit current, a high pressure is generated inside it. The smaller the MCCB or ELCB, the higher this pressure. To process this, with the TWIN BREAKERS, the pressure itself was

Table 1 Comparison of characteristics of molding compound

Item	Newly developed compound	Conventional compound
Mold strinkage (%)	0.05	0.2 ~ 0.3
Specific gravity	1.90	2.05
Water absorption (%)	0.1 max.	0.1 max.
Flexural strength at room temperature (kgf/cm^2)	12 min.	8 min.
Flexural strength at 100°C (kgf/cm^2)	8 min.	6 min.
Flexural modulus at room temperature (kgf/cm^2)	1,200 min.	800 min.
Flexural modulus at 100°C (kgf/cm^2)	750 min.	500 min.
Impact strength (Charpy) ($kgf\ cm/cm^2$)	30 min.	15 min.
Withstand voltage (breakdown) (kV/cm)	13 min.	9 min.
Insulation resistance in normal state (Ω)	10^{14}	10^{12} min.
Insulation resistance after evaporation (Ω)	10^{13}	10^{11} min.
Dielectric constant (50 Hz)	7.0	–
Dielectric dissipation factor (50Hz)	(1.4)	–
Arc resistance (s)	180 min.	130 min.
Tracking resistance (V)	600 min.	–
Heating resistance (°C)	180	180
Deflection temperature under load (°C)	150 min.	150 min.
Burning resistance	HB	HB

Evaluation standards conform to JIS.

The biggest factor which decides the strength of the molding compound is glass fiber. Formula composition and production method studies focused on the glass fiber were performed. Regarding the formula composition, if the glass fiber is made long and the amount of additive is made large, the strength is improved also, but molded product appearance and productivity are impeded. Therefore, the optimum kind of glass fiber was selected and the lowered by means of the AD technique previously described and strengthening of the molded case of cover was planned.

Strengthening of the molded case and cover can be first achieved by fusing together (1) strengthening of the molding compound, (2) refinement of metal mold design, and (3) setting of the optimum molding conditions. Here, the description is centered about strengthening of the molding compound.
optimum value was decided by taking its length and additive amount as parameters. The formula organization was designed by taking the shrinkage inhibitor, coloring agent, and other blending agent that have an affect on the appearance of molded case into consideration also.

The result was that a Charpy impact strength exceeding 1.5 times that of the conventional compound could be obtained as shown in *Fig. 25*. The characteristics of the compound developed this time and conventional compound are compared in *Table 1.*

The molding compound realized strengthening as described above, but finally, strengthening as the case cover, that is, the strength in the molded state must be increased. Therefore, a lowering of strength by breaking of the glass fiber can be prevented and even a strength of 1.5 times that of conventional parts as shown in *Fig. 25* can be obtained as a molded case by metal mold design and molding machine refinements.

9. CONCLUSION

Some of the numerous technical developments at the TWIN BREAKERS were introduced above. We are confident that the TWIN BREAKERS are new user-friendly products by the use of the AD technique based on Fuji Electric technology accumulated over many years and revolutionary concepts. We request the guidance and cooperation of those concerned in the future.