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NEW SERIES OF OUTDOOR AIR-BLAST CIRCUIT BREAKERS

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I. INTRODUCTION

Since 1960 Fuji Electric has been independently developing air-blast circuit breakers and successfully held an exhibition of RF 720 type air-blast circuit breakers in the fall of 1964, inviting all parties concerned. In the RF 720 type air-blast circuit breaker, the Fuji Electric nozzle packing system is applied to the continuously-pressurized type air-blast circuit breaker. It is obvious from international trends in related industries that this system is the last word in air-blast circuit breakers.

Type tests held by all electric power companies in February 1967 proved highly satisfactory. During this time, a series of RF 720 type cicuit breakers was completed covering each step in the 72∼204 kv range. More than one hundred of these circuit breakers have been manufactured so far. At about the same time as the RF 720 type series (30 ka class) was completed, a 84 kv unit of medium capacity with a breaking current of approximately 20 ka was beginning to be developed. This would seen to be a reversal of the trends toward large capacity and high pressure circuit breakers. However, among general users who mainly require circuit breakers of medium capacity, there is a tendency to arrange switchgears of the 60/70 kv class indoors or underground so as to eliminate various problems concerning noise, salt damage, increases in land prices etc. To cope with these problems, Fuji Electric has developed and put into production an RF 725 type air-blast circuit breaker of medium capacity which is compact, light-weight, easy to handle, and available in a cubicle-housed draw-out model. In the RF 725 type circuit breaker, practical performance is fully considered on the basis of the special Japanese engineering techniques by which the RF 720 type air-blast circuit breaker was developed.

With the development of the RF 725 type air-blast circuit breaker, Fuji Electric's outdoor air-blast circuit breakers for 72 kv or above now consist of two series: the RF 720 and 725. The constructions, performances, and test results of the RF 725 type air-blast circuit breaker will be introduced here.

II. NEW SERIES OF OUTDOOR AIR-BLAST CIRCUIT BREAKERS

1. Features

Outdoor air-blast circuit breakers have the following characteristics in addition to the advantages of conventional continuously-pressurized types.

1) Continuously-pressurized system using nozzle packing

In air-blast circuit breakers, a high blast pressure is very important for good breaking performance. The blast method is of two types: the "instantaneous blast" and "continuously-pressurized" systems. In the "instantaneous blast" system as shown in *Fig. 1*, the contacts are opened by blowing compressed air into the arc extinguishing chamber from an air reservoir. Only 60∼70% of the rated pressure is used in the initial blast to open the contacts.

The "continuously-pressurized" system is, as can be seen from *Fig. 1*, subdivided into the "exhaust valve" and "nozzle packing" systems. In the former, the contact is opened by discharging compressed air into the nozzle through the released exhaust valve. In this way compressed air is blasted between the contacts. However, 100% of the reservoir pressure can obviously not be utilized. In the latter system,

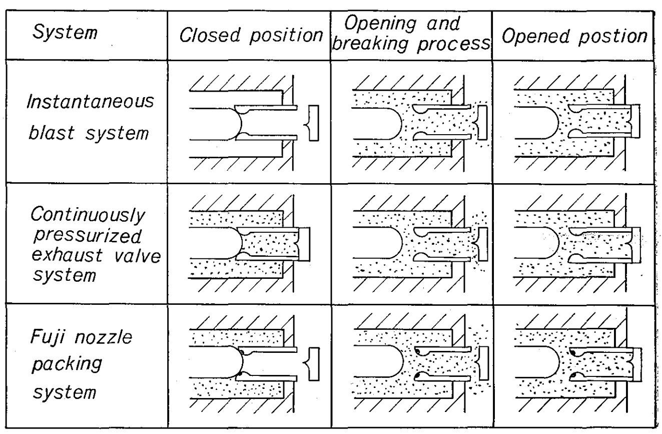


Fig. 1 Special features of Fuji continuously-pressurized ABB

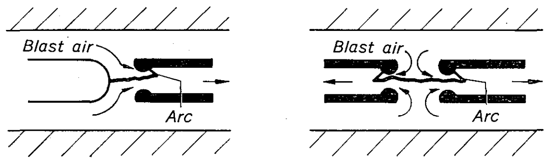


Fig. 2 Single flow (left) and double flow (right)

the difference in pressure between the outside and inside of the nozzle remains the same as the reservoir pressure in the closed position. This pressure is used only for opening the contact, so that the air is blasted more vigorously. The nozzle is shaped for axial blast which is most popular at present This system is also available in single or double flow. In comparison with the single flow, the double flow system allows for higher unit voltages. Fundamental construction of both systems is shown in *Fig. 2.* Better breaking performance is obtainable by employing the nozzle packing-double flow system and at the same time, contact wear can be minimized.

2) 84 kv unit

This single breaking unit rated for 84 kv is better than two 42 kv units since it requires fewer arc extinguishing chambers, shorter time for maintenance and inspection, fewer spares, and a smaller installation area.

3) Tulip-shaped contacts

(1) Unlike butt contacts, there is no bounce during closing.

(2) Since contact lamination for carrying current is separated from that for arcs, contact wear is much less even when breaking short-circuit currents.

(3) Making contact has nothing to do with air pressure, so even when air pressure is zero, there is no trouble in making contact.

