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ELECTRICAL LIFE OF THE T-TYPE MINIMUM OIL CIRCUIT BREAKER

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I. INTRODUCTION

Fuji Electric has manufactured and delivered hundreds of 3 kv and 6 kv T-type minimum oil circuit breakers, one of the most widely used type in Europe today, since production was first initiated under a licensing agreement with Siemens Co. The excellent performance displayed by this circuit breaker has been widely praised and accepted. Its construction and arc extinguishing principle have been previously reported in detail. The considerable reduction in the size of power distribution equipment, as well as installation space required, by arranging the circuit breakers in cubicles has been actually proven.

High performance and economy are basic requirements for modern switching equipment; however, at the same time, it is also important to assure high operational reliability. In order to satisfy these requirements, correct maintenance must be conducted. For this reason, definite maintenance standards must be presented. In order to establish a maintenance standard, the service life and effects of long use of the equipment must be properly analyzed and understood.

For instance, although intermediate voltage circuit breakers have been frequently used not only for power distribution systems but also to control large motors and power switching capacitors, the electrical life of these breakers has not been clearly established nor studied despite the apparent need of paying more attention to the electrical life of frequently switched circuit breakers. It appears that the development of maintenance procedures for 3 kv and 6 kv circuit breakers having various types of construction has been left up to the user.

However, in order to provide reasonable maintenance, standard maintenance procedures which are applicable to individual equipment having individual performance, since two equipment items having the same rating can sometimes display different performance, should be established.

The uniqueness of the T-type circuit breaker, whose construction differs completely from the tank-type oil circuit breaker, has prompted many requests for maintenance information, especially that pertaining to the electrical life of the contacts and deterioration of the oil. These problems are extremely important from the viewpoint of circuit breaker performance. This article is a detailed report of the experiments and analyses conducted on the T-type circuit breaker and is published to clarify these problems for your reference.

II. SERVICE LIFE OF THE CONTACTS AND ARC EXTINGUISHING EQUIPMENT

1. Equations Relative to the Service Life of the Contacts

The service life of the circuit breaker is governed by the service life of the contacts. The service life of the contacts is considered to be terminated when the maximum allowable contact wear reaches the limit inherent to each breaker. The speed of contact wear is a function of the shape of the contacts, contact material, breaking current, and arcing time. Each of these factors differs in individual circuit breakers, therefore, the service life of the contacts should be determined for each individual breaker.

Various equations indicating contact wear caused by both breaking current i and arcing time t have been presented. For instance, Williams and Smith[1] presented the following equation from experiments on spark discharge:

$$M = c\, i^{3/2}\, t \quad \cdots\cdots (1)$$

where c = material constant

Holm[2] presented the following equation after synthesizing results of experiments conducted by Wilson, Koller, and himself:

$$\frac{V}{Q} = d\sqrt{i} \quad \cdots\cdots (2)$$

where d = material constant
V = degree of contact wear

The significance of Eq. (2) can be easily understood by considering contact wear in the following manner: First, the rate of contact wear is determined by both the melting point of the contact material and the heat conductivity of the contacts. However, the greater the arc current increase the more important the heat conductivity of the contacts becomes. The arc current I can be given by:

$$I = a^2 \pi j \quad \cdots\cdots (3)$$

where j = current density
a = radius of the circular arc spot on the contact surface

Eq. (3) indicates that the sectional area of the arc spot increases as the arc current increases while the current density remains constant. That is, the radius of contact wear increases in proportion to $\sqrt{I}$. The amount of heat dispersed to the contact also increases in proportion to $\sqrt{I}$. On the other hand, thermal energy supplied to the contact increases in proportion to arc current. This means that arc voltage remains almost constant as the current range changes, arc energy is proportioned to I, and partial energy is supplied to the contact side as thermal energy. Therefore, the ratio of thermal energy radiated by heat conduction from the contact arc spot decreases as arc current increases and, as a result, the vaporization of the contact material increases.

Fig. 1 shows arc current in relation to contact wear per unit charge of a contact made of copper. The following equation may be derived from Eq. (2):

If $Q = it$ (t: arcing time)
then $V \propto i^{\alpha}$ ($\alpha \fallingdotseq 1.5$)

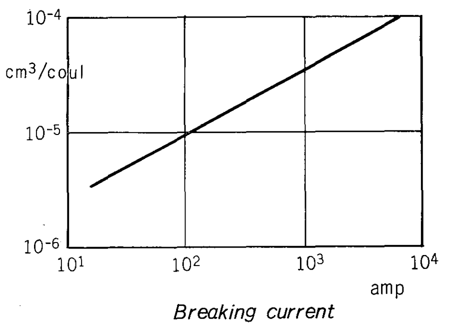


Fig. 1 **Relation of breaking current and contact wear**

H. W. Turner and C. Turner obtained the following equation[3][4][5] from their experiments on various contact materials through which 1 amp to 100,000 amp a-c and d-c currents were applied:

$$\frac{dM}{dt} = k i^{\alpha} \quad \cdots\cdots (4)$$

These experiments prove that the exponent α is not related to the contact material. According to experiments on magnetic contactors conducted by Turner, α was 1.6 for copper, silver, and silver cadmium oxide. Also, the numerical wear factor k had a different value for each different material. For instance, $k = 0.152$ for copper
$k = 0.051$ for silver
$k = 0.0251$ for silver cadmium oxide.
(But M: mg, t: ms, i: ka in Eq. 4.)

The value of k for each material becomes smaller in the following order: tin, aluminum, zinc, silver, copper, titanium, iron, nickel, molybdenum, tungsten, and carbon. If contact materials are so arranged that the material having the lowest melting point or lowest vaporization heat comes first, the order of the k values is exactly the same as that shown above.

All equations indicate that wear is proportional to the 1.5th to 1.6th powers of current and that the wear exponent is not related to the contact material.

2. Experiments on the Service Life of the T-type Circuit Breaker Contacts

The most practical and generalized equation in II. 1. is the one derived by Turner. However, it appears to be necessary to derive an equation for each breaker since each individual breaker has its own constant k of Eq. (4) and factors, such as operating method, construction, contact rod breaking speed, shape of the fixed contact, current path, blast of the arc extinguishing medium, pressure, etc. The results of the experiments will now be described.

