UDC 621. 316. 57. 064. 45

525 KV SYNCHRONOUS AIR-BLAST CIRCUIT BREAKER FOR 1 CYCLE INTERRUPTION

Yoshio Nitta

Nobuaki Kiyokuni

Kawasaki Factory

I. INTRODUCTION

As power consumption increases and manufacturing technology advances, many large power stations are constructed. These stations, however, are tending to be built in remote rural areas instead of in the urban centers where the demands are greatest but where lack of land, public hazard regulations and other such problems discourage such construction. The previous 275 kv systems are not sufficient for transmitting this large power output from the remote stations to the urban areas. Internationally, the trend is also toward high transmission voltages. In the United States, 550 kv is now being used and in Canada, the value is even higher at 750 kv. In Japan, 500 kv transmission will begin in a few year's time.

These new extra-high voltage systems must be more reliable than the previous 275 kv systems and the transmission capacity must also be improved. Therefore, the causes of faults within the lines must be eliminated, and if an accident should occur, it must be cleared up quickly.

In previous systems, the major cause of faults was lightning but in these new extra-high voltage systems, the large increases in transmission voltage will mean an even higher insulation level which will probably lessen the number of lightning faults considerably. However, there will be a big problem in providing sufficient withstand value against switching surge which occurs during transmission line switching, even though the insulation length is greater. Research into insulation characteristics for various types of gaps is proving to be highly revealing, and estimates of switching surge during operation are now possible by means of analyses using digital computers or transient network analyzers. Research is now being carried out into various methods of reducing surge magnification.

The time required for eliminating faults consists of the relay time, i.e. the time between the occurrence of the fault and the trip command, and the interruption time, i.e. the time between reception of the trip command by the breaker and the completion of interruption. Previously, these two times were about 3 cycles each for a total of 6 cycles. In terms of time, this is about 0.1 sec. However, efforts have been made to decrease this time in the extra high transmission lines in keeping with the higher reliability and larger transmission capacities. The new extra high voltage breakers are usually 2-cycle breakers.

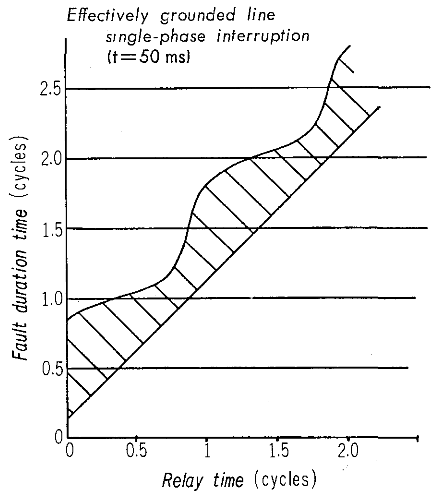


Fig. 1 Fault duration for single-phase interruption

In 1964, Fuji Electric completed a synchronous circuit breaker with a breaking time of 1 cycle, the lowest value that had ever been achieved.

The actual breaking time for this breaker is analyzed graphically in *Fig. 1* which shows the breaking time varies between 0.15 to 0.85 cycles in respect to the relay time. If the relay time in this figure is 1 cycle, the maximum fault duration time is 1.85 cycles, less than one-third of the former value. If the relay time is lowered to 0.7 cycles or less, the fault duration time can be decreased to 1.1 cycles or less.

At present, a high speed relay to much the capabilities of this breaker is being developed and details will be published soon. Combinations of these two devices can be said to be the ultimate in high speed breaker technology. Compared with the previous 3 cycle relay and 2 cycle breaker combination, high speed breaking with 1 cycle relay time and 1 cycle breaking time is a major step forward in transmission techniques since it allows for an increase in transmission capacity while reducing circuit damage.

Once the 1-cycle breakers were announced, they were used in 120∼300 kv power lines for over two years which proved their practicability. Based on this manufacturing and operating experience, a large capacity breaker was developed aimed mainly at 275 kv and extra-high voltages as mentioned previously.

This breaker besides having the shortest breaking time (1 cycle) so far developed anywhere in the world, also possesses the following features.

