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SYNCHRONOUS ABB FOR ONE CYCLE INTERRUPTION DELIVERED TO KEELER SUBSTATION, BONNEVILLE POWER ADMINISTRATION, U.S.A.

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I. PREFACE

Fuji Electric's peculiar products, the synchronous air blast circuit breaker for one cycle interruption has actual running experience of longer than six years in the power system of 110–275 kV[1].

With the repeated improvements based on these manufactural and operational experiences, the large capacity circuit breaker was developed in 1969 as a main object for application to the extra-high voltage power system[2]. In this circuit breaker, distinguishing technology such as synchronous closing for suppression of closing surge is incorporated the technology of synchronous one cycle interruption for the purpose of improving the stability and reliability of transmission power systems which are now getting more and more complicated and expanded.

Fuji Electric has recently manufactured the 550 kV synchronous one cycle ABB and delivered it to the Keeler Substation of Bonneville Power Administration.

Since Bonneville Power Administration (hereinafter referred to as the BPA) was feeling difficulties in the maintenance of system stability with the conventional interrupting time, he has displayed much interest in the interrupting time of the synchronous breaker since its announcement of its development.

Moreover, BPA has so far been requiring to suppress the closing surge less than 1.5 times even in the 500 kV transmission as a key for establishing the insulation design of 750 kV and 1,000 kV transmission in future.

Fuji has developed the synchronous closing system by two stage resistor closing for suppressing this closing surge. BPA, appreciating these technologies, has recently placed a special order for the 550kV synchronous circuit breaker to Fuji Electric. BPA prescribes his own standards with respect to the construction and electrical performances besides the general ANSI Standards in procurement of the power circuit breakers. The circuit breaker designed and manufactured in conformity to the ANSI Standards and BPA's specifications has passed the strict design test of BPA and recently been forwarded to the site. The outline and test results for this circuit breaker will be described in this article.

II. RATINGS

Table 1 shows the ratings of this breaker. The ratings in this table are in conformity to the series of ANSI•C37, and some revision and addition have been made according to the specifications of BPA.

III. FEATURES

This circuit breaker has the following features in addition to the outstanding feature of one cycle interruption.

***Table 1* Ratings**

Type	RF792P/500/3000DS
Nominal voltage	500 kV
Nominal 3 phase interrupting class	38,000 MVA
Rated maximum voltage	550 kV
Rated voltage range factor (K)	1.10
Rated continuous current	3,000 A
Rated frequency	60Hz
Rated interrupting time	1 cycle
Rated short-circuit current at rated maximum voltage	37,000A
Rated permissible tripping delay	1 sec
Max. symmetrical interrupting capability for standard duty cycle of CO+15 sec +CO	41,000 A
Max. symmetrical interrupting capability for reclosing duty cycle of O+zero sec +CO	38,000 A
3 sec. short time current carrying capability	41,000 A
Closing and latching capability	65,000 A
Rated withstand test voltage	
Low frequency, dry, 1 min.	740 kV
wet, 10 sec.	660 kV
Impulse withstand	1,550 kV
Switching surge withstand	1,050 kV
Rated permissible switching surge	1.5
Rated operating air pressure, High pressure/Low pressure	40 kg/cm²/17.5 kg/cm²
Rated operating voltage	AC 240 V
Rated control voltage	DC 125 V
Standard duty cycle	O-zero sec-CO-15 sec-CO-3 min-CO
Applicable standards	ANSI C37, BPA's specifications No. EDS•20-04•3-04-24-70

(1) By the adoption of operating pressure of 40 kg/cm^2, the unit breaking capacity can be increased and thereby four interrupting point for 550 kV can be established.
(2) The operating pressure of 40 kg/cm^2 is used for the current interrupting section alone and that of 17.5 kg/cm^2 is employed for the other sections to make the best use of the conventional experience, thus the stability of operation being intended.
(3) The noise produced at time of operation has been considerably reduced by the adoption of such a construction that blast air against the interrupting sections is once reserved in a large tank to be gradually exhausted to the atmosphere afterwards.
(4) The construction is strong by the adoption of frame work made of supporting porcelain tubes.

Moreover, the circuit breakers manufactured this time have been more improved as follows.

(1) To satisfy the requirements of BPA's specifications, the synchronous closing has been employed for the purpose of suppressing the closing surge below 1.5 times.
(2) By achieving the improvement of the construction, the high speed and stable operating characteristics have been gained and thereby the synchronous closing accuracy has been raised.
(3) The current transformers for the synchronous interruption have been accommodated in the main body of breaker.

Details of these improvements are given in the following sections.

IV. COMPOSITION AND OPERATION

Fig. 1 shows the present circuit breaker under shop test and *Fig. 2* shows the outline.

This breaker consists of the main body of circuit breaker, the separately installed central operating housing, and capacitor potential device. Further, as accessories, AC power supplier and air compressor unit are included in delivery. The central operating housing box is furnished with various kinds of valves, pressure gauges, pressure switches, different kinds of switches and meters, etc. to perform normal operation and automatic reclosing operation.

