FUJI 80.5 kV NON-RESTRIKE TYPE EXPANSION CIRCUIT BREAKER

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I. INTRODUCTION

In 1933 Fuji Denki completed Japan's first outdoor-use high tension porcelain type circuit breakers so called E. C. B, which had the capacity of 46 kV 750 MVA. Succeeding to these units the company has turned out one after another the same type breakers of 80.5 kV 1500 MVA, of 161 kV 2500 MVA and finally of 230 kV 3500 MVA. The last one manufactured in the quantity of 70 units in 1936 were mounted on the transmission line connecting the Soopoong Hydro-electric Power Station along Yalu River with industrial areas in Manchuria and North Korea. This is the first 230 kV transmission line of "Ultra-high Tension" the Orient has ever had.

Fuji Denki, since 1932, has supplied various "Expansion" type circuit breakers: the indoor-use type of 3 kV to 30 kV of which arc is quenched by the mixed liquid of water and glycol—the liquid is called "Expansion"—, or the outdoor-use of 10 kV to 230 kV arc-quenched by small quantity of mineral oil.

The adoption of this new "Expansion" system has brought a revolutionary extension of the rupturing capacity of circuit breakers, which it saved mineral oil, one of Japan's scanty materials, to a considerable extent. Now it has become a common sense for engineers to recommend this new type for the circuit breakers of more than 60 kV. Besides, because of the dependability upon their interrupting capacity, it has given a strong impetus to the development in the field of power supply. And consequently the completion of the above mentioned transmission line of 230 kV had become possible.

The adoption of this system also has contributed greatly to the manufacture of porcelain type circuit breakers, which stimulated many other. Japanese manufacturers to turn out numberless such new type circuit breakers.

The Fuji Expansion Circuit Breakers are equipped with arc-quenching devices that is an application of expansion principle as explained by Siemens Schuckertwerke: the hydrogen effect and expansion effect.

The fact that about 40% of total demand of circuit breakers is supplied with those of this type proves their high reliability. It is worth mentioning that the rather primitive design of 1933 has been much improved for 20 years ever since and also that the required ratings in Japan about circuit breakers are more severe than in Germany; it may be natural that the Fuji Expansion Circuit Breakers of today are superior in design as well as in quality. For instance, the 80.5 kV 2500 MVA 1200 A breaker of which we are going to explain has a conspicuous features;

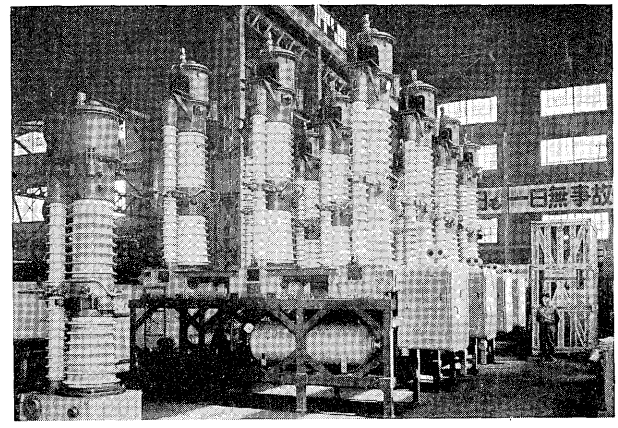


Fig. 1. Non restrike type expansion circuit breaker rated 80.5 kV. 2500 MVA on the works

The most important requisites for circuit breakers to be used in Japan are:

a) To be free from restrike phenomena as well as the abnormal voltage occuring therefrom at the instance of disconnecting charging current into transmission lines or exciting current on transformers.

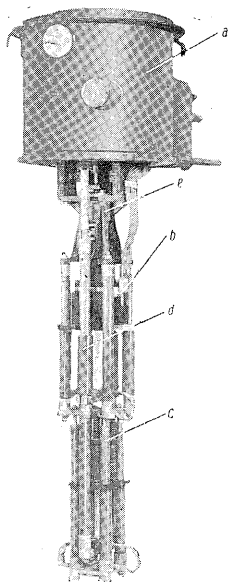
b) When the recovery voltage reaches twice the line-to-line voltage appearing when 2 phase ground occurred between different phases of transmission line of ungrounded system, and a generator stepped out, interruption is perfectly performed so that arcing time is average on every current value.

c) To have high-speed re-closing characteristics while the mechanism withstands 10,000 times of on-and-off operations without any troubles.

This type RF 650 B 80.5 kV 2500 MVA 1200 A circuit breakers satisfy all of these requirements. Especially as for the rupturing capacity mentioned in item a is guaranteed by several tests actually carried out on overhead transmission line and oil-filled cables.