4) Advantages of draw-out type (72/84 kv)

Recently, switchgears of the 72/84 kv class are being placed indoors or underground, so that disconnection involves drawing the circuit breaker out in most cases. In the 72/84 kv circuit breakers, the breaking chamber is constructed vertically so that it occupies a smaller area of the cubicle and hence facilitates checking.

5) Inspection and assembly are simplified.

The use of a light alloy and simple construction facilitates interior inspection. Considerable time can be saved for site erection since it is not necessary to match the link mechanism. (For example, only a little under one hour is required for 72/8 4kv circuit breakers.)

2. Outline of New Series

Fuji outdoor air-blast circuit breakers for 72 kv or over consist of two series: RF 720 and 725. *Table 1* shows the applications of each type of circuit breaker.

1) RF 720 series

This series has a standard unit with a maximum

Table 1 Applications of Air-Blast Circuit Breakers

Type	RF 720	RF 725
Voltage Range (kv)	72~204	72~300
Rated Current (amp)	2000, 3000	1200
Max. Breaking Current (ka)	31	22
Operating Pressure (kg/cm²)	15	15
Breaking Time (cycle)	3	3
Control Voltage (v)	Dc 100	Dc 100

breaking current 31 ka 84 kv based on the RF 720 type. The series is classified into three types according to application.

(1) RF 720 type

For general use with no parallel resistance provided.

(2) RF 721 type

This type is applicable when the breaker breaks large exciting current and reactor current. The non-linear resistor is provided for suppression of overvoltages.

(3) RF 722 type

This type equipped with low-value resistor and breaker unit for handling short line faults.

2) RF 725 series

This series has a standard unit with a maximum breaking current 22 ka 84 kv. Rated current is 1200 amp, and the supporting insulator can withstand 0.05 mg/cm² (69 kv) to provide effective insulation against any contamination. This type is not substantially different from the RF 720 type; only the breaking capacity and rated current are smaller. It is therefore light-weight and compact for easy handling. Like the RF 720 type, the 72/84 kv circuit breaker is available in the draw-out model. Breakers for more than 120 kv are made by connecting two units in series; the air resevoir separates according to the phase.

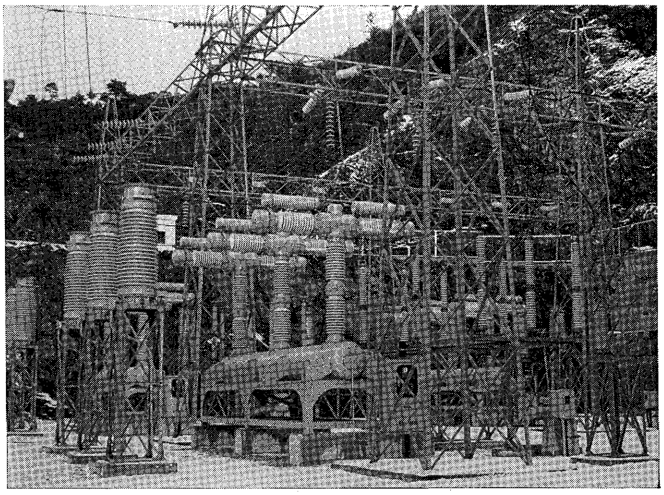


Fig. 3 168 kv 7500 Mva 2000 amp air-blast circuit breaker (type RF 720 J/140/2000D)

Table 2 Ratings and Specifications

Application		Type	Ratings: Voltage (kv)	Current (amp)	Breaking capacity (Mva)	Impulse level (kv)	Restriking voltage (kHz)	Short-time current (ka)	Making current (ka)	Breaking time (cycle)	Contact opening time (sec)	No-load Making Time (sec)	Operating Duty	Reclosing Time (sec)	Air Reservoir Capacity (l)	Air Consumption (in Atmospheric Pressure (l)) Closing	Air Consumption Tripping	Control Current at dc 100 v Closing	Control Current Tripping	Rated Operating Pressure (kg/cm²)	Weight (Body) (kg)	Permissible Amount of Salt at which Contamination Proofing is Guaranteed (mg/cm²)
Standard Model (Medium Capacity)	For contamination	RF725B/70/1200D	72	1200	2500	400	0.9	20.0	54.8	3	0.04	0.15	1min O— 3min CO—CO	—	660	50	1200	5	5	15	1600	0.05
			84				0.8	17.2	46.8													0.03
		RF725G/140/1200D	120		3500	750	0.6	16.8	46.0				1min O—CO—3min CO Reclosing	0.25	1300	100	2400				3600	0.03
		RF725G/140/1200D	168		5000	750	0.5	17.2	46.8						1300	100	2400				3800	0.03
		RF725G/140/1200D	204		7500	750	0.45	21.3	57.8						1300	100	2400				3800	0.03
		RF725J/200/1200D	240		7500	900	0.4	10.8	49.3						2000	150	3600				10,300	0.03
		RF725K/250/1200D	300		10,000	1050	0.36	19.2	52.5						2600	200	4800				11,000	0.03
Standard Model (Large Capacity)		RF720C/70/2000D	72		3500	400	0.9	28.1	76.5	3	0.04	0.17	1min O—CO 2min —CO	—	1200	135	1950	5	5	15	2700	—
			84			400	0.8	24.1	65.5													
	For contamination	RF720C/70H/2000D	72			400	0.9	28.1	76.5													0.03
			84			400	0.8	24.1	65.5													0.02
		RF720G/100/2000D	120	2000	5000	550	0.6	24.1	65.5				1min O—CO—3min CO Reclosing	0.25	2300	430	4000				5200	—
	For contamination	RF720G/100H/2000D	120	3000		550																0.03
		RF720J/140/2000D	168		7500	750	0.5	25.8	70.3						2600	430	4000				5800	—
	For contamination	RF720J/140H/2000D	168			750																0.02
		RF720J/140/2000D	204		10,000	750	0.45	28.3	77.2						2600	430	4000				5800	—
	For contamination	RF720J/140H/2000D	204			750																0.02
For Reactor Switching		RF721C/70/2000D	72		3500	400	0.9	28.1	76.5	3	0.04	0.17	1min O—CO 3min —CO	—	1200	185	2000	5	5	15	3000	—
			84			400	0.8	24.1	65.5													
	For contamination	RF721C/70H/2000D	72			400	0.9	28.1	76.5													0.03
			84			400	0.8	24.1	65.5													0.02
For Short Line Faults	Standard	RF722C/70/2000D	72			400	0.9	28.1	76.5													—
			84			400	0.8	24.1	65.5													
	For contamination	RF722C/70H/2000D	72	2000		400	0.9	28.1	76.5													0.03
			84	3000		400	0.8	24.1	65.5													0.02
	Standard	RF722G/100/2000D	120		5000	550	0.6	24.1	65.5				1min O—CO—3min CO Reclosing	0.25	2300	480	4050				5800	—
	For contamination	RF722G100H/2000D	120			550																0.03
	Standard	RF722J/140/2000D	168		7500	750	0.5	25.8	70.3						2600	480	4050				6400	—
	For contamination	RF722J/140H/2000D	168			750																0.02
	Standard	RF722J/140/2000D	204		10,000	750	0.45	28.3	77.2						2600	480	4050				6400	—
	For contamination	RF722J/140H/2000D	204			750																0.01