1) Increase in individual breaking capacity

In the previous models, 6 breaking points were needed at a pressure of 15 atm for a rating of 525 kv, 35 Gva. Raising the pressure to 40 atm and employing the synchronous breaking effect can disperse with 4 breaking points, and with only 2 breaking points for a rating of 300 kv, 25 Gva.

2) Two operation pressure systems

Increasing the individual breaking capacity requires the operating pressure to be raised to 40 atm. However, it is not necessary to increase the pressure to maintain the insulation of the open condition. Therefore, an operating pressure of 40 atm is not required for the entire breaker. It is designed with a pressure of 40 atm in the breaking section and 17.5 atm in the auxiliary breaking section.

3) Low noise

In the previous air-blast breakers, the air used for arc quenching was either exhausted directly or via a silencer. In this breaker, the arc energy is reduced by the synchronous breaking and the exhaust air is once stored in a tank on the ground side via insulators. This means that the air is exhausted very slowly and the operation noise can be decreased considerably.

4) Earthquake-proof construction

In devices used in extra-high voltage equipment, there is major problem concerning withstand to earthquakes. In this equipment, however, the framework including the noise prevention insulators described above provides high mechanical strength.

II. RATINGS

This breaker is divided into two breaking unit columns each representing two breaking point. Each

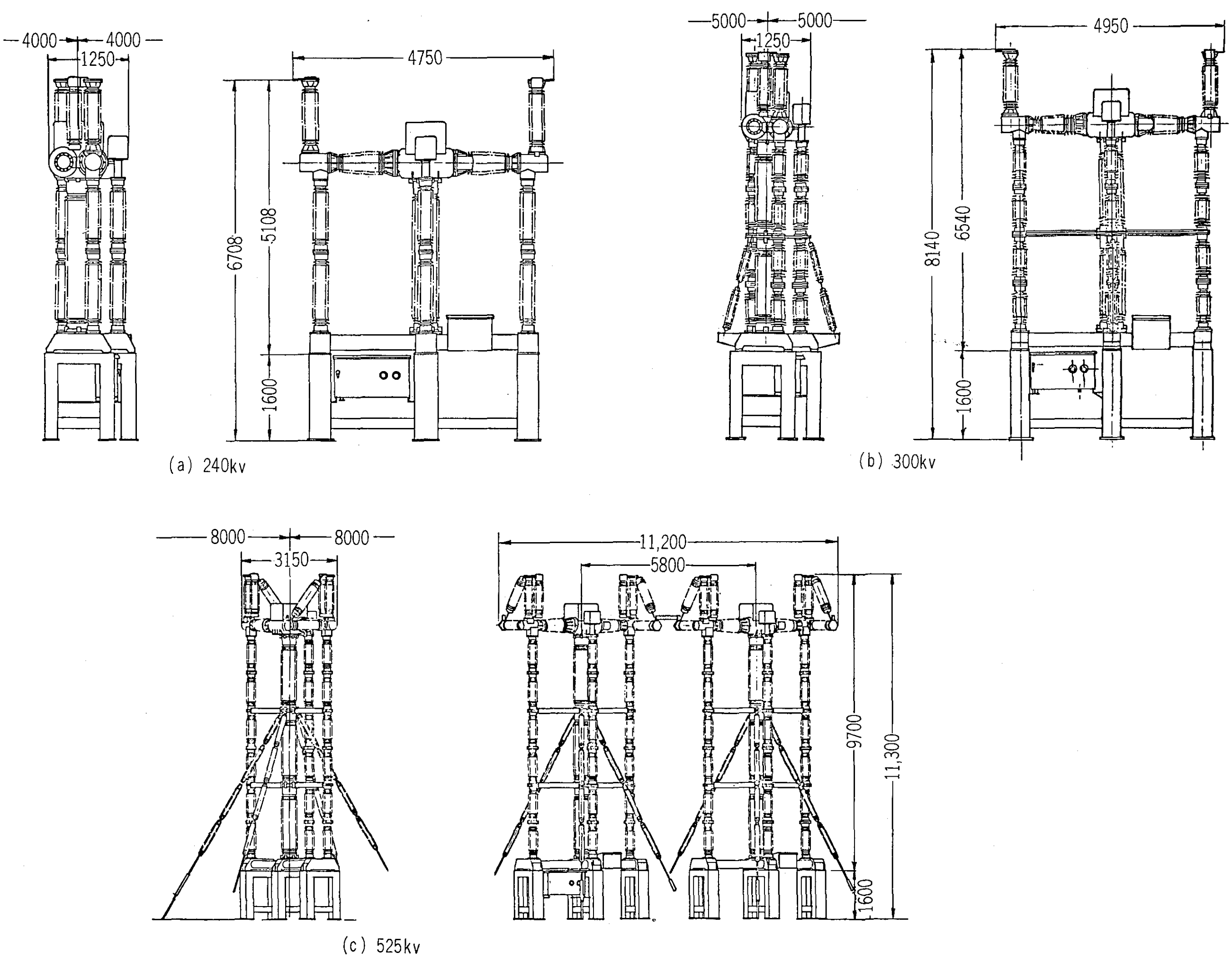
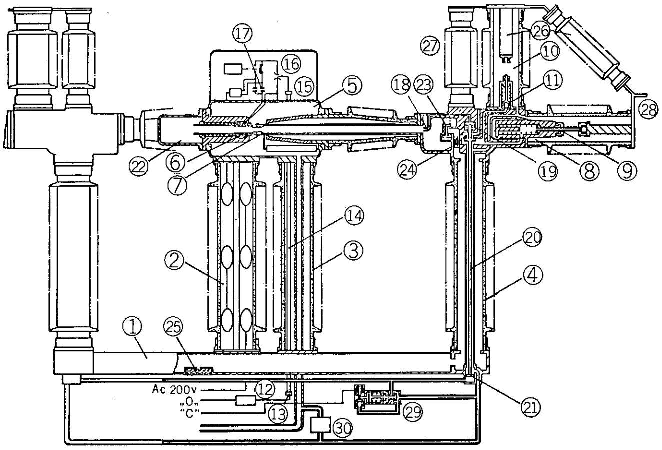