II. ARC-QUENCHING DEVICES FOR TYPE RF 650 B EXPANSION CIRCUIT BREAKER

The most important parts of a circuit breaker are



a head mechanism housing

e oil pump case for b

b cross flow oil blast chamber with moving contact

d insulating operating ladder

c elastic expansion chamber

Fig. 2. Outerview of new type chamber

the arc-quenching chambers. And as for this type there are provided two chambers with different characteristics: one expansion chamber with hydrogen and expansion effect, and the other cross flow oil blast chamber. These two chambers are connected electrically in series as illustrated in figure 2 and operate at the same time, disconnecting any of the current—from ordinary small current to the maximum fault current—by interrupting the arc at a definite length. An A.C. circuit is more easily cut off than a D.C. circuit. For, as a current oscillogram shows the current wave diminishes of itself when passing a zero point. As arc-quenching action, it is necessary to clear out rapidly ionized particles in the arc-path and to prepare the gap between two poles to restore its dielectric strength enough to withstand the recovery voltage.

There are two typical and fundamentally different way of arc-quenching.

a) Self-controlled arc chamber

In this chamber the action of quenching medium is generated and controlled by arc energy. In this case the action is affected by the intensity of the current.

b) Separately controlled arc chamber

In this chamber the action of quenching medium is controlled separately from arc energy; that is, the medium of oil or compressed air etc. is supplied from outside into the chamber by a mechanical power, therefore the quenching action is independent of the current intensity.

The above two theories of arc-quenching are applied to this type of circuit breakers: the theory a) is to the expansion arc chamber and b) to the cross flow oil blast chamber as hereinafter described. This theories has been well explained by Dr. Prince in America.

The hardness of breaking current in the arc

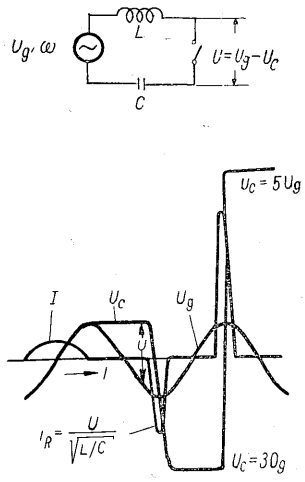


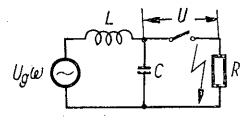
Fig. 3a Capacitive load

I. Charging current

Ug. Generator voltage

U. Recovery voltage between contact

Uc. Line voltage



i. Short circuit current

UR. Restrike voltage

Ud. Dielect strength (voltage) between contact

Fig. 3b Inductive load

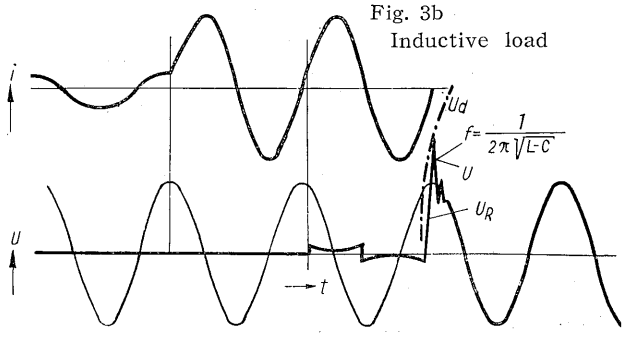


Fig. 3.
Current and voltage curves obtained when interruption with inductive load and capacitive load

chamber varies depending on the rate of rise of recovering voltage which is built up between the two poles. It is affected by the phase of current and voltage, Fig. 3 showing their relationship.

Fig. 3 a) illustrates concerning the capacitive load while Fig. 3 b) is of inductive load.

In general fault current is mostly inductive current and current (I) lags at the maximum 90° to the voltage (U).

At the instant when the current diminishes to zero, the voltage between the poles alters from arc-voltage to the recovering voltage (U). In this process the voltage passes through oscillation transient of $f=\frac{1}{2\pi\sqrt{LC}}$ and becomes stabilized into system voltage. Whether an arc is re-generated on not is governed by the difference between the rising rate of restrike Voltage (Ur) to be built up and the rate of deionization of dielectric strength (Ud).

As for the capacitive load in Fig. 2 a) the change of voltage is fundamentally different from that of inductive load. In this case the voltage

(U) between the poles is the difference of (Uc)—the line voltage remained charged on the capacitor at the instance of automatic extinction of current (I)—and (Ug), the voltage on the side of power source which alters at a regular period. That is $U = Uc - Ug$.