The T-type circuit breaker is equipped with an oil flow producing mechanism based on the principle of volume equilibrium as a featured system in arc extinguishing[6]. The oil is blasted to the arc extinguishing space radiating from the side of the contact rod. Construction of the contact is shown in *Fig. 2*. Tip 1 of the contact rod is made of insulation material. This is a very important part of the assembly and functions to achieve the extinguishing effect of the ring-nozzle as another feature of the breaker.

Tungsten-copper alloy is used as the material for both the arcing contact tip 2 and the arc ring of the fixed contact 3. When the contact of the breaker is closed, current flows from the main contact part 4 of the rod to the silver contact finger 5 in the fixed contact. When the contact is open, the arc ignites between the arc ring 3 and the arcing contact 2. The tests were conducted under 200 amp to 20 ka

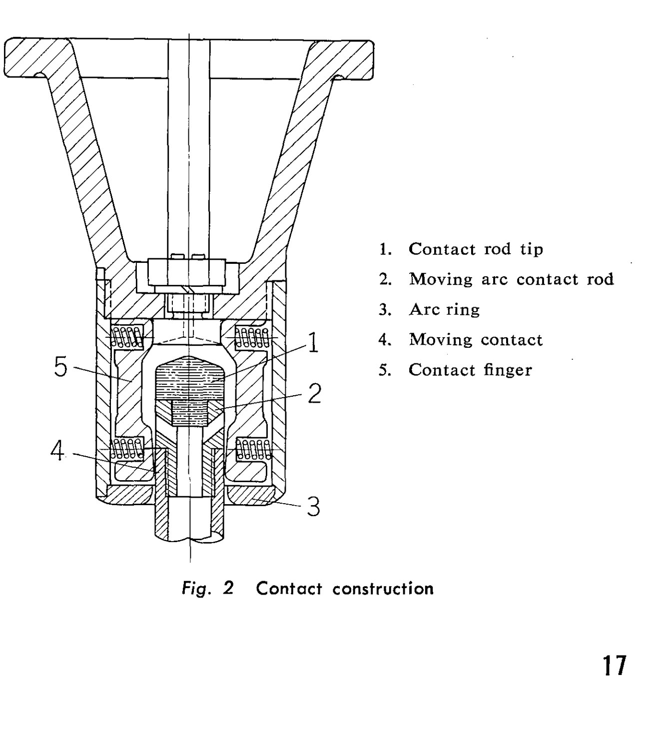


Fig. 2 **Contact construction**

breaking current for 8.4 ms to 20 ms. For the three different recovery voltages of 3.6 kv, 7.2 kv, and 12 kv, there was no difference in arcing time.

Fig. 3 is a photograph showing the movable contact, arc ring, and contact fingers after the 200 amp current test and 6000 on-off switching operations.

For simplification, if i of Eq. (4) is assumed as an rms value not influenced by time, then the following equation can be derived:

$$M = k i^{\alpha} t \quad \text{.......................................} \quad (4')$$

Fig. 4 indicates wear in relation to the number of interruptions using the breaking current and recovery voltage as parameters. As indicated in *Fig. 5*, a graph having the breaking current as the abscissa and wear per unit time (mg/ms) as the ordinate will show discontinuous points near 1000 amp. According to Turner, the existence of these discontinuous points can be described as follows: the origin of the wearing process lies in the existence of a pinch effect within the contact material itself due to the extremely high current density in the contact material at the bases of the arc rather than to the flow of thermal energy.

Therefore, thermal dispersion by thermal conduction cannot be expected since the wearing process is taking place within the contact material itself.

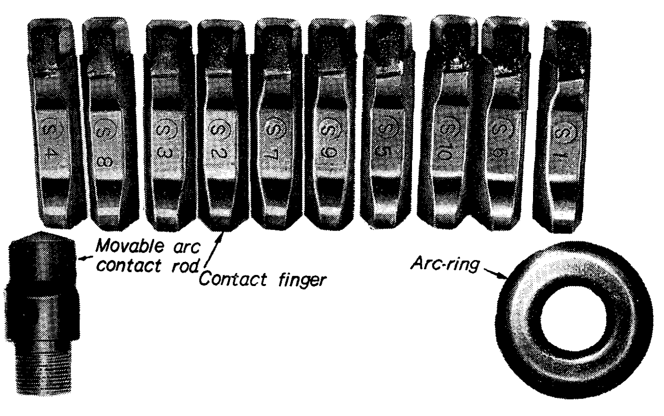


Fig. 3 Contacts after 6000 switchings at 200 amp

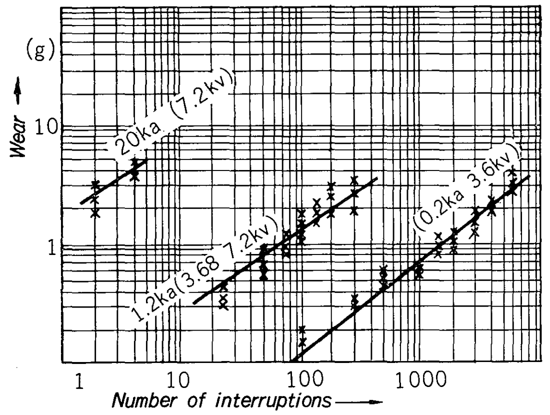


Fig. 4 Wear in relation to the number of interruption

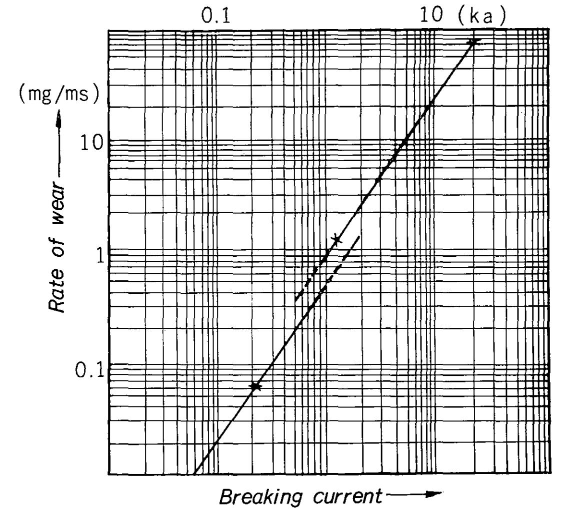


Fig. 5 Rate of wear and breaking current

The following conclusions can be made:

(1) The temperature of the metal at the bottom of the arc spot has no relation to the size of the contact since the area of the arc spot on the surface of the contact is considerably smaller in comparison to the size of the contact.