Fig. 2 **Dimensions of synchronous ABB's**

Table 1 **Ratings**

Model		RF792M/ 200/4000DS	RF792N/ 250/4000DS	RF792P/ 500/4000DS
Voltage	(kv)	240	300	525
Current	(amp)	2000/4000	2000/4000	2000/4000
Frequency	(Hz)	50/60	50/60	50/60
Breaking Capacity	(Mva)	20,000	25,000	35,000
Restriking Voltage	(kHz)	I, 0.4	I, 0.36	—
Closing Current	(ka)	131.3	131.3	110
Short Time Current	(ka)	48.1	48.1	40.5
Closing Time	(sec)	0.1	0.1	0.1
Breaking Time	(~)	1	1	1
Operating Pressure	(kg/cm^2)	40	40	40
Operating Voltage	(v)	200 ac	200 ac	200 ac
Control Voltage	(v)	100 dc	100 dc	100 dc
Withstand Voltage Dry 1 min Wet 10 sec	(ac) (kv)	395	460	805
Impulse	(kv)	900	1050	1800
Standard Duty Cycle		O—0.35 sec—CO—1 min—CO		



① Exhaust tank
② Insulator containing insulation transformer
③ Insulator
④ Insulator
⑤ Arc quenching tank
⑥ Movable breaking contact
⑦ Stationary breaking contact
⑧ Auxiliary breaking section
⑨ Auxiliary movable breaking contact
⑩ Resistance closing device
⑪ Movable contact of resistance closing device
⑫ Synchronous device
⑬ Photo-sender
⑭ Light guiding rod
⑮ Photo-acceptor
⑯ Trigger gap
⑰ Operating condenser
⑱ Detection nozzle
⑲ Operating piston
⑳ Pull rod
㉑ Balance piston
㉒ Air storage tank
㉓ Outlet valve
㉔ Filter
㉕ Silencer
㉖ Closing resistance
㉗ Voltage dividing condenser
㉘ Main circuit terminal
㉙ Closing valve
㉚ Decompression device