The change of (U) in this case is much slower than that in the inductive load, and because current is charging current which is small. In such a chamber as the self-controlled chamber in which quenching action is affected by arc energy, the recovery of dielectric strength between the poles is slow and restriking of arc occurs before the recovery voltage (U) reaches the maximum.

In this restriking arc phenomenon, as shown in the drawing, when restrike voltage (U) occurs at the arc should be maximum value and restrike current disappear at a half cycle, the line side voltage (Uc) become theoretically rises 3 to 5 times as high as voltage (U), and it is required to allowable limit of the dielectric strength of the machine. Moreover, theoretically there should not be more than one restrike.

Judging from the results of experiments, this abnormal voltage in the self-arc-control type arc-quenching chamber is far lower than the one in the chamber of separately-arc-control type, therefore even if there occur more than one restriking, it never attain to such a degree to destroy the insulation of the apparatus.

It can be regarded negligible except for special cases. RF 650 B type expansion circuit breaker has solved this problem by its adoption of separately controlled chamber. It does not produce restrike phenomenon in the breaking of the charging current.

The main arc chamber for expansion circuit breaker is its expansion arc chamber. The arc qenching theory of this chamber is as follows Dr. Kesserling's theory of expansion arc quenching taking advantage of adiabatic expanison of high pressure gas of quenching fluid generated by arc energy has been more clearly explained by Dr. Zuhlke and Dr. Bierman, since 1952.

The temperature of A.C. arc column is 9500°K at the crest value, 4000°K at zero. The arc fluctuates within this range. The arc is not stabilized below 4000°K and disappears completely below 3000°K — this indicates that the important action for arc-quenching is to cool off the arc by all means. In spite of any method in this point of view it has been made clear by several experiments that the material which has a distinct arc-quenching characteristics is hydrogen. Fig. 4 shows the thermal conductivity in the gas of high temperature.

This drawing illustrates that hydrogen which has the largest conductivity at around 4000°K is the most effective as arc-quenching gas. Both Fig. 5 and Fig. 6 show the quenching process in the expansion chamber and (b) in Fig. 5 represents arc-column and flames. (c) is a gas envelope surrounding (b) and (a) cylindrical layer of quenching fluid overheated.

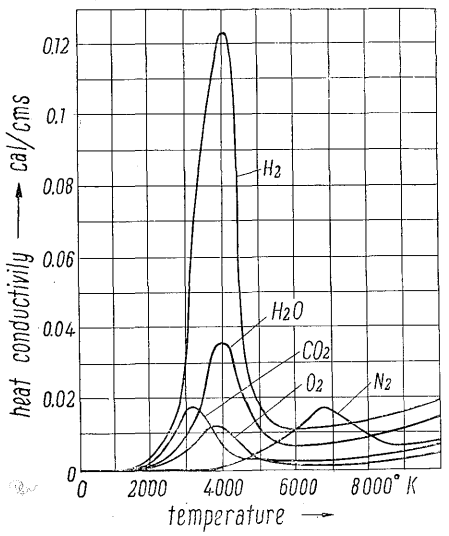


Fig. 4. Heat conductivity of gasses at high temperature

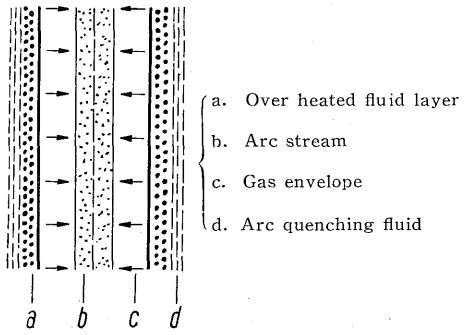
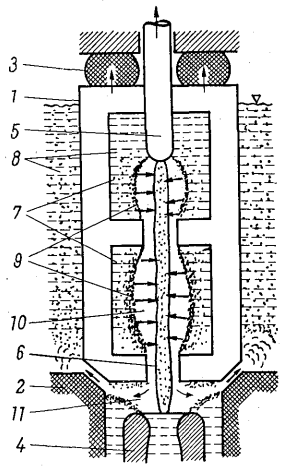


Fig. 5. Illustration of hydrogen effect

In the region of (c) there exist a number of atoms and molecules of hydrogen, which around the part (a) gather mainly molecules of the fluid.



1. quenching chamber
2. chamber seat
3. elastic ring
4. fixed contact
5. moving contact
6. arc stream
7. molecular of fluid
8. quenching fluid
9. over heated fluid layer
10. gas envelope
11. expand gas

Fig. 6. Extention of the arc in the elastic expansion chamber

The dissolution heat which is required for dissolving the fluid into molecules is not sufficiently acquired from the heat-conductivity alone of the part (c), but mainly supplied by radiation heat from the arc area.