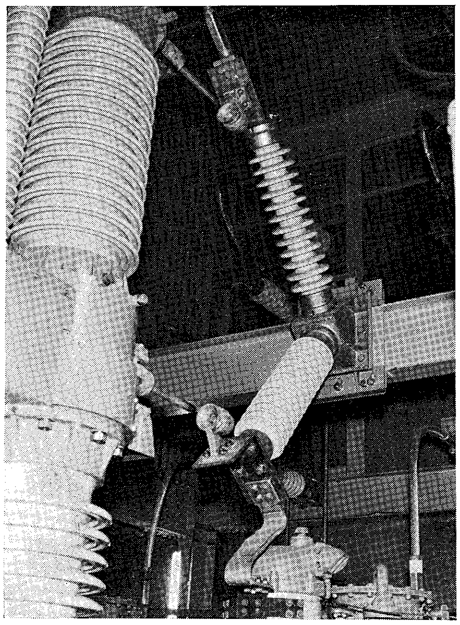
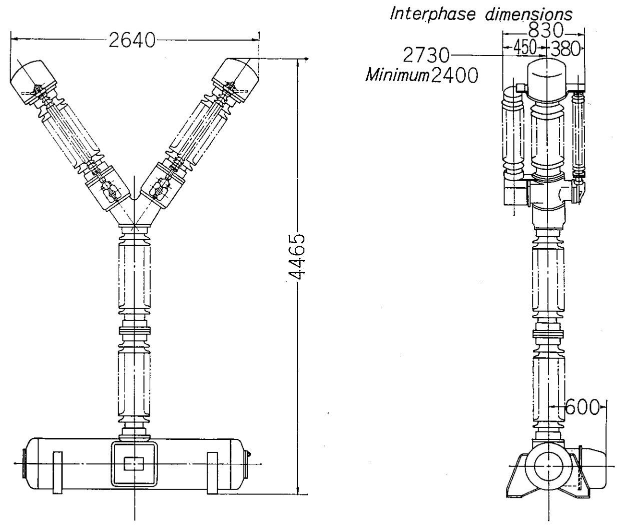
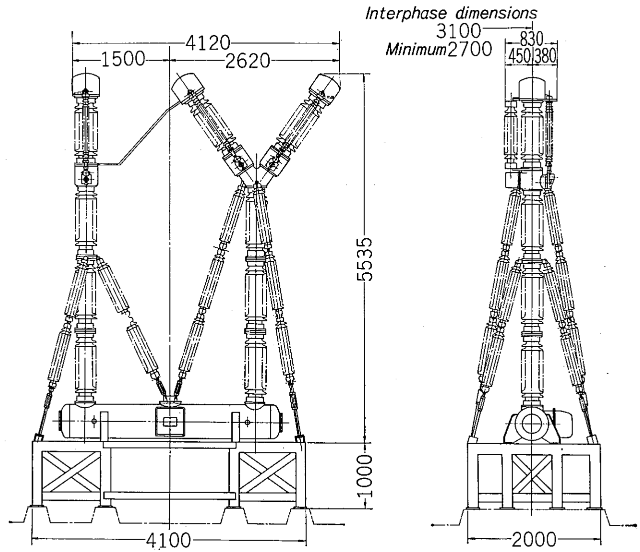