Fig. 4 Construction of synchronous ABB

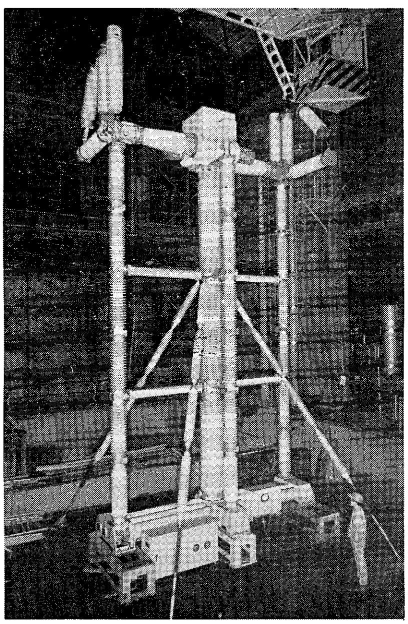


Fig. 3 One unit of 525 kv synchronous ABB undergoing operation test

of these units can be employed individually in the previous 275 kv lines. Rating required for 275 kv and extra-high voltage systems are listed in *Table 1* and the overall dimensions are shown in *Fig. 2*. *Fig. 3* shows a 525 kv unit undergoing an operation test. This unit is rather large in order to meet salt-contamination-proof in Japan.

III. CONSTRUCTION AND OPERATION

1. Construction

The operating principle of this breaker is the same as that used in former models, but a closing resistor and a resistance closing device in parallel with the auxiliary breaking section for suppression of the switching surge with extra-high voltages are provided as can be seen from *Fig. 4*. This figure shows an insulator with an insulation transformer, air feed pipe, an insulator having light guiding rods and two insulators for the resistance closing devices and the auxiliary breaking sections arranged on the insulator frame which also serves as an exhaust tank. These insulators and the bushings of breaking section form a Rahmen structure with a very high mechnical strength.

The main breaking section is located in the arc quenching tank on the upper part of the insulator with the insulation transformer. The arc quenching tank is normally under a pressure of 40 atmospheres. The tank only is maintained at this high pressure in accordance with the breaking requirements. The pressure in the auxiliary breaking section and the resistance closing device are decreased to 17.5 atmospheres via a decompression valve. With this type of construction, the 40 atmosphere pressure is present only in the several packings surrounding the movable contact and the stationary gasket in the 40 atm line. Almost all the operating valves are at 17.5 atm.

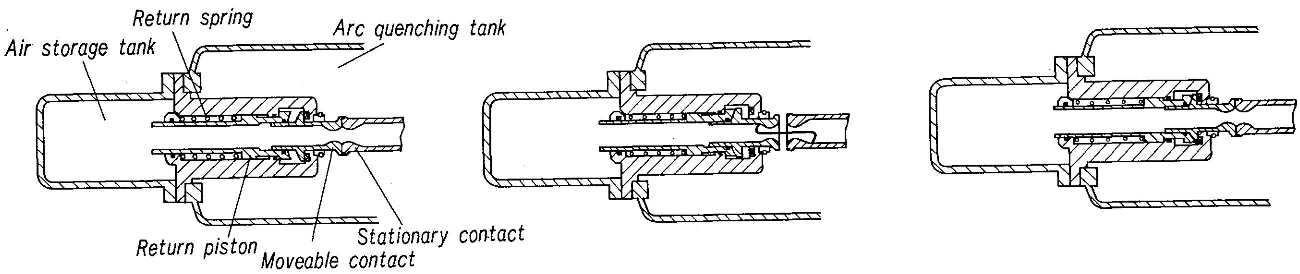


Fig. 5 Schematic diagram of breaking contact

This means that these breakers have the same stable operating characteristics as previous models.

2. Tripping

As in the previous synchronous breakers, when the trip command reaches the synchronous device a pulse arises which is synchronized just befor the zero point of the current flowing in the breaker, and this pulse switches on the photo-sender. The light ray passes via the light guiding rod in the insulator to the photo-acceptor on the high voltage side. Here it is reconverted into an electrical signal and makes the starting gap discharge. The movable contact is then opened by means of the charge stored in the operating condenser. Since this type of light ray is used in the trip system, even the support insulation in extra-high voltage breakers is higher, the command transmission time can be disregarded. One of the main features of this breaker is that the movable contact is opened about 100μs after illumination begins on the grounded side.