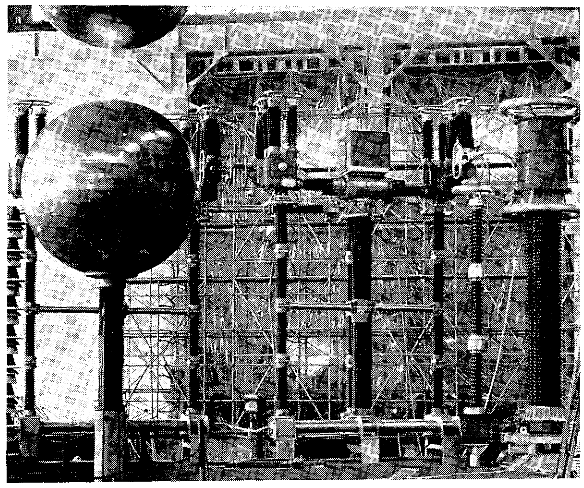


Fig. 1 550 kV synchronous ABB under tests

The main body of circuit breaker is not basically different from the conventional synchronous circuit breaker except the provision of two resistor closers for two stage resistor closing and mounting of a C.T. for synchronous interruption on the head of the breaker. With respect to operation, no difference exists in mechanism between both except some improvement has been intended, however a great difference exists in the electrical control section. The typical point which has been newly adopted this time will be explained below. The operation system is shown in *Fig. 3*.

1) Synchronous closing

The specifications of BPA requires to limit the

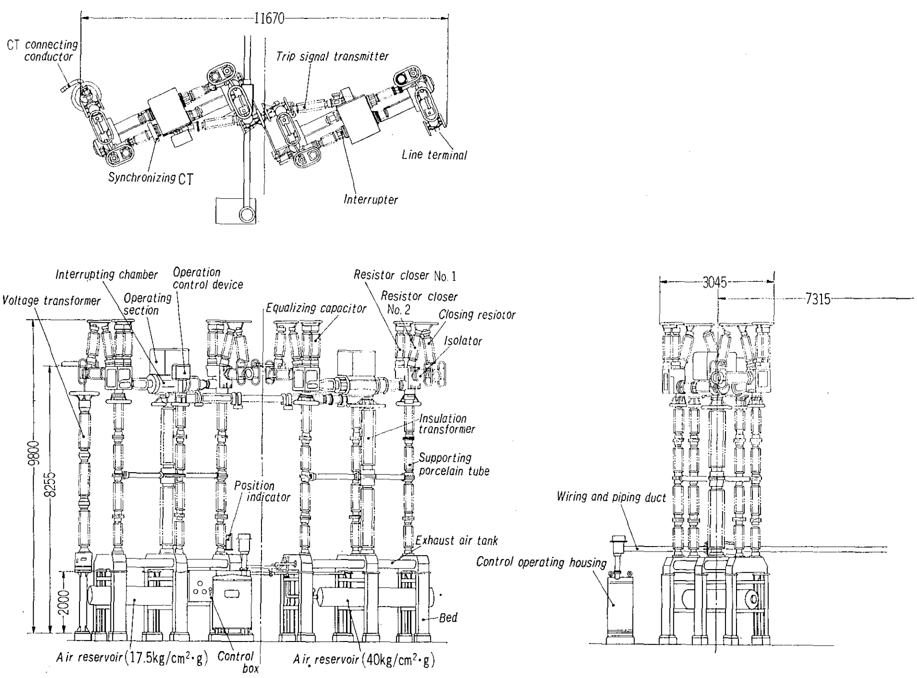
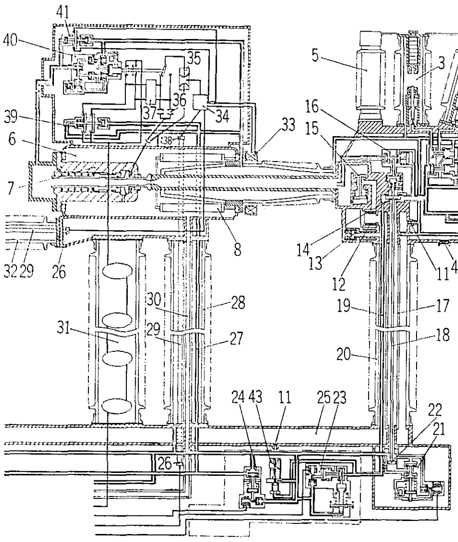


Fig. 2 Outline of 550 kV synchronous ABB (single phase)



1. Isolator
2. Closing resistor
3. Resistor closer No. 2
4. Resistor closer No. 1
5. Equalizing capacitor
6. Interruption chamber
7. Interrupter
8. Breaking resistor
9. Operation valve (Isolator)
10. Operation valve (Res. Closer)
11. Airing valve
12. Filter
13. Exhaust valve
14. Operation piston
15. Outlet valve
16. Lock valve
17. Air pipe
18. Pull rod
19. Air pipe
20. Supporting insulator
21. Closing valve
22. Balance piston
23. Aux. switch
24. Valve for quick recharge
25. Supporting frame (exhaust tank)
26. Photo pulse generator
27. Air pipe
28. Supporting insulator
29. Light guide rod
30. Air pipe
31. Insulation transformer
32. Signal transfer part
33. Synchronous C.T.
34. Synchronous device
35. Spark gap
36. Driving condenser
37. Charging device
38. Photo cell
39. Switch for quick recharge
40. Change over switch
41. Switch for demag. circuit
42. Silencer
43. Position indicator