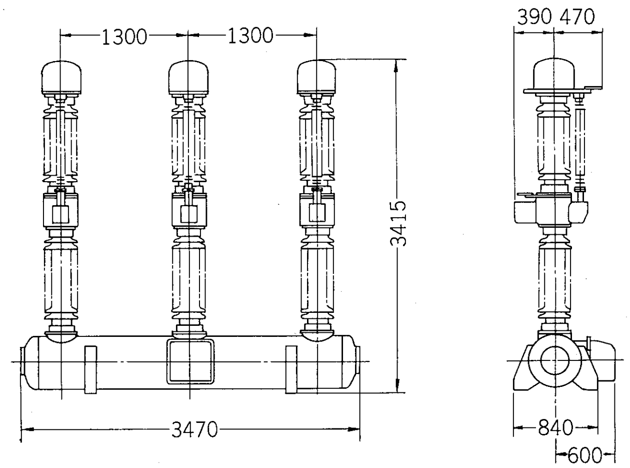
Fig. 4 **Disconnecting switch of draw-out type (type RF 720 C/70/2000D)**



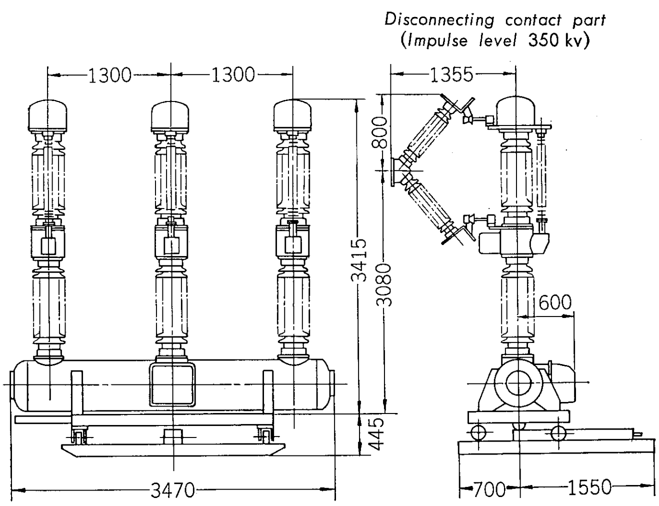
(c) **RF 725 G/140**



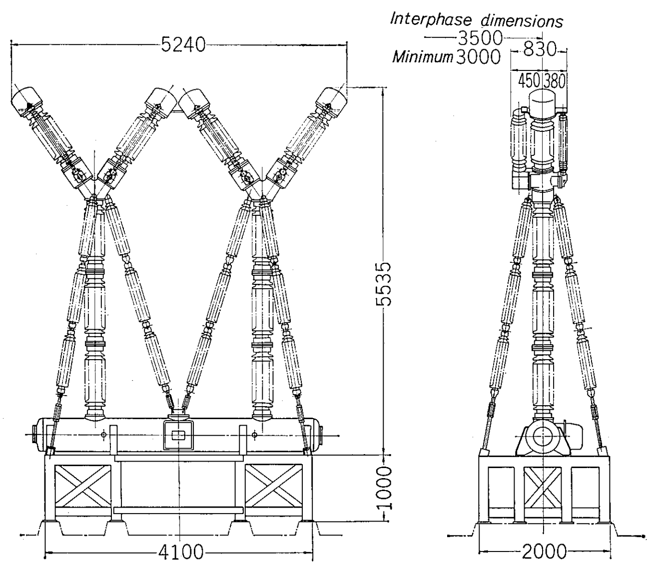
(d) **RF 725 J/200**



(a) **RF 725 B/70**



(b) **RF 725 B/70 (Draw-out Type)**



(e) **RF 725 K/250**

Fig. 5 **Outline**

Table 3 **Application of Air-Blast Circuit Breakers (Standard Type)**

Rated Breaking Capacity \ Rated Voltage	72	84	120	168	204	240	300
2500	RF725B/70	RF725B/70					
3500	RF700C/70	RF720C/70	RF725G/140				
5000			RF720G/100	RF725G/140			
7500				RF720J/140	RF725/G140	RF725J/200	
10,000					RF720J/140		RF725K/250

3. Ratings of New Series

Ratings are shown in *Table 2.* Outline dimensions of the RF 725 are shown in *Fig. 5.* Applications of each standard type of circuit breaker according to voltage and breaking capacity are shown in *Table 3.*

III. RF 725 TYPE AIR-BLAST CIRCUIT BREAKER

1. Ratings

Refer to *Table 2.*

2. Construction

The RF 725 type outdoor air-blast circuit breakers consist of 72~300 kv circuit breakers in 84 kv units.

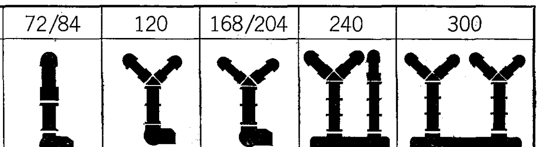
1) 72/84 kv

This circuit breaker is of the 1-pole 1-point breaking type, provided with 3 poles arranged vertically on a single air reservoir. There is one operating valve per 3 poles, and the manual operating valve, stop valve for feeding air to the air reservoir, air filter, etc. are separately encased near the body of the circuit breaker.