The arc which arises due to opening of the movable contact is quenched by a high pressure air blast in the arc quenching tank just after the current zero point. The air exhausted through the nozzles located in the stationary and movable contacts fills the air storage tanks on each of the down flow ends. As shown in *Fig. 5,* when the pressure in the tank on the movable side becomes equal to the pressure in the arc-quenching tank, the air blast ceases. After the auxiliary breaking section is opened as described later, the air is charged by a piston with a time delay and the movable contact is closed again by means of the return spring. After this, the discharge valve in the air storage tank on the auxiliary breaker side is opened and the high pressure air from the two storage tanks is discharged into the exhaust tank on the grounded side via a filter and the insulators. The air in the tank on the movable contact side is exhausted via the nozzle in the contact and the return piston is restored to its original position by the pressure of the air inside the arc quenching tank. The air in the exhaust tank is discharged to the exterior via a silencer over a period of several seconds

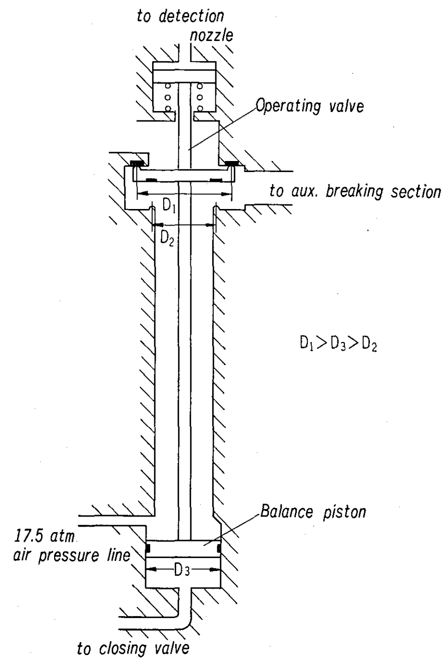
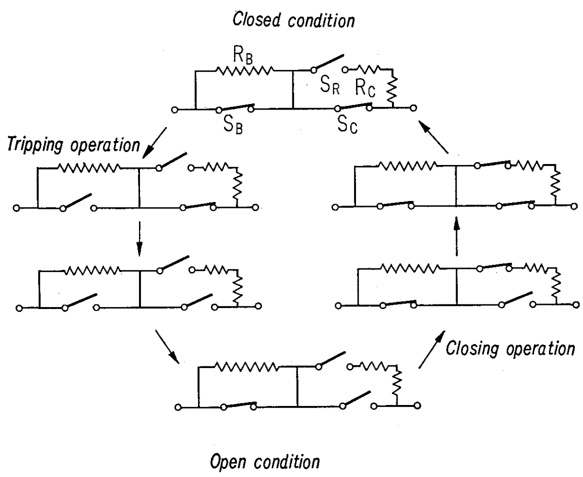


Fig. 6 Constructicn of pull-rod

so that there is almost none of the impact noise usually found in air blast circuit breakers. Since there is some residual pressure in the exhaust tank during high speed reclosing, the volume of the exhaust tank is selected so that this residual pressure will not influence the breaking capacity. This type of construction can be developed by the following conditions: there is almost no arc energy even during interruption of short-circuit currents because of the synchronous breaking, and the air blast period is also very short.

One portion of the blasted air on the stationary contact side is supplied to the upper piston in the auxiliary breaking section operating valve on the upper part of the pull rod through the detector nozzle in the air storage tank inlet on the auxiliary breaking side. The pull rod which is being held up by the air pressure difference between D_1 and D_3 is pulled in the downward direction by the air pressure which moves the balance piston when the pressure



SB: Main breaking contact
SC: Auxiliary breaking contact
SR: Resistance closing contact
RB: Parallel resistance for interruption
RC: Closing resistance

Fig. 7 **Standard operating process**

inside the operating valve is balanced by the air pressure from the detector nozzle. When the air charging is switched to exhaust in the operating valve of the auxiliary breaking section, the air behind the movable contact is exhausted and the air pressure opens the contact. The air blast in the breaking section is led directly to the operating valve and the time between the opening of the breaking section by the pull rod to the opening of the auxiliary breaking section is about 30 ms, 20 ms lower than in previous models. The relation $D_3 > D_2$ is selected so that the pull rod will be stopped in its downward movement if the pressure in the breaking section storage tank is exhausted through the discharge valve and there is no air in the upper part of the operating piston.