Fig. 3 **Construction ot synchronous ABB**

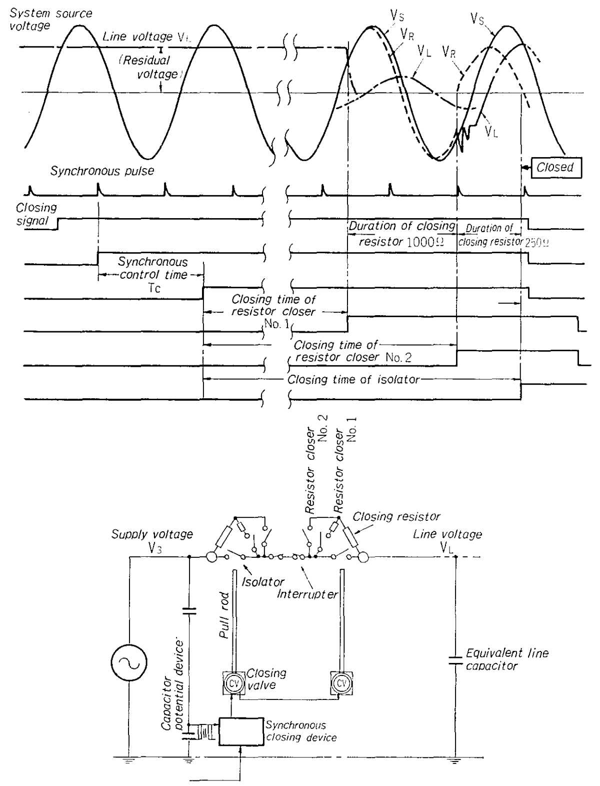


Fig. 4 **Principle of synchronous closing**

closing surge to a value of 1.5 times the source-side line-to-ground steady state voltage for at least 98% of random three phase operations under the specified line conditions and to 1.65 times for 99.85%. To satisfy such requirement, the two-stage resistor synchronous closing system has been adopted. This system is to insert the closing resistors in two stages and to short-circuit the second resistor synchronously. The suppressing effect on the closing surge with this system has already been described in another paper[(3)]. It has been cleared up as a result of examination that the requirements by BPA's specifications could be satisfied by changing the resistances, which to be inserted at closing stepwisely like 1000 ohm–250 ohm –0 ohm and controlling the short-circuit phase at time of changing to 0 ohm within ±2.9ms of optimum value. The phase angle at which the voltage between the terminals of closing resistor becomes zero, i.e., the optimum phase angle for short-circuiting the resistor is to be fixed to a certain phase angle of the source voltage depending upon the line conditions connected to the circuit breaker. Therefore, control of synchronous closing can be performed by detecting the phase angle of source voltage. This control is carried out by means of the synchronous closing control device installed in the lower portion of breaker. The synchronous closing control device has been manufactured based on the techniques of synchronous interruption control for which Fuji has hitherto actually much experience and therefore this control device has sufficient reliability. Further, a large number of printed board semiconductor circuits are used in this control device and accommodated extremely compact in the lower control box in unit system. *Fig. 4* shows a principle diagram of synchronous closing. The synchronous pulse synchronized with the specific phase angle of source voltage is usually being generated by utilizing the secondary voltage of capacitor potential device (PD). With a closing signal given, the closing valve is energized after a certain control time having a reference for the next synchronous pulse to start the closing operation.

The closing valve is attached on the balance piston under the operating rod of each unit. The condenser charged by the constant voltage power supply is discharged by means of a mercury relay and this discharge current is applied to four coils of closing valves to operate the closing valves. Accordingly, operation has been made extremely stable and operating time has been much shortened. If the lower portion of balance piston is applied with operating air through the closing valve, the rod is pulled up to convey the operation to the upper portion.

With respect to each contact closing time of resistor closer No., 1, resistor closer No. 2 and isolator, this is to be pneumatically controlled by each operation valve of the resistor closer and isolator and regulated so as to come to the specified resistor inserting time.

The synchronous pulse generation phase angle and the above control time are regulated so that the closing phase angle of isolator may come to a specific phase having a low closing surge. The control time is automatically regulated so as to keep the closing point within a certain permissible limit of error against a variety of changes of the service conditions. Moreover, the most careful consideration has been paid to elimination of affection given to the closing time such as pressure, temperature, operating conditions, intermittent operation, etc. to say nothing of curtailment of closing time and reduction of frictional force in the sliding parts.