The expansion chamber, as shown in Fig. 6, is closed by the pressure of inserted elastic members, where the arc has came in contact with quenching fluid brings forth high pressure gas.

The chamber is so constructed that, as the value of high pressure gas is accumulated up to a certain degree, the gas leaks out of chamber to expand itself.

The parts (a) (b) (c) in Fig. 5 are well balanced each other at their pressure and temperature ; however, when the chamber is opened by the uprising gas pressure and the pressure around the arc and gas envelope decreases rapidly, there occurs a steep pressure inclination between the gas envelope (c) and the arc area (b). According to this phenomenon the hydrogen atoms, molecules contained in the gas envelope and molecules on the surface of fluid permeate toward the center of arc with high speed.

In this case, if the value of the current is about zero, the supply of arc energy is insufficient, which makes the inclination much steeper; in other words, the de-ionization becomes near the perfect accomplishment.

This theory is hydrogen effect. Also the gas stored in the chamber escapes through the opening with high speed, so that the pressure in the chamber instantly drops, bringing forth efficient hydrogen effect. And at the same time the fluid particles and low temperatured steam jet penetrate into arc steam core providing effective cooling of the chamber.

Thus at the instant when the current passes the point zero the ionized particles between the poles are dissipated rapidly and the chamber regains dielectric strength.

Let's brief the above operation. In the expansion chamber if the current is more than a few hundred amperes the chamber itself opens the loopholes and quenches succesfully the arc by expansion effect, while against the lower current by hydrogen effect it interrupts the arc through averaging process of arc-length, from lower current to heavy.

By this explanation now it becomes well-understood that the fluid used as an arc quenching medium must be water or mineral oil which generates large volume of hydrogen.

Generally speaking, for the indoor-use circuit breakers with the capacity of smaller than 30 kV is employed the mixture of distilled water and glycol, a kind of fluid the so called "Expansion", and for out-door use type of more than 60 kV a little quantity of mineral oil.

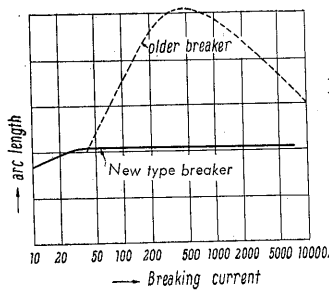


Fig. 7. Arc length versus breaking current for a new type expansion circuit breaker and for older breaker

The Fig. 7 shows the comparison of arc length between an older expansion chamber and a lately developed new type chamber. The reader will see in the new type that every arc length is almost equal. This is the most ideal characteristics obtained by the employment of both the improved expansion chamber and the oil-blast chamber.

The specification of type RF 650 B expansion circuit breaker is as follows :

a) Rating :

Rated voltage	80.5 kV
Rated current	1200 A
Rated frequency	50/60 cycles
Asymmetical rupturing capacity at rated voltage :	2500 MVA
Making current (crest value) :	45,000 A
1 second short time current :	60,000 A
Total breaking time :	0.1 sec
Duty cycle :	O–1 min–CO–3 min–CO or CO–15 sec–CO
Withstandable voltage test	
impulse (full wave)	440 kV (1.5 × 40 μs crest)
low frequency	180 kV (1 min.)

Heat run test and other tests in accordance with the stipulation of JEC-57 (Japanese Electro-Technical Comittee Standard) or ASA C 37.4–1945.

b) Operation system and particulars :

Closing	5–10 kg/cm^2 compressed air
Tripping	electric magnet
Trip free machanism	electrical and pneumatical
Closing time	0.25 sec.
Minimum no-voltage term on reclosing	0.15 sec.

c) Erection :

Concrete foundation or iron frame structure.

d) Oil quantity and weight :

Total weight of 3 phase sets circuit breaker included current Transformers, without oil 5050 kg.

Total oil for 3 phase sets circuit breaker included insulation oil for current transformer 950 *l*.