3. Closing Operation

The closing operation proceeds as follows. The operating air is sent to the lower part of the balance piston in the lower part of the pull rod by the closing valve, the pressure acting on the balance piston to move downwards ceases, the rod is pulled upwards by the pressure in the operating valve and operating air is sent to the auxiliary breaking section and the resistance closing device. This operating air first raises the piston in the resistance closing device and the resistor is connected in the circuit. Then the resistor is shorted by closing auxiliary breaking section with a time delay. After this the contact of the resistance closing device is opened by spring tension and this open condition is maintained until the next closing operation.

By utilizing the pull rod, the closing time in this breaker is reduced to less than 0.1 sec although it is an extra-high voltage breaker. If closing valves are provided in each of the balance pistons and one part of the auxiliary breaker construction is altered, a high speed closing breaker with a closing time of about 0.05 sec is possible.

Fig. 7 shows the contact arrangement and time coordination during closing and tripping.

IV. CHARACTERISTICS

The various characteristics for this breaker are as follows.

1) Operating characteristics

A typical example of the operating characteristics

Table 2 **Operation Characteristics**

Tripping Operation				Closing Operation			
Operating pressure (kg/cm²)		Control voltage (v)	Opening time (sec)	Operating pressure (kg/cm²)		Control voltage (v)	Closing time (sec)
H. press. side	L. press. side			H. press. side	L. press. side		
44	15	125	0.026*	40**	19.3	125	0.084
40	17.5	100	0.026	40	17.5	100	0.083
34	19.3	60	0.026	40	15	75	0.081
44	19.3	60	0.026	40	19.3	75	0.085

* No load opening time: decreased to a minimum of 0.0015 sec when current is flowing

** Since the closing operation has no relation to the high pressure, the high pressure value is maintained at the rated value.