2) 120 kv, 168 kv, 204 kv

Each of these circuit breakers is of the 1-pole 2-point breaking type, provided with Y-shaped poles standing on a single reservoir. There is one operating

Table 4 **Basic Construction of RF 725 Air-Blast Circuit Breakers**

Voltage (kv)	72/84	120	168/204	240	300
Construction					
Breaking point/pole	1	2	2	3	4
Supporting insulatator/pole	1	2	2	6	6
Air reservoir/pole	1	1	1	1	1

Note: (1) 72/84 kv type: One air reservoir per 3 poles.

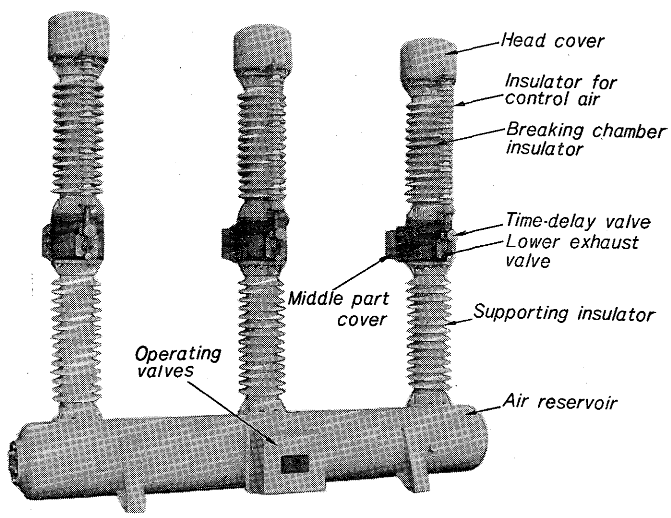


Fig. 6 RF 725B/70/1200D air-blast circuit breaker

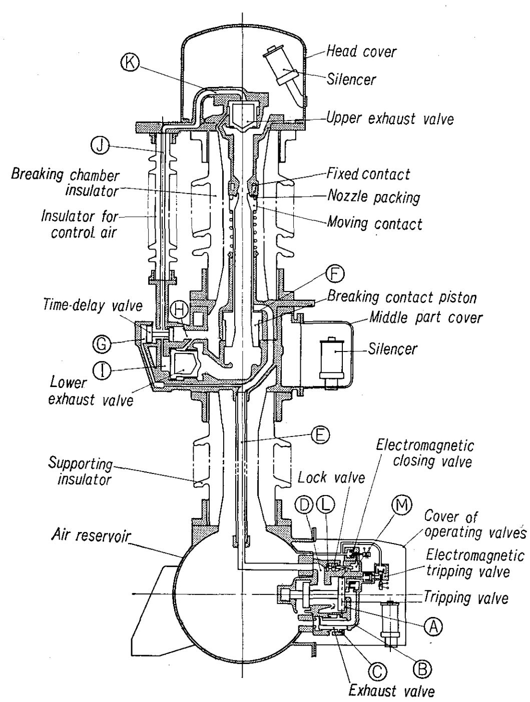


Fig. 7 Schematic diagram (closed position)

valve per pole and it can be used for single phase auto-reclosing. The separate control cabinet is the same as for the 72/84 kv type.

3) 240 kv, 300 kv

There are also 1-pole 3-point breaking (240 v) and 1-pole 4-point breaking (300 kv) models made by combining 168 kv units.

Table 4 shows the basic construction of these circuit breakers. As is evident from the table, circuit breakers of more than 120 kv can be assembled by adding several parts to the 84 kv unit and operating valves. This means that parts are completely interchangeable. When there are more than 2 points in series, a voltage equalizing condenser is mounted in parallel with each breaking contact part so as to share voltage proportionally with each unit. An external view of the 72/84 kv type is shown in *Fig. 6* and the schematic diagrams are given in *Figs. 7* and *8*. The construction consists of an air reservoir, operating valve, lock valve, closing valve, electromagnetic valve at ground potential, supporting insulators on the reservoir, insulating tube in the interior for feeding or exhausting air. Above them is the middle mechanism which consists of a breaking contact and its driving piston, lower exhaust valve and its time-delay valve for operating time adjustment, and an airing valve.

The upper part is made up of breaking chamber insulator, insulator for control air, and head mechanism at the top consisting of a fixed contact and upper exhaust valve.

3. Performance

1) Breaking movement

In *Fig. 7*.

(1) Electromagnetic tripping valve is energized.

(2) Compressed air (hereafter referred to as "air") enters Ⓐ, and tripping valve moves to the left.

(3) Air in air reservoir enters Ⓕ through Ⓓ and Ⓔ, and presses breaking contact piston downwards.

(4) Contact opens and nozzle packings release seal; thus blast flows between the contacts to extinguish arc.

(5) Air flowing through Ⓓ and Ⓔ turns to Ⓖ, and the time-delay valve is moved to the right.

(6) Air pressure is exerted on Ⓗ, Ⓙ, Ⓚ and Ⓘ to set upper and lower exhaust valves in motion, thereby keeping exhaust away from the contact.

(7) Then, air comes in to Ⓛ to set the lock valve in motion to the right; thus completing preparations for closing.

2) Closing movement

In *Fig. 8*.

(1) Electromagnetic closing valve is energized.

(2) Air enters Ⓒ and exhaust valve moves to the left.

(3) Air in Ⓐ, and Ⓑ is exhausted into the atmosphere and the tripping valve returns to the right.