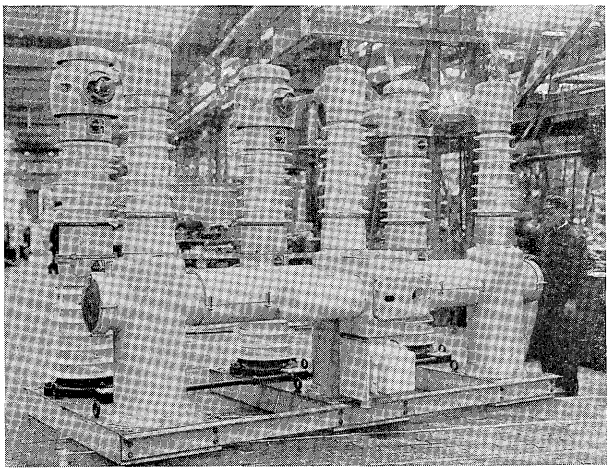


Fig. 8. Older expansion circuit breaker with air isolating switch rated 80.5 kV 1200 MVA 800A manufactured in 1933.

III. EXPANSION BREAKER DESIGN, CONSTRUCTION OF BREAKERS

Fig. 8 illustrates Type RF620 80.5 kV breaker first completed in 1934. In this primitive designed breaker there is an air isolating disconnecting part arranged in series and mechanically interlocked to the arc quenching chamber. This being a low oil breaker, voltage is made to be borne at the disconnecting part in an opening state of breaker in order to as if the carbonized sludge of oil stick to the surface of breaking chamber, do not cause the breaking down of insulation for recovery voltage between poles. This complicated mechanism, however, is not suitable to the high speed opening and breaking characteristics required the latest circuit breakers. For this reason, an improved type is made to have the breaking part in the oil instead of the old arrangement. This has become possible because of the fact that arc energy decreased by the improvement of arc quenching chamber, which reduced the formation of carbonized substances.

Fig. 9 shows a complete cross section of type RF 650 B unit. The breaking chamber is held by supporting insulators including a current transformer. The breaking chamber consists of a cross type oil blast chamber upper place and an elastic expansion chamber underneath. Two sets of moving contacts are simultaneously operated by a common insulating ladder. There two sets of chambers are so designed as to have enough potential distribution and insulation distance to withstand rated recovery voltage impressed on each set. An oil pump provided on top of the oil blast chamber blasts oil across the arc stream by means of a piston to be operated by spring force previously stored upon with opening operation of the breaker. In order to protect a porcelain vessel including the breaking chamber from internal pressure produced at the

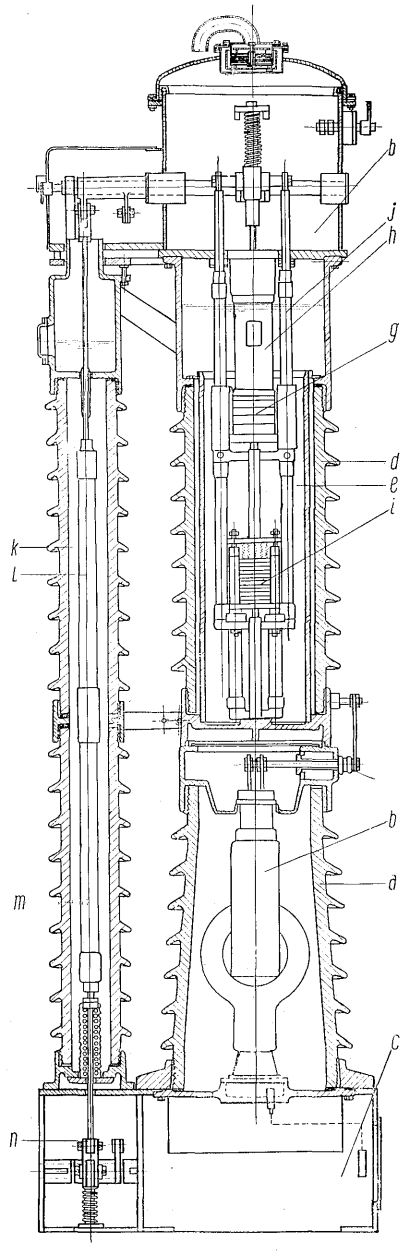


Fig. 9.
Sectional drawing of expansion circuit breaker type RF650B rated 80.5 KV 800 A 2500 M.V.A.