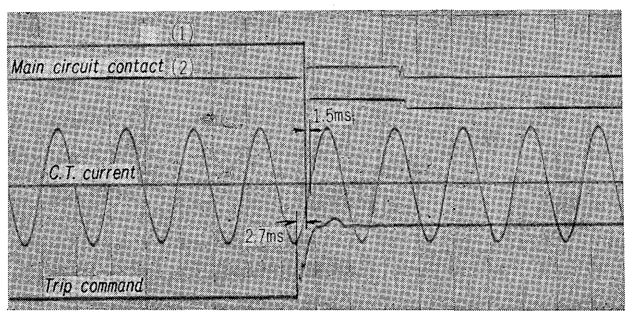


Fig. 8 **Oscillogram of synchronous operation**

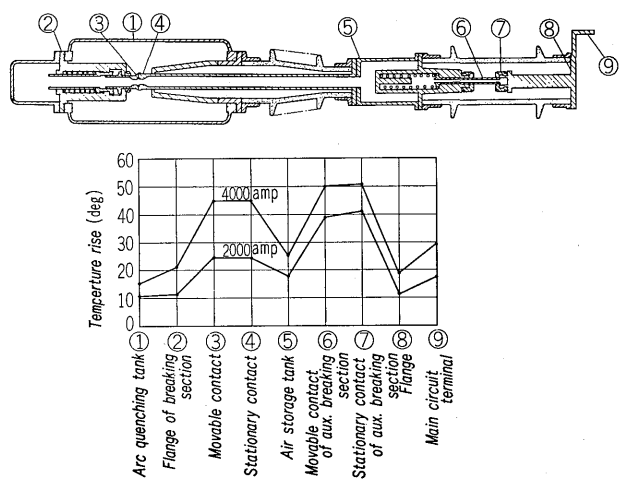


Fig. 9 **Results of heat run test**

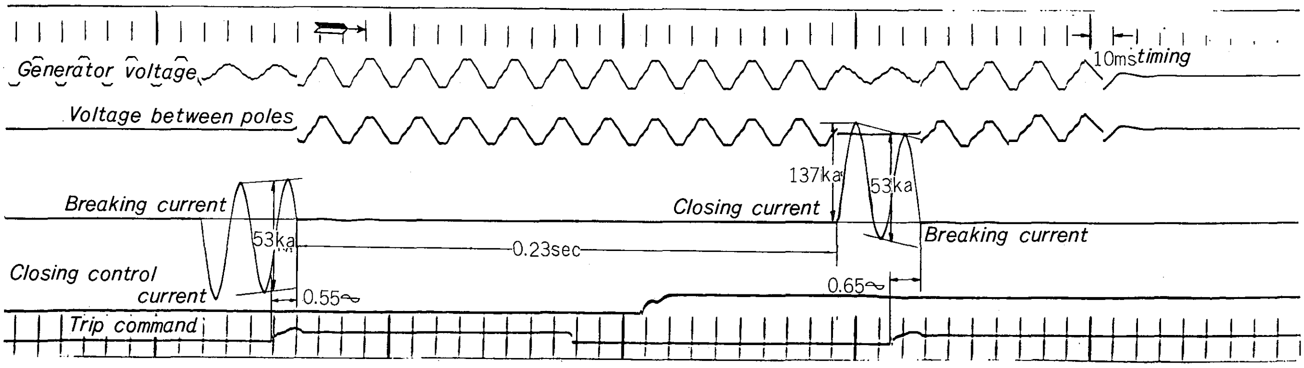


Fig. 10 Oscillogram of high speed reclosing duty

Table 3 **Results of Interruption Tests**

Test Conditions	Operation	Number of Breaking Point	Operating Pressure (kg/cm²)	Test Voltage (kv)	Breaking Current (kv)	Arc Time (ms)	Breaking Time (cycle)	Restriking Voltage Frequency (kHz)	Restriking Voltage Peak Value (kv)	Test Circuit
Short-Circuit	O-0.25 s-CO	2	40/17.5	210	1.9	1.5	0.5~0.6	4.35	382	Actual load
	O-0.25 s-CO	2	40/17.5	11	53	1.65	0.55~0.65	7.9	29	Actual load
	O	1	34/15	approx. 103	46.6~52.5	1.4~1.8	0.4~0.47	2.58	190~200	Equivalent circuit
	O	1	34/15	approx. 112	37.8~41	1.7~1.9	0.38~0.52	6.7	220~230	Equivalent circuit
	O	1	34/15	approx. 115	18.9~20	2.1~	0.42~0.57	7.5	220~230	Equivalent circuit
Out of Phase	O	1	34/15	approx. 127	11.5	1.8	0.48	1.98	343	Equivalent circuit
SLF	O	1	34/15	approx. 105	40.1~40.8	1.46	0.44	52.3*	23*	Equivalent circuit
	O	1	34/15	approx. 98	34.3~35.4	1.65	0.41	20.5*	51.3*	Equivalent circuit
	O	1	34/15	approx. 105	26.8~27.4	1.56	0.45	9.65*	93.6*	Equivalent circuit

* Value of restriking voltage on line side

is given in *Table 2*. The opening time under no-load conditions is 0.026 sec because of the delay time circuit, but when current is flowing in the synchronous device, the poles are opened by synchronizing with the current zero point and the opening time reaches a minimum of 0.001 sec. *Fig. 8* is an oscillogram of an operating test carried out with current flowing in the CT circuit. The contacts are opened at 0.0027 sec after the trip command and the synchronous time (time before the current zero point) is 0.0015 sec. A high speed reclosing time of 0.25 sec is possible.

2) Current carrying characteristics

In this breaker, the materials used in the current conducting parts and the arc quenching tank differ for ratings of 2000 amp and 4000 amp. The results of heat run tests carried out for each of the ratings showed a temperature rise in the contacts of 41°C for the 2000 amp rating and 50°C for 4000 amp. The temperatures in each of the parts are shown in *Fig. 9*. There was almost no difference in these values before and after the breaking test since there was very little contact damage because of the synchronous breaking.