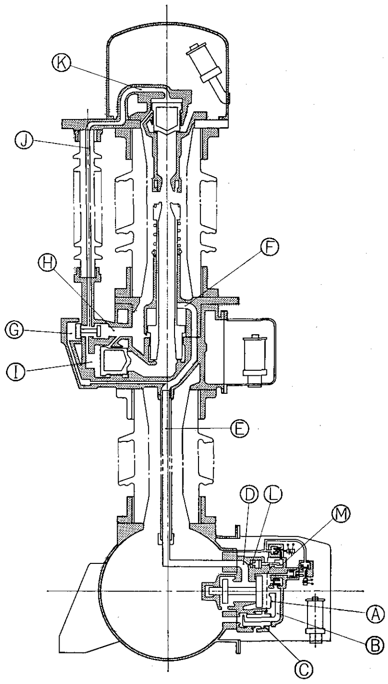


Fig. 8 Schematic diagram (open positon)

(4) Air in Ⓕ is exhausted into the atmosphere through Ⓔ, and Ⓓ.

(5) Breaking contact moves upwards to return to the closing position.

(6) Air in Ⓒ is exhausted and the time-delay valve moves to the left.

(7) Air in Ⓘ, Ⓙ, and Ⓚ is exhausted into the atmosphere; lower and upper exhaust valves return to the left or right so that air in the tube is exhausted into the atmosphere.

(8) Air is Ⓛ is also exhausted and the lock valve returns to the left so that air in Ⓒ is exhausted into the atmosphere.

(9) Exhaust valve returns to the right, and air in the reservoir enters Ⓑ, thus completing preparations for breaking.

3) Trip free

If a tripping signal comes in from the relay circuit during a closing signal, the circuit breaker, after it has completely closed once (since contact "a" of the auxiliary switch is mounted in series in the tripping signal circuit), will perform breaking and stay in this position. If the closing signal continues after breaking, the breaker will not close again. It will only close again once the closing signal is suspended and then resumed.

This locking operation is performed pneumatically by the lock valve; i.e. if the closing signal continues after breaking, the lock valve body will be subjected to an air blast on the Ⓛ and Ⓜ sides, but, because of the difference in the size of the areas exposed to the pressure, the lock valve body is pushed upwards and prevented from moving so that reclosing will not take place. If reclosing is required, it is necessary to stop exciting the electromagnetic closing valve

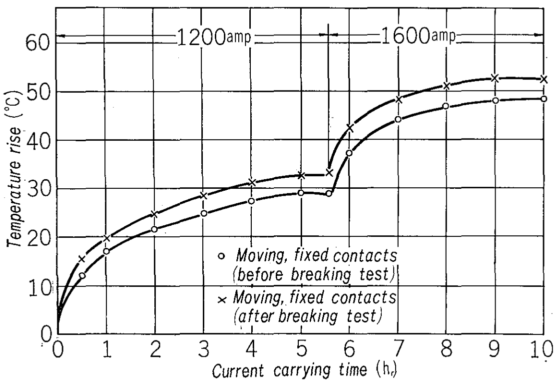


Fig. 9 **Results of current carrying test**

once, reduce the pressure of Ⓜ to the atmospheric level, lower the lock valve body, connect Ⓜ with Ⓒ, and excite the electromagnetic closing valve again.

4. Test Results

Various tests including a reference test were performed on the 84 kv unit in accordance with standards stipulated in JEC145 and in B112 (Rules for Electric Power Companies)

1) Current carrying test

The rated current is to be standardized at 1200 amp. However, test results indicate that up to 1600 amp of current can be carried. Two contacts, one which had not undergone the breaking test and one which had previously undergone a breaking test satisfied the values in the JEC standard up to 1600 amp. Results of tests for 1200 amp, 1600 amp (60 Hz) are shown in *Fig. 9*.

2) Breaking test

(1) The short-circuit current breaking test

Table 6 **Stipulations in IEC (S76) and JEC 145 Short-circuit Current Breaking Tests**

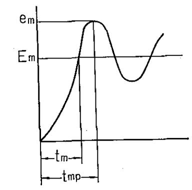
	IEC [17 a(S 76)] 72.5 kv Rating		JEC 145 84 kv Rating
	Standard	Practice	
Reference Recovery Voltage $\frac{E_m}{\sqrt{2}}$ (kv)	$72.5\times\frac{\sqrt{3}}{2}=63$ kv	73 kv	$84\times\frac{\sqrt{3}}{2}=72.8$ kv
Peak Value e_m(kv)	125 kv	137 kv	$72.8\times0.9\times\sqrt{2}$ $2\times1.3=121$ kv
r.r.r.v (v/μs)	$\frac{E_m}{t_m}$745 v/μs	836 v/μs	$\frac{e_m}{t_{mp}}=214$ v/μs
f (kHz)	$\left(\frac{1}{2t_{mp}}=2.38\text{ kHz}\right)$	(2.34 kHz)	$\frac{1}{2t_{mp}}=0.8$ kHz
Fundamental Wave			