2) Synchronous interruption control

The separately installed current transformers have so far been used to obtain the current of power system for the synchronous interruption. However, it has been very difficult to accommodate the synchronous current transformers in the ordinary current transformer tank owing to increase of short-circuit current, increase of time constant of its DC component, etc. This is due to that the waveform is liable to be distorted due to mutual effect of windings and that the size of current transformer itself becomes very large. In consequence, the mold type bushing current transformers exclusively used for the synchronous interruption have been developed and mounted upon the circuit breaker.

Owing to such dimensional restriction as to be accommodated in the breaker, a resistance-inserting means in CT secondary circuit has been adopted for minimizing residual magnetic flux stored within CT core every operation of current-interruption. As a result of this, the internal residual magnetic flux has suddenly reduced, thus making the sectional area of core small. Accordingly, there is highly accurate synchronizing even under 50 kA reclosing duty cycle. The incooperation of the CT does not change the basic operating principles of the equipment but there are comparatively major changes in the breaker control system from the conventional system. By this improvement, the synchronous circuit breaker has promoted to the higher grade making the best use of manufacturing techniques of semiconductor controls and running experience. *Fig. 5* shows a principle of synchronous interruption of the present circuit breaker.

It may be a great difference that the synchronous detecting section which was hitherto installed on the ground has been assembled in the head of breaker together with CTs. The conventional head portion of breaker had such functions as to convert the photo pulse for synchronous tripping into an electric signal, trigger the spark gap, discharge the operating condenser, and start the interrupting operation. By the latest improvement, the head portion must have such functions as to convert the trip photo-pulse into an electric signal, generate the synchronous pulse for synchronous interruption, trigger the spark gap, and transmit the photo-pulse for synchronous tripping to the another interrupting section connected in series. These functions are incorporated as an synchronous device to be mounted upon the head portion.

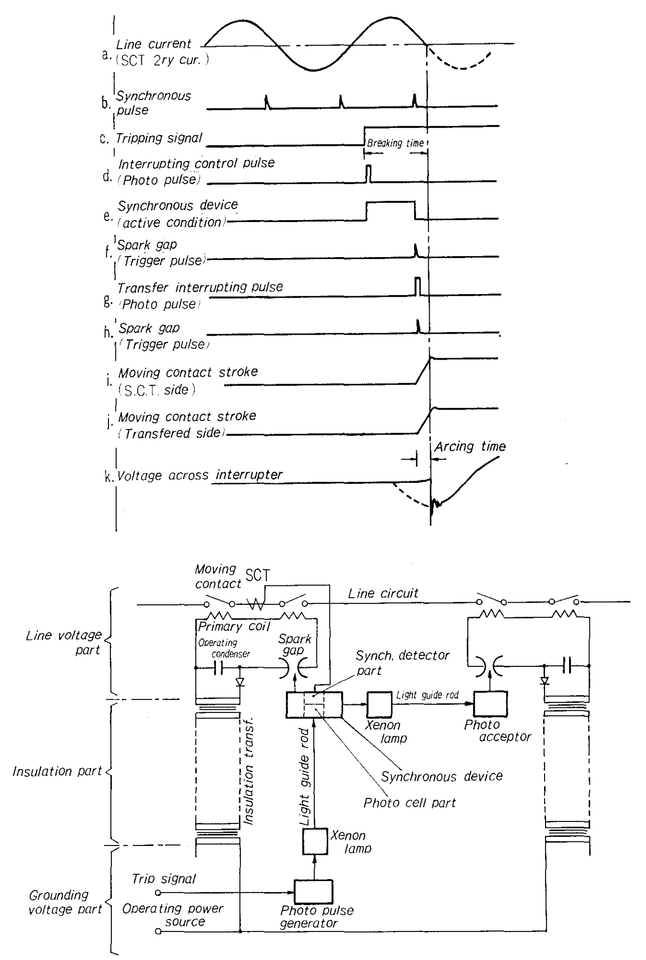


Fig. 5 **Principle of synchronous interruption**

The trip signal given to the breaker is converted into a photo pulse by the photo-pulse generator in the lower portion to be transmitted to the head portion. If the current flowing in the breaker exceeds a certain value, the synchronous device generates always the synchronous pulse at 1.5 ms prior to zero point of the current. However, the charged energy of condenser in the trip circuit which to generate the trigger pulse is always zero and the condenser is so composed as not to be charged until the photo-pulse is transmitted to the head portion. Upon receiving the photo-pulse at the head portion, the trip circuit is actuated by the next synchronous pulse to send trigger pulse to the spark gap. At the same time, trip photo-pulse is sent to the another head portion connected in series in the same phase from this head portion. This transfer photo-pulse is converted again into an electric signal by the photo-acceptor to actuate the spark gap as a trigger pulse. By utilizing this photo-pulse, each interrupting unit connected in series can be tripped off with almost no time difference by the synchronous pulse gained by one current transformer and one set of synchronous detecting device per phase. The transmission of photo-pulse to the another head portion is carried out through the light guiding rod installed inside the porcelain tube as in the connection between the lower portion and the head portion.

The porcelain tubes are so fabricated as to be free from the dimensions, considering errors in assembly and vibration due to earthquake etc. The mechanical operation of the present breaker after operation of the interrupting section is not different from that of the conventional breaker.