(2) The rate of temperature rise at the bottom of the arc spot is rapid and instantaneous since current flows through an extremely small portion of the contact material.

There are exceptions to the above rules since the arc current increases at a certain region.

That is, when the arc current is increased above 300 amp, the thermal energy brought to the surface of the contact becomes so high that it starts to melt a wide region of the contact surface. This current is called the " discontinuous wear current " by Turner.

The value of the discontinuous current is obviously influenced by the size of the contact and, if the size of the contact is constant, it is influenced by the material of contact.

In the case of a copper contact, these discontinous points exist in the region of 800 to 1000 amp and the wear exponent remains constant while the numerical wear factor k becomes 15 times larger as the current increases to the region above the discontinuous points.

According to the preliminary tests, the discontinuous points in the T-type circuit breaker lie near the 1000 amp region. The constants, which should be used with Eq. (4) and derived from *Fig. 5*, are shown in *Table 1*.

In the regions above and below 1000 amp, there is no evidence of such a sudden increase in the numerical wear factor as is the case with copper contacts.

All data presented above is based on the tests conducted with oil as the medium and, as reported by Wilson regarding his experiments, there would be no apparent difference of the rate of wear between switching in oil and air.

Table 1 **Wear Factor for Contact**

Breaking Current Range	Up to 1000 amp	Over 1000 amp
Wear Exponent α	1.65	1.65
Wear Factor k	0.67	0.9

It has been thought that switching in oil would cause the contacts to wear faster than in air; however, it can be assumed that this difference is caused by the different liquid blast effects rather than the different medium. Evidence for the assumption made above is the test data furnished by Pucher(7). According to this data, there is no difference in the rate of wear between the minimum oil breaker and the air-blast breaker.

The rate of wear of the arc ring in the fixed contact is smaller than that of the movable contact. The reason for this is that the arc ring is heavier and, therefore, has a larger thermal capacity than the movable contact. Also, the arc spot can move around on the surface of the arc ring but not on the movable contact.

3. Allowable Wear Limit of the Contacts and Parts of the Arc Extinguishing Device

Wear of the contacts should be kept within a certain limit to assure proper functioning of the contacts. If wear exceeds the allowable limit, the contacts will gradually lose their current carrying capacity for load current and short-circuit current until the switching operation is completely stopped due to fusing of the contacts. Generally, a combination of arcing contact and main contact, as shown in *Fig. 2*, will provide a solution to this problem. In this case, the arcing contact is specifically used for arcing when the contact is open and the main contact to carry the current when the contact is closed. Since each manufacturer uses his own contact material and construction it is very difficult to generalize the service life of contacts. For instance, it was suggested that a contact having a 25% wear on the effective contact area should be replaced with a new contact. However, this merely suggests a general rule. Therefore, it is not advisable to evaluate the life of a contact only from its current carrying capacity. A contact has to be replaced before it reaches the limit of its current carrying capacity if it increases friction by wear causing difficulties in the switching operation. If the blasting condition of the liquid jet or electrical field distribution between contacts changes due to wear of the contacts, the determining factor in establishing the life of contact should be governed by these symptoms.

It will be a problem if the insulation design of the arc extinguishing components is made without anticipating the reduced dielectric strength in the arc extinguishing chamber caused by the accumulation of small particles of metal splashed from the contact.

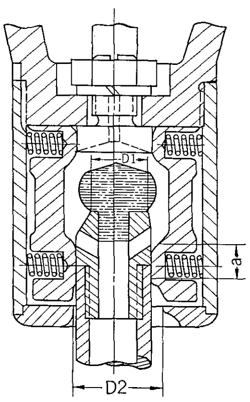
Not only the wear of the contact but also the cracking of the arc-chamber insulation will reduce the dielectric strength causing the interrupting performance to become undesirable. Low performance interruption also occurs if the sectional area of the liquid nozzle increases to a value above the allowable value.

Considering the above fact, *Table 2* shows the calculated life of the contact and the allowable wear limit of the insulation for the arc extinguishing device of the T-type circuit breaker. As shown in *Table 2*, the part of the T-type circuit breaker having the highest wear rate is the movable arc contact. In this case, the life of the movable arc contact is terminated when its diameter is reduced from 20 mm to 16 mm after the 4th interruption of a 22 ka short-circuit current. *Fig. 6* shows the worn condition of the contact and insulation of the arc-extinguishing chamber after completion of a duty cycle 0–1 min–CO–3 min–CO at 7.2 kv, 250 Mva. *Table 3* shows the dimensions of the contacts and chamber insulator after completion of the duty cycle. From this, it can be seen that the insulation of the arc extinguishing chamber reaches the allowable wear limit after 9 interruptions of the rated breaking current. It can also be seen that the insulation of the arc-extinguishing chamber has a much longer life than the life of the movable contact.

It may be suspected that the insulation at the tip of the movable contact of the T-type circuit breaker is fast, however, as shown in *Fig. 6*, the wear is actually almost the same as that of the arcing contact.

Table 2 **Allowable Wear Limit for Contact and Arc Chamber**

Location	Dimensions at Delivery (mm)	Dimensions of Allowable Wear Limit (mm)
Hole Diameter of Chamber Cover	23	25
Hole Diameter of Chamber Insert (refer to *Fig. 16*)	21	23
D_1	20	16
a	14	10
D_2	22	24



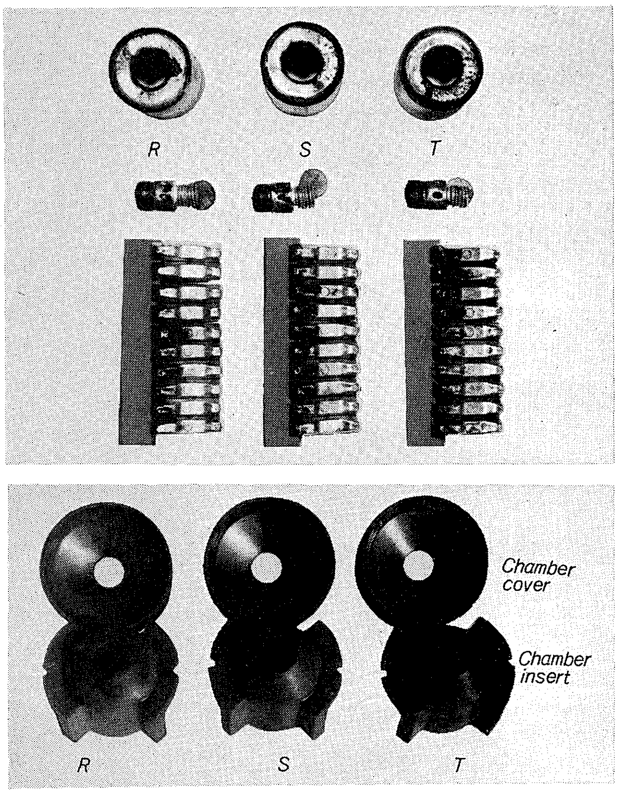


Fig. 6 Contacts and chamber insulators after duty cycle at 7.2 kv 250 Mva

If the arcing time t_0 and the number of allowable switching operations n_0 at the rated breaking current I_0 are known, the life of the contact at arcing time t and current i can be derived from Eq. (7).