a. Supporting insulator
b. Current transformer
c. Base frame
d. Porcelain vessel of arc chamber
e. Insulating cylinder vessel
f. Expand gas vessel
g. Oil blast arc chamber
h. Oil pump mechanism
i. Expansion arc chamber
j. Insulating ladder with moving contact
k. Porcelain vessel for operating rod
l. Operating insulation rod
m. Oilseal bellows
n. Link mechanism to drive housing

instant of interruption, an insulating cylinder vessel made of " Repelite " is provided inside of it. For insulating material used for the arc quenching chamber, high grade material having resistance against arc is selected from much experience. Oil isolating disconnecting parts to bear line voltage impressed on between breaking contacts after interruption are formed by oil films existing when the moving contact come out of the quenching chamber. Arcing elements of the moving contacts and the tulip shaped fixed contacts employ copper-tungsten. On operating ladder working on the moving contact is operated by a mechanism in a breaker head house, and this mechanism is linked by a pneumatic drive kept at ground potential by an operating insulating rod. As shown in Fig. 9 the arc

chamber is in such a design as to facilitate the maintenance by lifting it as one body with the upper part of mechanism from the porcelain vessel. In general a rotating porcelain is used as an operating member in the place of an insulating rod in the case of porcelain breakers, but sufficent strength can not be expected from a long and slender porcelain column as an expansion circuit breaker and an insulating rod made of " repelite " is employed separately.

IV. CONSTRUCTION OF PNEUMATIC DRIVE HOUSING

The drive of expansion circuit breaker employ a pneumatic drive operated by compressed air of 5–7 kg/cm^2. The most important requisite of breakers is reliability of operation. The daily opening and closing operation has no bearing on the arc quenching ability to interrupt fault current, but failure of its mechanism affects greatly to the power supply. Therefore, in the course of development, great effort has been made in the construction itself or in the selection of materials.

Fig. 10 shows a vertical type pneumatic drive. It's drive housing is, as shown in Fig. 1, mounted on the supporting frame base of breaker. The drive is operated by compressed air of 5–7 kg/cm^2. Owing to the development of small compressor unit, the compressor set to be used for drive, it has been made smaller and in after made an individual supply to each breaker, being used placed inside the frame base. The foundation of breaker is of concrete or of iron frame work. When transporting the unit in divided state, the frame work can be shipped with the link mechanism and drive mounted on it, which dispenses with the trouble of adjusting the link mechanism in reassembling the unit at the site. Thus it is able to keep the condition of tests at the factory as it is, this method being, there, the most recommendable. However, the size of shipping package becomes bulky and transportation charges become expensive.

The tripping mechanism and trip free mechanism are the heart of driving, the relating being shown by the control diagram in Fig. 11. The mechanism bringing lock the breaker to the closing position

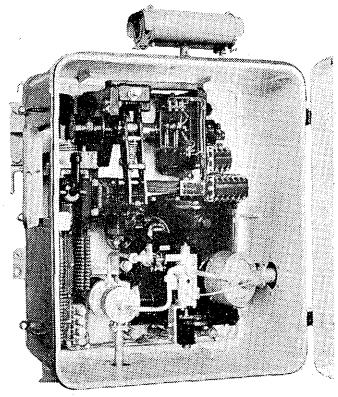


Fig. 10 Vertical type pneumatic drive for Expansion circuit breaker type RF 650 B and parts detail shown Fig. 11

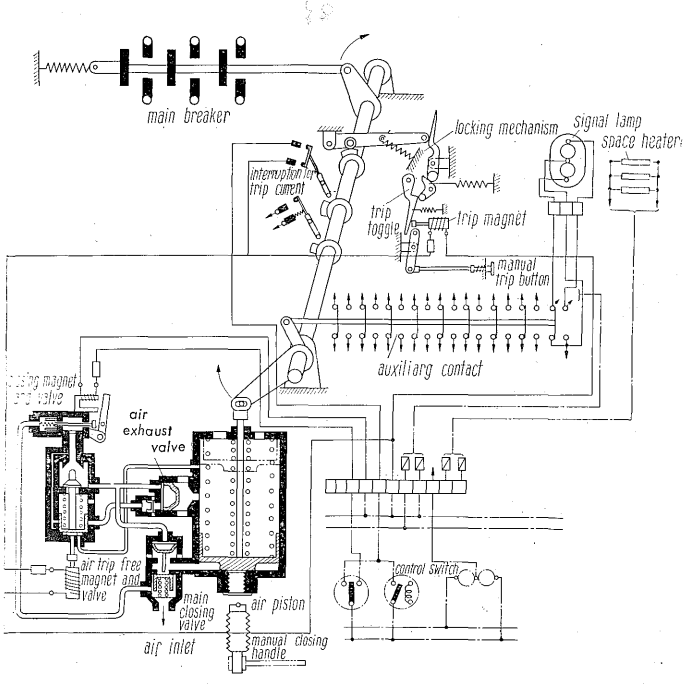


Fig. 11. Control diagram of expansion circuit breaker RF 650 B type in opening condition

is called an indirect system, which divides large breaking spring force by means of several steps of lever links and supports it by a tripping toggle at last. That is, if this toggle is released by hand or a magnetic plunger, these lever links are dismembered to open the breaker. Merit of this system is that none of members bear large localized load, resulting in no severe requirement on materials and high reliability in operation. The dead time which occupies the greater part of breaking time of breakers is influenced by this construction to a considerable extent. Hence, the determination of this mechanism has been done based on the results of thorough experiments.