3) Re-charging of operating condenser

It is indispensable for interrupting operation of the present breaker that the operating condenser of condenser driving section has been charged at the specified voltage. That is, to fulfil the duty cycle, this condenser must have always finished the charging in that time. Naturally, the air pressure must have recovered to higher than the specified value. To fulfil the reclosing duty cycle "O"–0 sec–"CO" –1min–"CO", such method has so far been employed that two condensers are provided to be alternatively changed over in use at each interruption in "O"–0 sec–"CO" cycle and both condensers are charged in 1 min. for the last "CO". However, the duty cycle according to the BPA's specifications is "O"–zero sec –"CO"–15 sec–"CO"–3 min–"CO", and so recharging after O–CO operation is required to perform within 15 sec.

In order to prevent increase of the operating source capacity in the present breaker, an electric circuit is particularly installed for limiting the charging of condenser after operation of O–CO to one-condenser which is required for the next interruption, thereby performing recharging within 15 sec to satisfy the duty cycle required by BPA.

4) Low noise construction

Similarly to the conventional circuit breaker, the high pressure air used for blasting against the interrupter is not directly discharged to the atmosphere but reserved in the exhaust tank at ground side through supporting insulator thus gradually being discharged later. The air in the exhaust tank is once discharged in the cabinet through exhaust valve at the head portion and then passing through a silencer exhausted to the outside. Further, this silencer is also used as a discharge path of operating air for the isolator, etc. This construction has been accomplished due to the fact that the arc energy and air consumption are minimized due to the synchronous interruption, thus noise at time of operation being considerably reduced.

Furthermore, the exhaust air valve is normally closed to completely seal off the interior of supporting insulator. Air in the porcelain is constantly maintained a little higher than the atmospheric pressure and thereby penetration of water is prevented to secure the safety on insulation. It goes without saying that the breaker, being exposed to the open air during the shop test, has undergone the withstand voltage and flashover tests. As a result of these tests, it was ascertained the breaker was provided with a sufficient allowance.

V. ACCESSORIES

The present breaker is attached with current transformers, capacitor potential device, AC power supplier, and air compressor equipment beside the circuit breaker.

The capacitor potential devices are used for introducing the source voltage to the synchronous closing control device and therefore when utilizing those installed as substation equipments, they are not necessary. Further, the present breaker requires a stable AC operation source beside the operating air. Although the house power supply might be available as operation source, a non-interruption AC power supplier was delivered. Moreover, according to the contract, a high pressure air compressor equipment exclusively used for the breaker was manufactured and furnished. Because of the breaker operating pressure exceeding 40 kg/cm^2, the compressor was designed for the rated pressure 150 kg/cm^2. This compressor equipment consists of a compressor having working pressure 150 kg/cm^2, pressure reducing units to 40 kg/cm^2 and 17.5 kg/cm^2, air tanks, dryer, and other components. The AC power supplier and compressor equipment are of outdoor use and accommodated in an exclusive cabinet respectively.

VI. TEST RESULTS

The characteristics of this type of circuit breaker were already reported in Fuji Electric Review(2). BPA has prescribed his own severe testing specifications and various kinds of tests have been executed based on this specifications. These tests have been checked in details in the presence of BPA's inspector. As a result of these test, the breaker has successfully passed the BPA's exacting design test and thereby their functions have been verified. Here will be reported the main test results among the tests executed at that time.

1) Mechanical operation test

The opening time of this circuit breaker is 22 ms at time of no load. The breaker shows synchronous interruption when a current exceeding the rated current is flowing, and the opening time in such case is determined by the current phase at time of despatching the trip signal, however it is in general 1 ms at the minimum. On the other hand, the closing time, being also synchronously controlled by the closing control device, is 92 ms at the minimum.

The mechanically operating time after energizing the closing valve upto short-circuiting the resistors under the rated conditions of closing is 67 ms. This value shows a closing time for the two stage resistor closing system. The high speed closing with a closing time of 60 ms can also be performed for the requirements of closing surge below 2.0 times.

The operation tests were carried out in conformity to the standards of ANSI. In addition, BPA added the certifications of switching characteristics in the operation tests as shown in *Table 2*, for the purpose

Table 2 **Test schedule of mechanical operation**

No.	Item	Operation condition	Number of times of switch-operations
1	Simple switch operation, CO	Synchronous, rated	295
2	Simple switch operation, CO	Synchronous, rated	295
3	Reclosing switch operation, O–CO	Synchronous, rated	50
4	Reclosing switch operation, O–CO	Synchronous, minimum	10
5	Reclosing switch operation, O–CO	Synchronous, maximum	10
6	Duty cycle switch operation O–0.33 sec–CO–15 sec –CO–3 min–CO	Synchronous, rated	5

of verifying if or not the characteristics would change due to continuous switching operation, considering the speciality of this breaker such as synchronous closing and synchronous interruption. Beside these tests, the operation tests were executed under the service conditions variously changed.