$$\frac{n}{n_0}=\left(\frac{i_0}{i}\right)^{\alpha}\cdot\frac{t_0}{t} \quad \cdots\cdots (5)$$

Arcing time is constant and independent of the breaking current in the case of the T-type circuit breaker and, since $\alpha=1.65$,

$$\frac{n}{n_0}=\left(\frac{i_0}{i}\right)^{1.65} \quad \cdots\cdots (5')$$

Fig. 7 is plotted from Eq. (5′) using $i_0=22$ ka and $n_0=4$. Since the wear factor for the region above 1000 amp is also used in the region below 1000 amp

Table 3 **Dimensions of Contacts and Chamber Insulator after Duty Cycle at 7.2 kv 250 Mva**

Location	Phase	Max. Wear Dimension (mm)	Min. Wear Dimension (mm)
Diameter of Movable Contact Rod D_1 in *Table 2*	R S T	17.58 17.82 17.16	19.42 19.58 19.38
Diameter of Arc Ring D_2 in *Table 2*	R S T	22.48 22.33 22.58	22.22 22.06 22.06
Hole Diameter of Chamber Insert (5.17 in *Fig. 16*)	R S T	21.65 22.30 22.08	21.06 21.05 21.07
Hole Diameter of Chamber Cover (5.15 in *Fig. 16*)	R S T	24.06 24.15 24.36	23.48 23.66 23.72

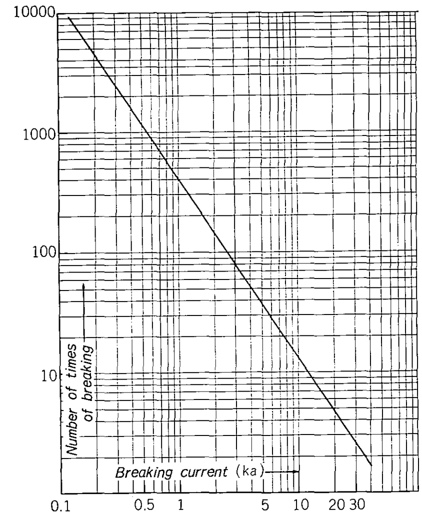


Fig. 7 Electrical life of the contact of the T-type circuit breaker

in plotting the curve, the breaking current can be considered to be larger than shown in the region below 1000 amp.

However, in actual breaker use, *Fig. 7* is useful only for reference during maintenance and inspection since the magnitude of the current and number of breakings are not automatically recorded. Therefore, the rate of wear must be actually inspected for maintenance purposes.

III. SERVICE LIFE OF THE INSULATING OIL

1. Conventional Maintenance Standards

According to the maintenance standards recommended in Japan, the insulating oil of the tank-type oil breaker should be replaced or filtered when its dielectric strength reaches the value shown below:

Rated breaker voltage	Dielectric strength
60 kv min.	less than 20 kv
20 to 30 kv	less than 15 kv
20 kv max.	less than 10 kv

If other performance presents problems, determine the acid value and judge the dielectric strength value by referring to the following standard:

less than 0.2	good
less than 0.5 but greater than 0.2	caution
greater than 0.5	no good

An inspection is also recommended after load current, charging current, or exciting current has been switched more than the following number of times:

Rated breaker voltage	Breaking frequency of load current
60 kv min.	approx. 1000 times
20 to 30 kv	approx. 500 times
10 kv max.	approx. 300 times

These maintenance standards are based on the following concepts: Short arcing time and large amount of oil in breakers over 60 kv do not present oil deterioration problems since these breakers generally utilize small current breaking arc extinguishing devices using an external energy source. However, breakers in the 3 to 10 kv range use a small amount of oil and frequently employ arc extinguishing devices using internal energy source for extinction; therefore, a maximum of 300 breakings is established since the dielectric strength decreases quickly after the accumulation of carbon and metallic impurities.

It may be thought that the T-type breaker using a fractional amount of oil, compared to a conventional type of breaker, may cause the oil to deteriorate faster and therefore require more frequent maintenance and inspection than the conventional type of circuit breaker. According to studies and analysis of these subjects, Fuji found that oil deterioration is much slower than in the conventional type and the interval required for maintenance and inspection can be increased over the conventional standards. Also, conventional thinking on the use of insulating oil as a breaking medium should be revised as far as the T-type breaker is concerned.

2. Volume of Carbon and Decomposed Oil at the Time of Breaking Operation of the T-type Breaker

The energy of the breaking arc must first be found before the volume of carbon and gas generated at the time of breaking can be determined. Arc energy A at the time of breaking can be given by:

$$A=\int_0^{t_a} U_B\, i\, dt \quad \text{.......................} \quad (6)$$

where U_B = arc voltage, i = breaking current, and t_a = arcing time.

Eq. (7) can be employed to analyze the arc voltage as a function of time since the arc voltage in a conventional breaker rapidly increase as the arcing time progresses.

$$U_B=\frac{E_B}{m}(e^{vmt}-1) \quad \text{....................} \quad (7)$$

Where E_B: potential gradient of the arc

v: average breaking speed

By manipulating the exponential function of Eq. (7), Eq. (8) can be derived.

$$U_B=E_B v\left(t+\frac{mv}{2}t^2\right) \quad \text{.................} \quad (8)$$

Usually m is about 0.4 and the larger m or v is the more rapidly the arc voltage increases with time. In the case of the T-type breaker, $m=0$ can be used since breaking takes place by using a unique ring-duct nozzle extinction principle by breaking while keeping the arc voltage to a minimum. This means that the arc voltage will increase linearly in proportion to time as shown in the breaking oscillogram of *Fig. 8*. Therefore, the arc voltage can be given by the following equation:

$$U_B=E_B\, v\, t \quad \text{.............................} \quad (9)$$

According to Kesserling[8], E_B=200 v/cm for the oil blast. The mean breaking speed of the T-type breaker is 320 cm/sec. By using these values in Eq. (9), the following equation can be derived:

$$U_B=6.4\times10^4\, t \ \text{[v]} \quad \text{.............................} \quad (10)$$

Eq. (10) matches the actually measured arc voltage of the T-type breaker interruption test.