The trip free mechanism is the one being situated between the link mechanism of breaker and the closing mechanism of drive. The trip free mechanism of direct type that is used in general, however, is not used for heavy duty expansion circuit breaker. When trip free operation is carried out by this method, a coupling which

dismember the mechanical relation between the closing mechanism of drive and the breaker link, is used. The use of this coupling, when the breaking spring force becomes large leads to a construction difficult to handle on account of the employment of high grade special structural materials, so it is taken up only for expansion circuit breakers of below 30 kV, and the air trip free mechanism is employed for heavy capacity breakers. In this method no dismemberable part as the above mentioned is used between the breaker link and closing mechanism. The trip free is a system in which air fed to the compressed air cylinder is rapidly exhausted by controlling the closing air valve and an air piston linked in series with the breaking link is reset to the initial position without disturbing the breaking speed of breakers. Thus, no special coupling is required for trip free and only a simple trip free air valve is used, which results in easy handling, high reliablity and welcome everywhere.

The construction of bearing parts is important in the mechanism that require speed characteristics of high speed operation. For this reason ball bearings are all used to the bearing parts.

As auxiliary contacts, type 9A9B are provided as a standard. A control circuit to the trip magnet is connected through 1A of these contacts and in quite important. In order to protect a relay that flows current to the circuit and contacts of control switch, operating current is interrupted with their contacts. In case of pneumatic drive, moisture contained in exhaust compressed air is liable to form rust in general, but in this drive exhaust in made outside of the housing and no trouble is experienced.

The low voltage auxiliary circuit has been improved to safty withstand the impulse voltage test of 7,000 V.

V. OPERATION

Each removable construction member of expansion circuit breakers is provided with an opening spring and each member starts simultaneously upon releasing the tripping toggle of drive, curtailing the dead time contained in the breaking time greatly. The closing is completed by operating force of the air piston which overcome these spring forces. The operation is made either by remote control from the switchboard or a direct action of the pneumatic device. The closing into live lines can not be made except by compressed air. Direct work in the drive is operated through direct manual handling of the air control valve. Since the manual operating handle is of screw drive, it can be operated only when adjusting the link mechanism. As a countermeasure of the failure compressed air source, it is recommendable to perform closing operation directly in the drive by replenishing gas (air or nitrogen) of necessary quantity, from a gas bomb previously stored, to a portable air tank having a closing device. The opening in done by pushing away the catch of magnetic toggle with a trip lever provided in the drive housing. The trip free mechanism of expansion circuit breakers is of air trip free method, and if the trip valve is locked at an operating position, compressed air is not fed to the cylinder ever though closing operation is made by mistake. Then the breaker does made any motion. For this reason, it is effectively utilized as a lock device of breaker in the reclosing control sequence.

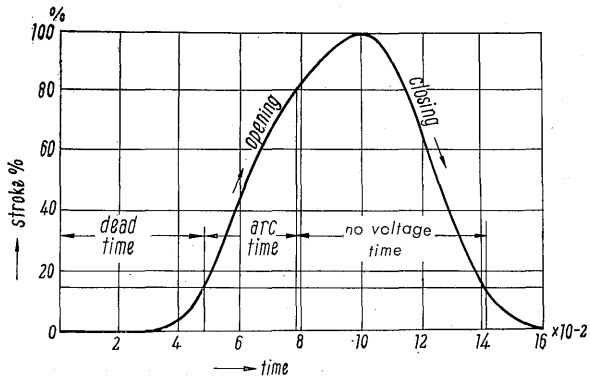


Fig. 12. Speed characteristic curve of expansion circuit breaker rated 80.5 kV 2500 MVA 1200 A

The latest progress in the transmission line engineering calls for constant and very short breaking and reclosing time to breaker. Fig. 12 illustrates closing-opening speed characteristic curves. The life of circuit breakers is greatly affected by absorption of breaking mechanical energy at an opening end. The curve illustrated indicates that the oil dash pot of drive in absorbing mechanical energy properly at the opening end. Also the fact that operating time is speedy, proves this breaker is operable, as it is, as 3 phase reclosing breaker when the requirement of no voltage term is under 8 cycles.