As a result of these tests, we found that dispersion of the closing time of isolator, i.e. dispersion of the time required to short-circuit the resistors was ± 1 ms. As previously described, the permissible deviation for synchronous closing is ± 2.9 ms. Some electrical error produced by the closing control device must be taken in account, however it was ascertained that, even this error was included, the closing time of the breaker had a sufficient allowance for the above deviation.

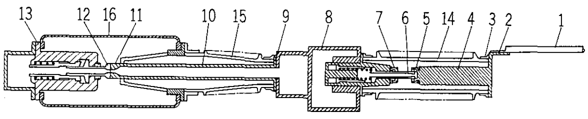
2) Heat run test

The circuit breakers having 2000 A rating and 4000 A rating have been so far manufactured as standard. As the breaker for BPA is rated for 3000 A, 2000 A rated breaker was reconstructed to raise it to 3000 A rating.

Fig. 6 shows the records of heat run test carried out using the contacts after mechanical operation tests. Since there is extremely little damage to the contacts due to the synchronous interruption, these value show very little difference between before and after the interruption test.

Table 3 **Dielectric test items and test voltages**

	Test item		Test voltage
Circuit breaker	Low frquency withstand voltage test	Dry	740 kV 1 min
		Wet	660 kV 10 sec
	Standard surge withstand voltage test	—	1,550 kV, each 3 times for negative and positive waves
	Switching surge withstand voltage test (※)	Dry	1,050 kV, each 3 times for negative and positive waves
		Wet	Same as the above
	Coordination test (※)	Impulse	1,750 kV (1,550 kV × 1.1)
		AC	814 kV (740 kV × 1.1, 2 sec)
	Visible corona test (※)	Dry	335 kV (normal line to ground voltage × 1.05)
		Wet	Same as the above
	Radio interference voltage test (※)	—	Same as the above
Porcelain bushing	Low frequency withstand voltage test	Dry	945 kV, 1 min.
		Wet	770 kV, 10 sec.
	Standard impulse withstand voltage test	Dry	1,800 kV



No.	Measuring	Temperature rise, °C	No.	Measuring	Temperature rise, °C	No.	Measuring	Temperature rise, °C
1	Conductor (1 m apart from terminal)	23	7	Slide contact	33	13	Flange	33.5
2	Terminal	20	8	Connecting frame	8	14	Porcelain enclosure (Isolator)	13
3	Flange	18	9	Flange	12	15	Bushing insulator (Interrupter)	15
4	Contact support	26.5	10	Conductor (middle)	42	16	Interrupting chamber	16.5
5	Fixed contact (Isolator)	37	11	Fixed contact (Interrupter)	46			
6	Moving contact (Isolator)	35	12	Moving contact (Interrupter)	44			

(Note) Room temperature: 22°C Carrying current: 3,000 A Charged air pressure: Interrupter 40 kg/cm²
Frequency: 60 Hz Current carrying time: 11 hours Isolator 17.5 kg/cm²

Fig. 6 **Results of heat run test**

Table 4 **Results of short circuit interruption tests**

Test condition	Duty cycle	Test voltage (kV)	Closing current (peak value) (kA)	Interrupting current (sym. value) (kA)	Arcing time (ms)	Transient recovery voltage: Initial peak value (kV)	Initial rate of rise (kV/μs)	Peak value (kV)	Time to peak (μs)	Delay time (μs)	Remark
Short-circuit	CO	—	118	41	1.5	—	—	—	—	—	Synthetic test
	15 s – CO	(114)	118	41	1.5	182	0.8	274	1,270	0	
	CO	—	—	41	1.5	—	—	—	—	—	
	0.33 s – CO	(114)	71	41	1.5	181	0.8	274	1,270	0	
	CO	21	117	43	1.5	—	—	—	—	—	Direct test
	15 s – CO	21	117	43	1.5	—	—	—	—	—	
	CO	126	12	5	1.3	—	—	309	247	—	
	15 s – CO	126	12	5	1.3	—	—	309	247	—	
	C	7.2	118	—	—	—	—	—	—	—	Tripping delay
	1 s – O	6.5	—	42	1.5	—	—	—	—	—	
SLF	O	(126)	—	38	1.5	※ 28	※ 2.2	—	—	—	※ TRV of line side
	O	(126)	—	31	1.5	※ 71	※ 2.1	—	—	—	
Out of phase	O	(166)	—	11	1.4	240	0.5	296	2,050	0	

(c. f) All the interrupting times are within a range of 0.5~0.8 cycles.
The breaker presented for test: Numbes of breaking points 1, operating pressure 40 kg/cm² & 17.5 kg/cm²