If a detailed examination is made of the T-type circuit breaker arcing time as shown in *Fig. 9*:

Preparation time (time required to provide sufficient arc extinguishing ability after opening of the contact)
=0.42 to 0.52 cycle

Waiting time (time required from completion of preparation for arc extinguishing to the time when current becomes zero)
=0.16 cycle...(3-phase breaking)

The time interval between the first phase breaking and final phase breaking is 0.25 cycle.

These time relationships remain constant in all current magnitude ranges and are independent of the magnitude of the breaking current. The variation in the 0.16 cycle of waiting time is unavoidable as long as extinction is performed at the current zero pause, and variation caused by the arc-extinguishing

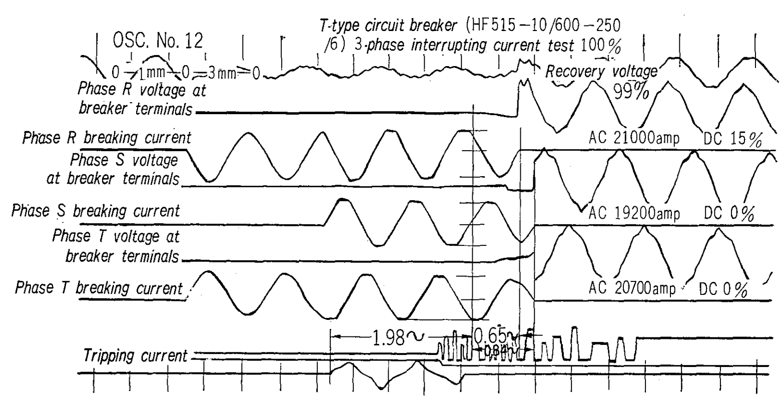


Fig. 8 **Oscillogram of breaking test at 7.2 kv, 250 Mva**

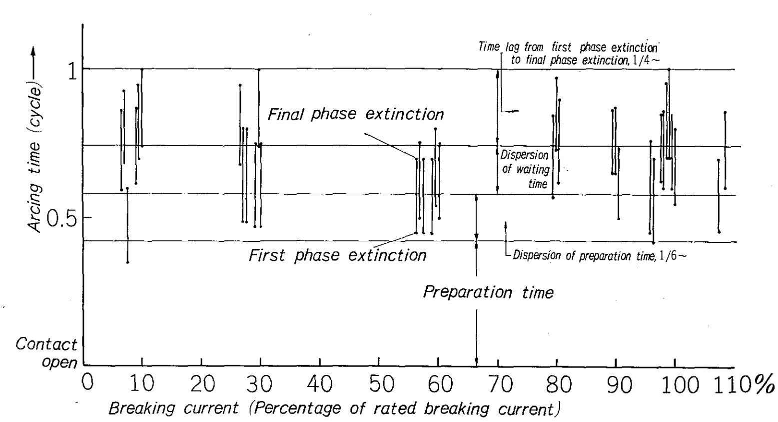


Fig. 9 **Arcing time of the T-type circuit breaker**

device itself is equal to a variation of 0.16 of the preparation time. These values prove that the breaking performance of the T-type breaker is extremely stable. From this data, the mean arcing time can be derived as follows:

Mean arcing time at first phase breaking
$=$ preparation time $0.42+$ variation of preparation time $0.08+$ variation of waiting time $0.08=0.58$ cycle

Mean arcing time at final phase breaking
$=0.58+0.25=0.83$ cycle

Fig. 10 shows the breaking arc power in breaking a 1kA current as a function of time for each case of a mininum arcing time of 0.67 cycle, mean arcing time of 0.83 cycle, and a maximum arcing time of 0.99 cycle. Arc power at any desired breaking current value can be derived from these graphs. *Fig. 11* compares the instantaneous peak values of the arc power produced at the final phase breaking at the maximum arcing time and at the first phase breaking at the minimum arcing time in the T-type breaker chamber and in a chamber of the conventional type breaker. That is, all the instantaneous peak values of arc power produced in the chamber at the breaking time should be dispersed within the hatched area. In the case of the T-type circuit breaker, the calculations described above accurately match the values derived from measurement, and the instantaneous peak value of arc power is about 50% that of other types of breakers. Variation is also less than that of other types of breakers.

Arc energy during the breaking time is used in contact heating, radiation and conduction from the arc column, heating and vaporization of the oil, decomposition of the oil, expansion of the gas, and heating the gas. The typical distribution of the arc energy derived from experiments, which were conducted by Bruce, on oil breakers having an extinction chamber is shown in *Fig. 12*. According to the drawing, the arc energy used in heating, vaporization, and decomposition of the oil amounts to 37% of the total energy.

If the oil is decomposed by the arc energy, hydrogen (H_2), acetylene (C_2H_2), methane (CH_4), and ethane (C_2H_6) will be produced. Carbon (C) and oil vapor (this vapor becomes liquid state oil after the temperature drops) will also be produced.

The volume of these gases per 1 kJ of arc energy, when measured from sampled gas having a temperature of 20°C at atmospheric pressure, is 60 cc/kws (Bauer's constant). The relation between the oil volume W_0 [gr] decomposed by the breaking arc, carbon ε [gr], and the produced gas V_g [cc] converted to a gas with a temperature of 20°C and an atmospheric pressure can be given by the following equations:

$$W_0=(5.83\alpha+11.66\beta+5.70\gamma+11.54\delta)\times V_g\times 10^{-6}\ [\text{gr}] \quad (11)$$