Table 5 **Synthetic Test Results using Weil Circuit**

Test	Operating Duty	Test Voltage (kv)	Breaking Current (ka) Objective	Breaking Current (ka) Actual Symmetric component	Breaking Current (ka) Actual Dc component (%)	Making Current (ka) Objective	Making Current (ka) Actual	Arcing Time	Restriking-Voltage Natural frequency (kHz) Objective	Natural frequency (kHz) Actual	Peak voltage (kvp) Objective	Peak voltage (kvp) Actual	Rate of rise of resriking voltage (v/μs) Objective	Rate of rise of resriking voltage (v/μs) Actual	Operating Pressure (kg/cm²g)
Short-Circuit Test	30% "O"	92	6.0	6.1	17	—	—	0.51	4	13.9	134	169	1070	4700	15.0
		87		6.2	11	—	—	0.50		13.9		159		4420	
		90		6.1	10	—	—	0.05		13.9		166		4610	
	60% "O"	89	12.0	12.8	6	—	—	0.47	2.93	6.25	134	163	785	2040	12.7
		90		12.6	13	—	—	0.51		6.25		165		2060	
		90		13.0	45	—	—	0.54		6.25		165		2060	
	110% "O"	74	21.9	21.8	0	—	—	0.53	0.8	2.34	134	137	214	640	12.7
		78		21.2	22	—	—	0.55		2.34		143		667	
		74		21.1	26	—	—	0.55		2.33		137		640	
Out-of-Phase Breaking Test	50% "O"	100	10.0	10.5	3	—	—	0.45	0.8	1.67	178	185	285	617	12.7
		99		10.4	11	—	—	0.47		1.67		182		607	
	25% "O"	109	5.0	10.4	1	—	—	0.49		1.67	191	200	306	667	
		109		10.5	6	—	—	0.47		1.67		200		667	
Double Phase-to-Ground Fault Breaking Test	87% "O"	87	17.4	17.5	23	—	—	0.54	0.8	1.39	154	160	246	444	12.7
		90		17.7	2	—	—	0.51		1.39		165		458	
Reduced Voltage Actual Loading Test	110% O-1min-CO-3min-CO	20	21.9	22.0		55.0	60.0	0.5	—	10	—	31.4	—	0.437	12.7

Notes: (1) 72 kv 2500 Mva was used for breaking current and 84 kv for test voltage. Testing conditions were thus decided so as to satisfy ratings of both 72/84 kv, 2500 Mva.

(2) Based on JEC-145 and B-112 standards.

yet been reached.)

2) Breaking test under special conditions

Breaking tests for double phase-to-ground faults, and out-of-phase were conducted using the Weil circuit. Out-of-phase breaking was tested for combinations of 50% I, 2.0E and 25% I, 2.5E (IEC (S76)), and no problems arose. For reference, no abnormality occurred in the short line fault breaking test when a linear resistor of the same magnitude as surge impedance was inserted at the breaking point. Results are also shown in *Table 5*.

3) Noise measurement

Operating noise of ABB has recently presented a problem and many low noise models have been announced. The RF 725 type air-blast circuit breakers are not provided with special silencers. However, noise is much less than previously. Tests showed that even during short-circuit current breaking the sound at 10 meters was only 2 phons or so higher than during no-load running. Results of noise measurements made in the shop are shown in *Fig. 11*.

According to noise measurements made on various types of Fuji circuit breakers after delivery, sound measured at 1 m from the building (iron plate construction) was 4~6 phons lower for outdoor installation and approximately 17 phons lower for indoor installation than the shop measurements. The results suggest that RF 725 noise at the site is actually several phons lower than the values shown in *Fig. 11*.

For low noise models operation noise is considered to be the same value as standard-type closing noise as is shown in *Fig. 11*. This value is the same as announced by other companies for their low noise models.

(Note: Noise level is measured with JIS Noise level meter)

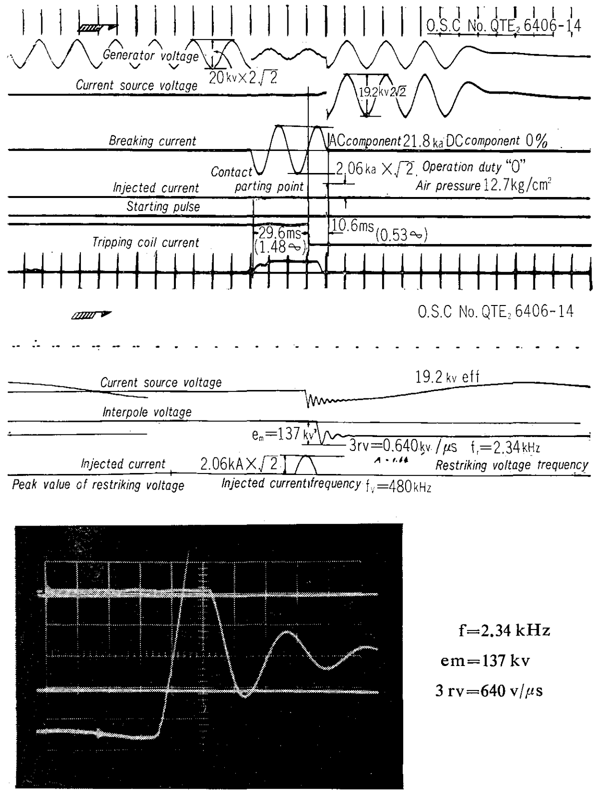


Fig. 10 Oscillogram of 110% interrupting tests (72/84 kv)