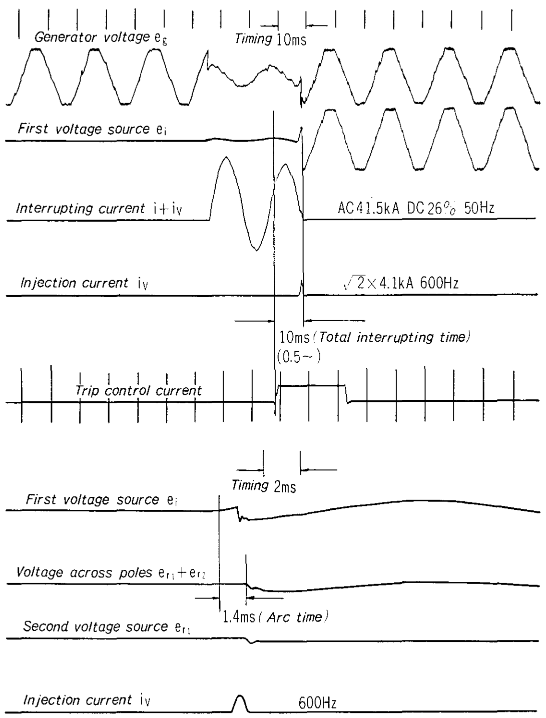
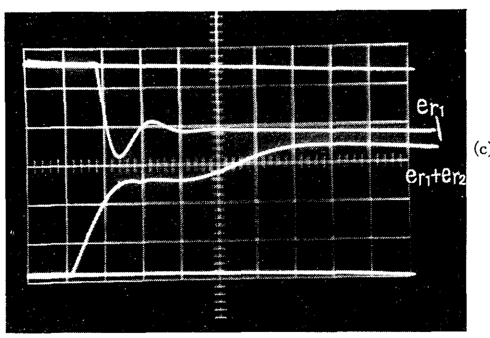


Fig. 7 **Oscillograms of short-circuit interrupting test (41 kA)**



Timing scale e_{r1}: 500 μs/div
$e_{r1}+e_{r2}$: 200 μs/div
u_1: 175 kV u_c: 252 kV
t_1: 210 μs t_2: 1,180 μs

Fig. 7 **Oscillograms of shost-circuit interrupting test (41 kA)**

3) Dielectric withstand test

Various kinds of dielectric tests were carried out according to the BPA's specifications as shown in *Table 3*. Successful results were obtained in the tests. The items marked with ※ in the table were executed for the circuit breaker being combined with current transformers.

Further, with respect to the insulation transformers and capacitive voltage transformers, the internal corona measurement has been executed upto the dielectric withstand test voltage after finishing all dielectric tests as the breaker, however no harmful internal corona appeared at all. Furthermore, for making sure of reliability for the semi-conductor circuits for the synchronous tripping, synchronous closing, etc. employed in this circuit breaker, specific tests by chopped wave voltage equivalent to BIL and impulse heavy current were performed for the circuit breaker under running. Even under this working conditions neither misoperation nor abnormality such as deterioration of characteristics of control elements were found at all.

4) Interrupting test

With respect to the interrupting characteristics of this circuit breaker, the performance of unit interrupting point for composing 300 kV two break circuit breaker was already verified in accordance with JEC and reported in the Fuji Electric Review[1].

As the interrupting tests in conformity to the standards of ANSI have recently been executed for the circuit breaker destined for BPA, these test records will be reported below.

The short-circuit test was carried out based on the requirements of ANSI C37-0722 and IEC17A.

The circuit breaker has been proved to provide a sufficient breaking capability as a result of direct tests at Takeyama High Voltage Power Laboratory in addition to the synthetic tests by Fuji short-circuit testing equipment.

Particularly as for the synthetic test, our specific three power source synthetic testing method has been developed for acquiring the transcient recovery voltage by 4-parameter indications in conformity to the standards' and thereby we have obtained successful results.

Moreover, the trip delay, i.e. interruption test with current continuation for one second after closing of short-circuit current has been executed, which has not so far been verified because this term is not specified by JEC. No thermal abnormality in the circuit breaker proper has been observed at all even under this condition. Further, no effect has been