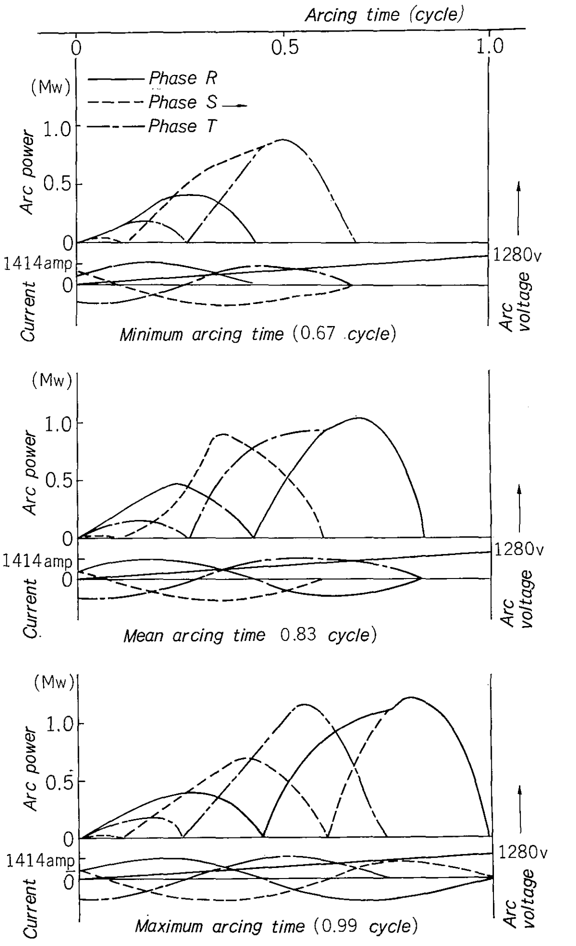


Fig. 10 Changes of arcing power at each phase of breaking (1 ka breaking current)

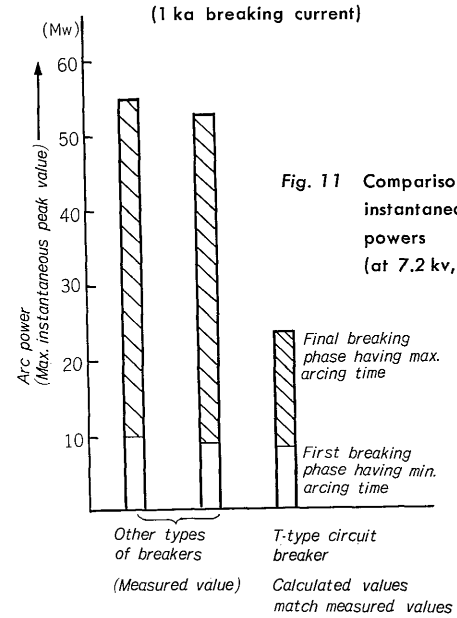


Fig. 11 Comparison of maximum instantaneous arcing powers (at 7.2 kv, 250 Mva)

$$\varepsilon=\{4.99(\alpha+\beta)-5.12\gamma+0.12\delta\}\times V_g\times 10^{-6} \quad (12)$$

where α, β, γ, δ indicate the percentage of gas for H_2, CH_4, C_2H_2, C_2H_6 respectively. The following equations are obtained by using Eq. (11) and (12) and percentages actually measured:

$$W_0=6.2V_g\times 10^{-4} \quad (13)$$

$$\varepsilon=2.44\ V\times 10^{-4}\ [\text{gr}] \quad (14)$$

Table 4 **Oil Decomposition Volume and Carbon Volume vs. Breaking Current**

Breaking Current (amp)	200	1200	12,000 (at 150 Mva, 7.2 kv)	20,000 (at 250 Mva, 7.2 kv)
Arc Power (final phase breaking) (Mw)	0.159～0.241	0.953～1.46	9.53～14.6	15.9～24.1
Mean Arc Energy of Each Breaking (kw • s)	1.38	8.3	83	138
Gas Volume Produced at Each Breaking and Converted to Atmospheric Pressure at 293°K	30.7	184	1840	3070
Decomposed Oil Volume (at each breaking) (gr)	0.019	0.114	1.14	1.9
Free Carbon (produced at each breaking) (gr)	0.0075	0.045	0.45	0.75
Actual Measurement of Free Carbon) (gr)	20.4 (*1) 0.0034(*2)	5.47 (*3) 0.0183 (*2)	—	—

*1 (6000 breaking) *2 (each breaking) *3 (300 breaking)

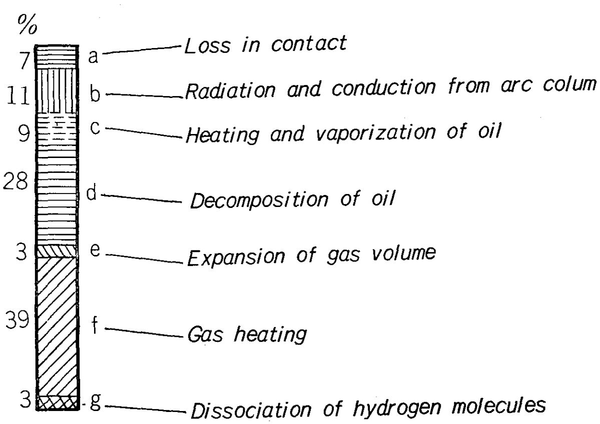


Fig. 12 Distribution of arc energy

Table 4 shows the arc current, oil volume decomposed by arc energy, and the calculated carbon volume corresponding to each breaking current of the T-type breaker. As shown in the table, the volume of the decomposed oil at a rated current of 1200 amp breaking is only 1/10 cc and the volume of the decomposed oil at the rated short-circuit breaking current is 2 cc.

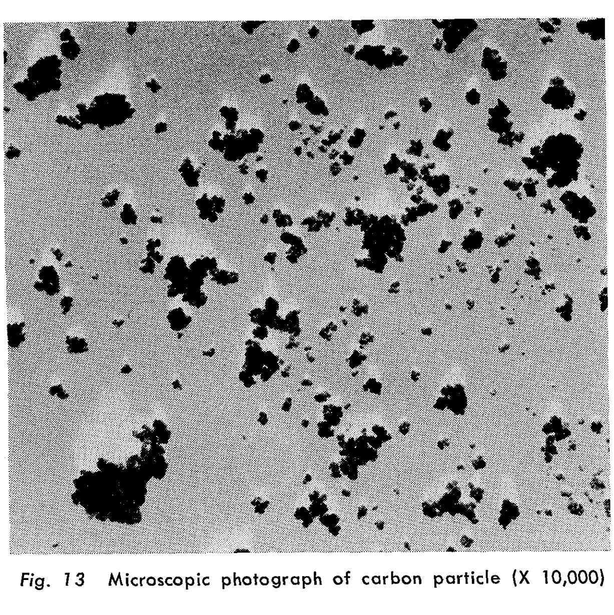


Fig. 13 Microscopic photograph of carbon particle (X 10,000)

For example, the volume of the decomposed oil for first phase breaking after 1000 load current switchings at a 200 amp current is only 20 cc. This oil volume decreases the indication of the oil volume gauge by 3.2 mm. The volume of free carbon after 1000 switchings at 200 amp is approx. 10 gr which is 0.5% of the total weight of the oil per phase. The size of the free carbon particles is 0.03 to 0.1μ as shown in *Fig. 13*. It is hardly believable that these particles can adversely affect the operation of the moving parts of the breaker.