VI. TEST RECORDS OF EXPANSION CIRCUIT BREAKERS

The reliability of interruption of expansion circuit breaker has been testified by the results shown by experience in the field for past 20 years. But a 10 MVA short circuit generator is used at the factory to repeat research for future improvement. On the other hand field tests were repeated by using an actual network and expected results were obtained. Field tests obtained the maximum rupturing capacity in Japan were conducted at Himeji substation of the Kansai Electric Power Company

in 1946. These test recorded the maximum 1,070 MVA in 161 kV system, but they were carried out with a breaker having the same arc quenching chamber as that of 80.5 kV, completing interruption at 1–1.5 cycle arc length to testify superiority of the expansion chamber as well as obtaining much valuable information for the improvement of expansion breakers.

On the other hand, field test were conducted regarding abnormal voltage due to "Restrike" of current in the course of interruption of charging current and transformer exciting current which has been discussed as new problems of transmission line surges. The abnormal voltage due to this "Restrike" varies greatly by interrupting methods. In general, abnormal voltage is small as compared with a separately arc controlled chamber in a self controlled arc chamber like the expansion chamber, and there is an opinion that no special consideration is needed for special construction. But "Non Restrike" is desired as a general requirement as evident. It is specially demanded for the circuit breaker of cable system. Type RF650B type expansion breakers are designed specially to satisfy this requirement, Fig. 13 (a) (b) (c) showing the result of the field test, (a) that of experimental test proved by using static condensers at the factory. An improved chamber based on this result was used to conduct field tests in the actual network ; (b) is a test osciillogam of 60 kV oil cable feeders and (C) that of 80.5 kV overhead lines. Both tests proved no "Restrike" occurs and expected results are available.

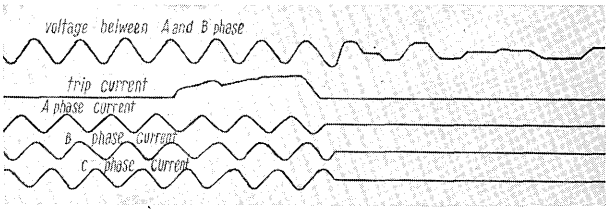
As to the reliability of structural parts, continuous making and breaking tests of 10,000 times were conducted in the presence of the customer, fatigue of materials and wear being carefully investigated.

VII. CONCLUSION

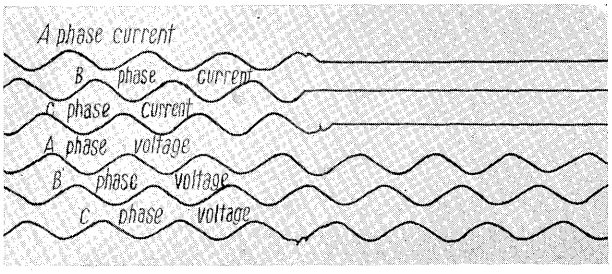
Fuji expansion circuit breakers which gave a birth in 1933 have been greatly improved through a successful history of 22 years. As a result, the latest 80.5 kV Type RF650B breaker has been completed as one of fruits.

The power source of transmission line lives is ever enlarging. The rupturing capacity of breakers is increasing in proportion to it and 80.5 kV 2500 MVA capacity is no longer enough. To cope with this situation expansion breakers provided with series resistance to limit current are now being built. In this new design, current is not interrupted in the expansion chamber but is transfered to resistance as its function.

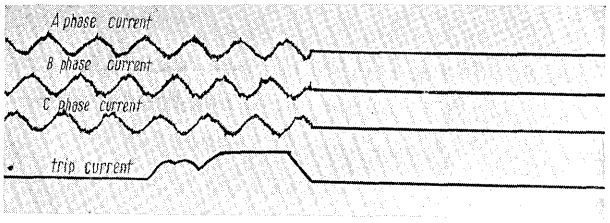
Excellent arc quenching ability of hydrogen effect and expension effect displayed by the expansion chamber has made possible of manufacturing 400 kV breakers as super high tension circuit breakers using self arc controlled chamber. They have been already completed by the Siemens Schuckertwerke ; we are also now about to completed 287 kV breakers. In 1931, we investigated the manufacture of air blast circuit breakers now regarded as representative units by using a separately arc controlled method. As a result we started to build expansion circuit breakers with a determination to adopt practieal and the most reliable self arc control method. We will further concentrate our effort in the improvement of these breakers.



a. 67 kV 52 interrupting (static condenser) tested on work's laboratory



b. 77 kV 20 A interruption tested on overhead 77 kV line of Kansai Electric Power Company



c. 69 kV 29 A interruption tested on oil cable 69 kV line of Tokyo Electric Power Company

Fig. 13. Current and voltage obtained by field test for capacitive load by expansion circuit breaker.