3) Insulation characteristics

Since the test equipment was under repair, tolerances for the withstand values required in each section were considered. The insulator containing the insulation transformer can withstand ac 325 kv and an impulse of 750 kv per unit. At 525 kv, the required withstand voltage is obtained for 3 levels. The auxiliary breaking section and the resistance closing device can withstand ac 250 kv and an impulse of 600 kv per point. The required withstand voltage was obtained at 4 points.

In addition, it was also confirmed that no internal corona occurred in the insulation transformer up to ac 200 kv per unit and also a chopped wave test not included in the Japanese breaker regulations revealed that there were no internal potential oscillations.

After current interruption, the air blast from the main breaking section is conducted via the auxiliary breaking section insulator to the exhaust tank on the ground side. It was feared that this might have some influence on the inner surface of the insulator. The short-circuit test was repeated without the filter and insulation test was performed with one of the insulators after short-circuit current breaking of a total of 1000 ka or over. The results of these tests confirmed that there was no change in insulation characteristics befor and after the short-circuit test with no flash over even at 300 kv per one insulator. This results is obtained because the arc energy during synchronous current breaking is extremely low, only a small percentage of that in usual breakers. Therefore, this feature is possible only in a synchronous type breaker with such a construction.

4) Breaking characteristics

With the 525 kv, there are 4 breaking points but with the 300 kv rating, there are 2 breaking points for each unit so that breaking characteristics for individual breaking point are required to fulfill these two conditions. Tests were carried out with both actual load circuits and synthetic circuits. The range in which the breaking phenomena are determined by thermal breakdown near the current zero point was tested by means of a Weil synthetic circuit and an SSW synthetic circuit was employed for verification of the insulation breakdown region where the peak value with the Weil circuit was not quite sufficient. The results of the test are outlined in *Table 3* and an oscillogram for high speed reclosing is shown in *Fig. 10*.

5) Salt contamination characteristics

With the insulator containing the insulation transformer and the air feed pipe insulator arranged in parallel, tests were performed at each unit. The withstand value was 160 kv for a salt deposit of 0.03 mg/cm^2 and 130 kv for 0.06 mg/cm^2. For a rating of 525 kv, there was sufficient withstand up to a satisfactory phase voltage with one line grounded at a deposit of 0.03 mg/cm^2, and in respect to the normal phase voltage for 0.06 mg/cm^2.

6) Operating noise characteristics

As was described previously, the air blast at the time of interruption is not discharged directly to the exterior. After being stored in the exhaust tank, it is discharged gradually. Therefore, even with the high pressure of 40 atm, the operating noise per one interruption unit of this breaker is only 93 phons at 10 m, an extremely low value. The operating noise characteristics are shown in *Fig. 11*.

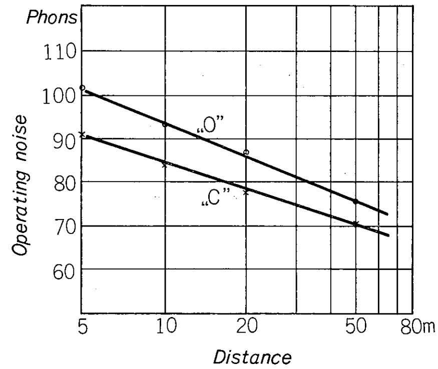


Fig. 11 Results of noise test

V. CONCLUSION

The 1-cycle breaker developed by Fuji Electric attracted immediate international attention because of its short breaking time. These breakers have already been operating in 300kv systems for over 2 years with no problems whatsoever. On the basis of this experience a new large capacity breaker has been developed incorporating a host of features.

The breaking time is shortened, the fault duration time is decreased but relay time has ultimate limits. In order to get the most out of these 1-cycle breakers, Fuji Electric has been developing a 1-cycle relay. Recently success was achieved and details will be published soon. By combining the 1-cycle breaker and the 1-cycle relay, it will be possible to achieve a fault duration time of 1.5 cycles. As this is expected to advance the technology of extra high voltage systems, it is hoped that this development will serve as a guide to all those working in this field.