3. Influences on Insulation and Breaking Performance by Deterioration of Insulating Oil, and Maintenance Procedures

It is very difficult to prevent insulating oil from loosing its insulating capability. The number of current breakings increase as a result of decomposed insulating oil and free carbon caused by the breaking arc. *Fig. 14* shows plots made by using actually measured values to indicate arcing time variations and dielectric strength of oil at a 200 amp breaking current after 6000 breaking operotions without changing oil. The dielectric strength of the oil dropped from 30 kv to 15 kv when tested at the power frequency but there was no sign of change in the arcing time. Duty cycle tests on the rated interrupting capacity using the same deteriorated oil indicates no change in arc extinction ability. Observation on the change of oil state at 200 amp breaking is as follows: At the 100th breaking, the oil is not as dark; at the 300th breaking, the oil is completely black; at the 2500th breaking, there is a bad smell when the oil is inspected; at the 3000th breaking, the oil looks as if it increased in viscosity but when tested there is no difference in viscosity between new oil and the deteriorated oil as shown in *Table 5*.

Fig. 15 shows the influence of the decreased dielectric strength of the oil to the insulation between two contacts. Symbol ○ is for a 15 kv dielectric strength of the oil and symbol ● is for a 30 kv dielectric strength of the oil. It indicates that oil will withstand a 70 kv voltage at the power frequency applied continuously to two contacts spaced 60 mm

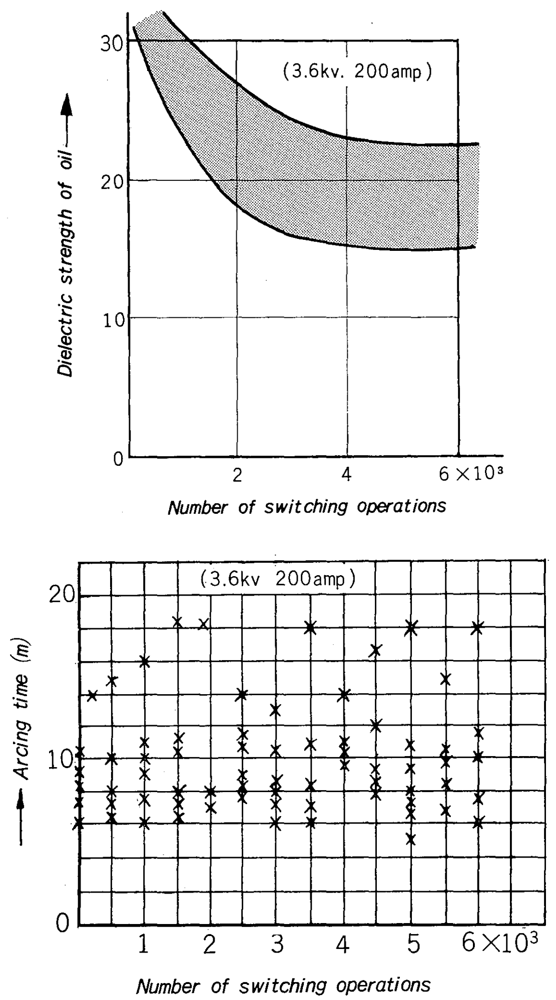


Fig. 14 **Arcing time and dielectric strength of oil vs. number of switching operations**

apart. Actually, it is impossible to find any difference between oil having a 30 kv dielectric strength and oil having a 15 kv dielectric strength. Since the T-type breaker has a 95 mm contact distance, it can be said that it has sufficient dielectric strength.

Deterioration of the oil will not influence the dielectric strength between the contact and the grounding metal plate since the charging device is supported by an insulator located outside the breaker pillar.

Table 5 **Viscosity of New and Deteriorated Oil**

Item		New Oil at Delivery	Deteriorated Oil after Reaching the Limit of its Electrical Life of Contact
Carbon	(%)	—	1.01
Viscosity (Cst)	10°C	35.1	35.8
	20°C	21.3	21.4
	30°C	13.4	13.7
	75°C	3.9	3.9
Dielectric Strength (kv)		55.1	15.5
Acid Value		0.002	0.01

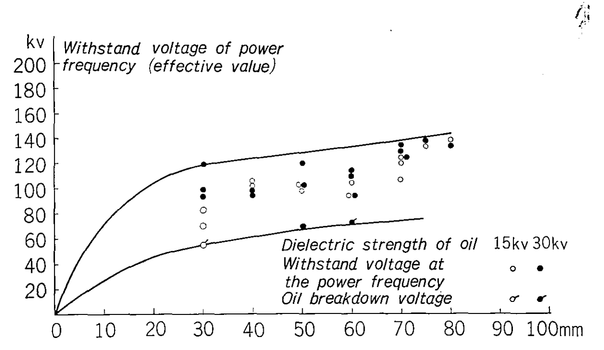


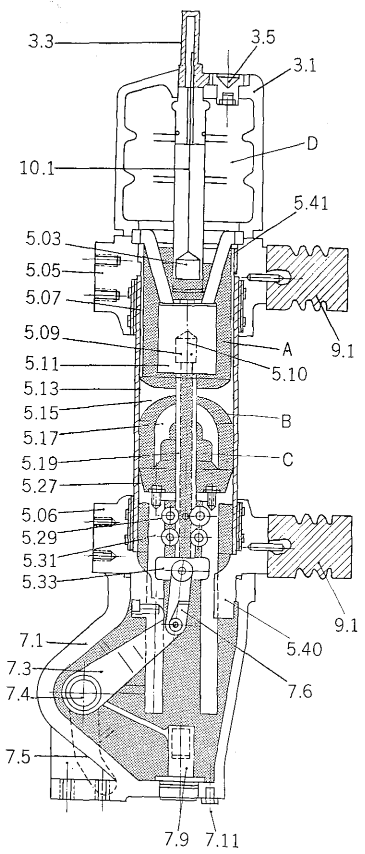
Fig. 15 **Dielectric strength of oil vs. contact stroke**

In the case of circuit breakers rated below 10 kv, it is advisable to inspect the oil after 300 load current breakings, charging current breakings, or exciting current breaking. Breakings which fall in this class mostly use internal extinguishing energy. As compared to circuit breakers rated above 60 kv which use external extinguishing energy, the dielectric strength of the oil of these breakers presents a serious problem when breaking small currents, especially charging current. The T-type breaker will complete breaking within one cycle, which is the same as breaking a large current, by using the oil flow produced by the principle of volume equilibrium in the small current region thereby assuring the nonexistence of restriking. It can be concluded from the above that deterioration of the insulating oil will have no affect on breaking performance and insulation. Therefore, it is rather too frequent if the oil of the T-type breaker is inspected every 300 breaking operations.