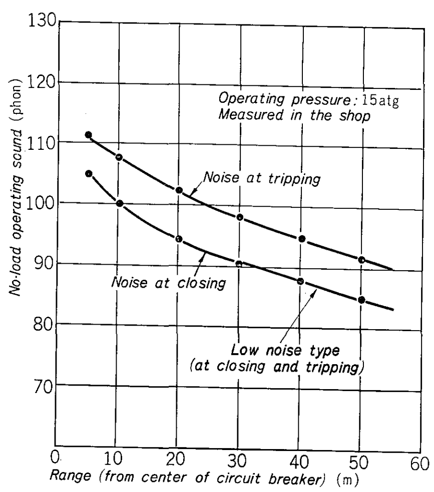


Fig. 11 Characteristics of operating noise (72/84 kv)

The short-circuit test was performed by breaking 30, 60, and 110% short-circuit currents using Fuji Electric 1500 Mva short-circuit testing equipment. The Weil synthetic test method was used for the test. Results are as shown in *Table 5*. IEC (S76) Stipulations are severer than those of JEC 145 No. I so far as restriking voltage is concerned. The test this time was carried out in accordance with IEC (S76).

A comparison of stipulations for IEC (S76) and JEC 145 short-circuit current breaking tests is shown in *Table 6*. (IEC standards are now being considered in detail and no conclusion has

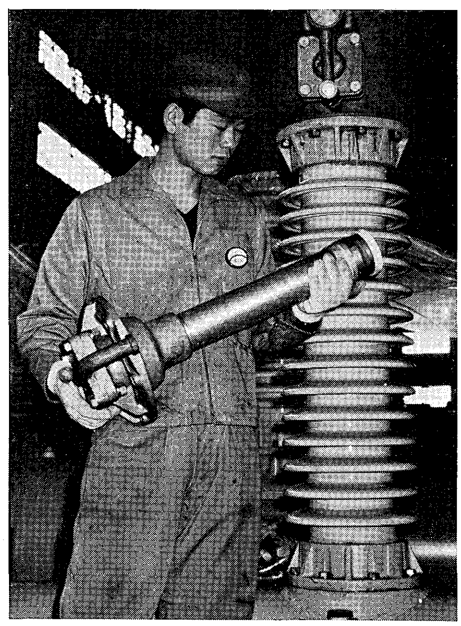


Fig. 12 Head part mechanism (weight 12 kg)

Fig. 13 Contact overhauling (72/84 kv)

4) Measurement of contact checking time

As shown in *Fig. 12,* the head mechanism weighs only 12 kg, and can be handled by one man. One employee can set up the scaffolding, disassemble and check the head mechanism and move the contact in 1.5 hours or so. *Fig. 13* shows an employee overhauling the contact.

5) Deformation and life of nozzle packing

It has already been reported that the nozzle packing can still be used with only slight wear even after 190 ka breaking. This time, tests on deterioration and permanent deformation were carried out. Permanent deformation was measured by fixing the disconnecting contact and breaking contact as shown in *Fig. 14* in closed position and heating the nozzle packing in a thermostatic oven to quicken deterioration.

Standard silicone rubber, Fuji's standard nitrile rubber (heat resistant) and chloroprene rubber (heat resistant) were used as comparative samples. Working temperature was 95°±1°C and the test covered 34 days. The deformation rate was calculated using the A dimension in the figure as follows: $A - A'/A \times 100$ (A: initial dimension, A′: dimension measured at each step during test).

Results are as shown in *Fig. 15.* Permanent deformation reached a plateau in 16 days and did not increase after that. Of the three samples tested, silicone rubber showed the least deformation. The value was approximately a 10% flexible margin; which obviously presents no problem in practice.

After this test, an air leak test was carried out on the three packings, but, no leakage was found in any packing.

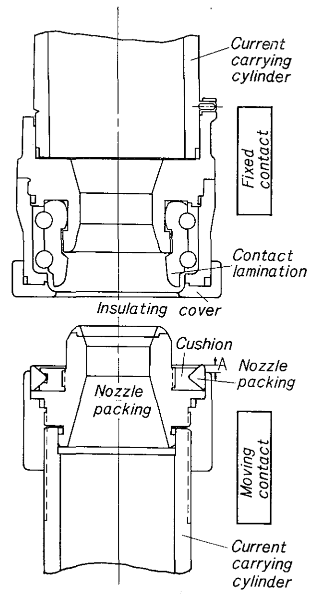


Fig. 14 Testing equipment of nozzle packing

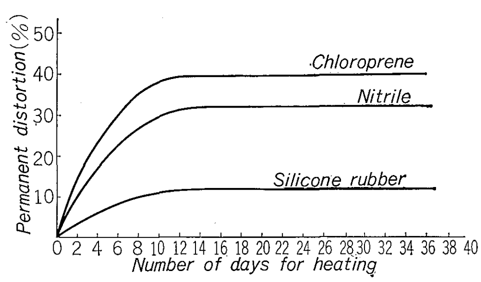


Fig. 15 Deformation of nozzle packing (heating condition)

IV. CONCLUSION

Outlines of the RF 725 type outdoor air-blast circuit breaker and all of the Fuji Electric outdoor air-blast circuit breakers have been introduced above. In accordance with present demands for advancing the practical performance of circuit breakers, Fuji Electric is confident that its circuit breakers with nozzle packings will meet users' requirements, in regard to excellent breaking performance, simplified operation and refined construction. It is hoped that these Fuji products prove satisfactory for normal use in all related fields of industry as high quality circuit breakers.