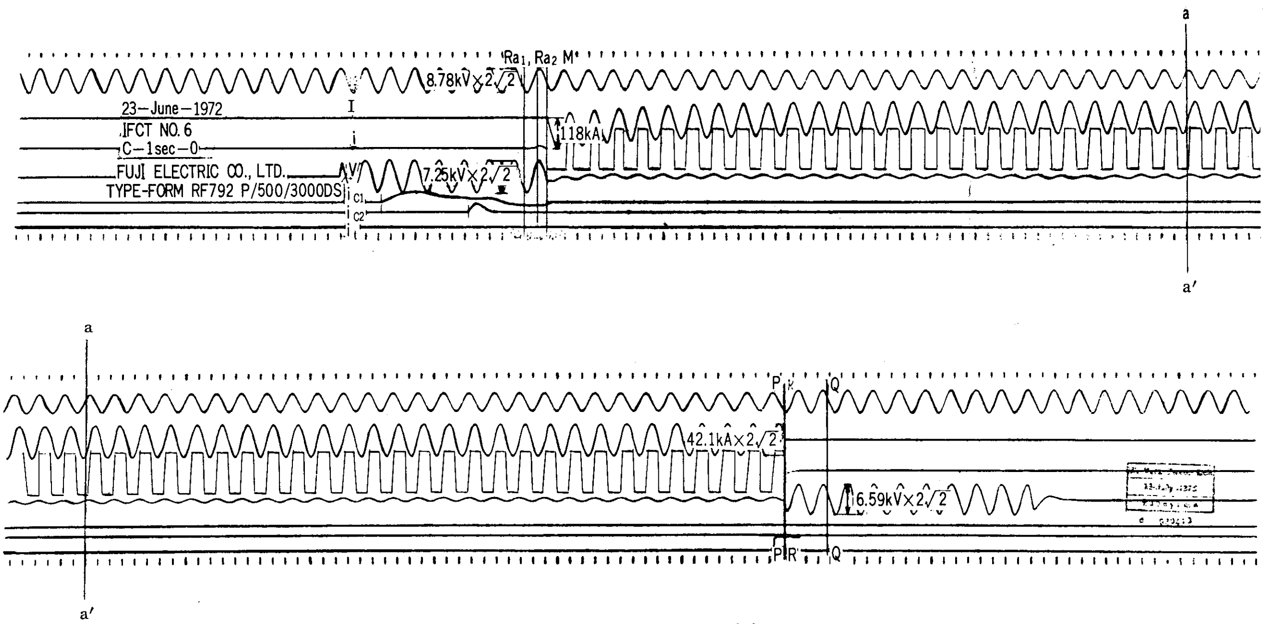


Fig. 8 Oscillogram of tripping delay test

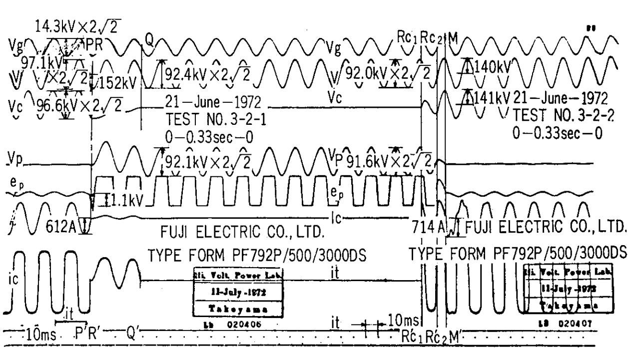


Fig. 9 Oscillogram of synchronous closing at HVPL

given to the synchronous CT, synchronous detecting device and so on, and the arcing time at time of current interruption has not shown any change, thus proving the high reliability of synchronus interruption. For reference, the short-time current test was executed with 3 sec current continuation, thereby confirming no abnormality was existent in the circuit breaker.

The results of short-circuit test are outlined in *Table 4*. The oscillograms of short-circuit test by three power source synthetic testing method and of tripping delay test are shown in *Fig. 7* and *Fig. 8*

Table 5 **Results of charging current interruption tests**

Breaking point	Operating pressure (kg/cm^2)	Duty	Test voltage (kV)	Interrupting current (A)	No. of times of restriks of arc	No. of times of reignition	No. of times of test	Remarks
1	40/17.5	O	92	120	0	0	6	Interrupting current: phase control of $\pi/3$
		O	92	460	0	0	6	
		O—C	92	460	0	0	2	Check of syn. close

respectively.

The charging current test was carried out with currents up to 460 A at the Takeyama Laboratory and no occurrence of reignition and restrike has been observed. At the same time as this test, verification for the synchronous closing has been made by operation of " O "—0.33 sec—" C ". As a result of this test, it was ascertained that the resistors were accurately short-circuited in the predetermined phase angle. The outlines of results of charging current interrupting tests are shown in *Table 5* and the oscillogram of synchrouous closing test are shown in *Fig. 9*.

5) Other tests

Beside the above tests, the no-load mechanical life test, cantilever test, noise test, etc. were executed. Moreover, as occasion demands life test, temperature cycle test, cold-resistance test, flashover test, and so forth were performed for each component part.

VII. CONCLUSION

BPA who had displayed much interest in the synchronous circuit breaker developed by Fuji's own technology, considering the effect given to the system by curtailment of interrupting time and also recognizing Fuji's technology for the severe closing surge suppressing specification, decided to adopt the synchronous circuit breaker. As so far explained, a variety of features have been added to this circuit breaker and its performance have been verified by numerous tests. BPA is now intending to execute the switching test, charging current interruption test, reclosing test, short-circuit test and so on as field acceptance tests by the use of his actual power system. We are confident that these field tests will successfully finish, thus the true merits of this circuit breaker being proved as expected by BPA.

Finally, we expect that the techniques for one cycle interruption and closing surge suppression by synchronous closing bestowed on this circuit breaker will fulfil an important role in the technical advancement of ultra high voltage system of 500 kV and further up to 750 kV and 1000 kV and at the same time we sincerely hope to give us your kind guidance for utilization and improvement of the same circuit breaker.

Reference

(1) Synchronous air-blast circuit breaker for one cycle interruption delivered to Hokuriku Electric Power Co., Inc. Fuji Electric Rev. Vol. 13, No. 4 1967

(2) 525 kV synchronous air-blast circuit breaker for one cycle interruption Fuji Electric Rev. Vol. 15, No. 5 1969

(3) Synchronous closing circuit breaker for one cycle interruption Fuji Electric Rev. Vol. 16, No. 2 1970