A question then may arise regarding the time when inspection should be performed. In the case of the T-type breaker, it is recommended to replace the oil when the contacts require replacement in accordance with the life limit shown in *Fig. 7*. Experiments indicate that the life of the insulating oil is much longer than the life of the contact; however, the maintenance intervals should not be extended indefinitely. The main reason for this is the possibility of flashover in the oil of the arc extinguishing chamber caused by excessive carbon and metal particles. Replacing the oil when the contact is replaced will assure proper maintenance for the breaker.

Deterioration of the oil by the breaking arc has been mainly described, but it also occurs without breaking operations. For example, a decrease in the dielectric strength of the oil will be influenced by water in the oil. *Fig. 17* shows the effect of water in the oil on the dielectric strength of the oil.

As far as circuit breakers used indoors are concerned, the moisture absorbed from the air is almost negligible and, even if the dielectric strength is reduced by the effect of atmospheric moisture, it will cause no substantial effect on the performance of the breaker as shown in *Fig. 17*.



A : Chamber section
B : Ring duct
C : Chamber section
D : Air-cushion chamber
3.1 : Breaker head
3.3 : Gauge glass
3.5 : Vent plug
5.03 : Float for oil level indicator
5.05 : Upper terminal
5.06 : Lower terminal
5.07 : Distance tube
5.09 : Arc contact rod
5.10 : Contact rod tip
5.11 : Fixed contact
5.13 : Insulating tube
5.15 : Chamber cover
5.17 : Chamber insert
5.19 : Contact rod
5.27 : Deflector plate
5.29 : Current transfer roller
5.31 : Guide rod
5.33 : Crosshead
5.40 : Support
5.41 : Pressure ring
7.1 : Crank housing
7.3 : Inner crank
7.4 : Shaft
7.5 : Outer crank
7.6 : Pull bar
7.9 : Damper
7.11 : Oil drain plug
9.1 : Cast resin insulator
10. 1 : Gauge glass

Fig. 16 **Construction of T-type circuit breaker pillar**

The next subject to be described is deterioration by oxidation. That is, increased acid value caused by heat and contact with oxygen will cause the materials in contact with the insulating oil to wear. Impurities caused by wear will reduce the dielectric strength. Usually, the performance of the oil rapidly drops when the acid value reaches 0.5 [KOH mg/g], and in the neighborhood of 1.0 the oil starts to cause wear of the materials in contact with it.

Therfore, it is recommended that the oil be changed if the acid value reaches 0.5. *Fig. 18* shows continuously measured acid values of insulating oil used for 30 years. This suggests that the acid value of insulating oil is influenced by the ambient temperature and environment but usually presents no substantial problem. Breakers having extremely low switching frequencies should be checked for dielectic strength and acid value at periodic inspections and, if the condition is comparatively good, the interval between periodic inspections can be extended to several years.

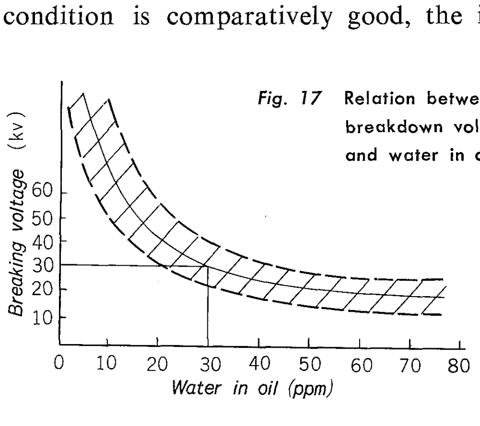


Fig. 17 **Relation between breakdown voltage and water in oil**

IV. CONCLUSION

The above descriptions have focused on the electric life of the T-type circuit breaker, especially the life of the contacts and insulating oil as the arc extinguishing material. It is possible to extend the service life of oil circuit breakers in load current switchings used in high-voltage motor control if designed is proper.

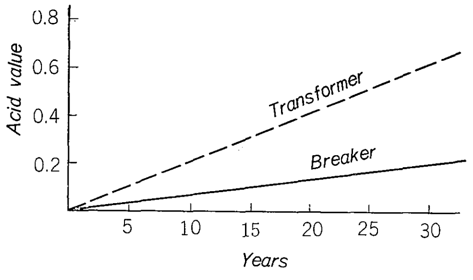


Fig. 18 **Acid value of oil vs. time**

In short, basic maintenance principles for the contact and insulating oil of the T-type breaker include replacing the contact and insulating oil when the contact reaches the limit of its service life as it corresponds to breaking current as shown in *Fig. 7*. In this case, it may be not economical to purify the insulating oil. A few liters of new oil for each breaker will not cost too much. Another important point is that the dimensions of each component, the life of which is terminated by wear, are clearly determined, and the time required to disassemble and assemble the breaker is very short as shown in *Table 6*.

The authors will be pleased if the above helps to obtain a proper understanding of the T-type circuit breaker to realize proper operation by adequate maintenance based on reliability and helps to improve productivity.

Table 6 **Time Required to Interchange Fixed and Moving Contact**

Type of Work	Time Required	Tool Used
Removing Breaker Head *(3.1)	45 sec	Hex wrench ×1 Chip changing tool ×1 Retaining ring changing tool ×1
Changing Chamber and Fixed Contact *(5.11, 15, 17)	93 sec	
Removing Movable Arc Contact Rod *(5.09)	52 sec	
Installing Movable Arc Contact Rod *(5.09)	35 sec	
Installing Breaker Head *(3.1)	93 sec	

* Refer to *Fig. 16*

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