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NEW PUFFER TYPE "F-SCHALTER" (F CIRCUIT-BREAKER) SERIES WITH LOW NOISE LEVEL AND LARGE BREAKING CAPACITY

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I. INTRODUCTION

In Japan, SF_6 gas circuit-breakers have been on the market for only eight years. It has only been four years since the patent rights held by the Westinghouse Electric Corp. of the United States on the use of SF_6 gas as an arc quenching medium have lapsed and many manufacturers have started to produce the SF_6 gas circuit-breaker.

SF_6 gas has many interesting characteristics compared with other arc quenching mediums. Both the arc quenching and insulation characteristics are excellent. In 1969 when the patent right came to an end, Fuji Electric rapidly completed a series of the SF_6 gas circuit-breakers ranging from 300 kV, 25GVA to 72/84 kV, 3.5 GVA and in the four years since, about 500 of the breakers have been manufactured. In addition to completing the series, investigations for the increase of the capacity, starting with so-called the double-pressure type, and now with the single-pressure type, have been carried out and further efforts have been made to make the breakers low noise level and maintenance free.

The result of these efforts is the low noise level, large breaking capacity single-pressure type (or puffer type) F-Schalters (F circuit-breakers), described in this article.

These new series of F-Schalters are provided with oil-hydraulic operating units of complete local manufactures.

Table 1 **Fuji F-Schalter manufactured**

1973–May–20

		1970	1971	1972	1973
Double-pressure type	240 kV	0 unit	6 unit	2 unit	6 unit
	168	14	19	5	1
	120	9	5	3	4
	72/84	0	4	2	0
Single-pressure type	168	0	0	0	2
	120	0	0	4	1
	72/84	26	82	75	203
	Total	49	116	91	217

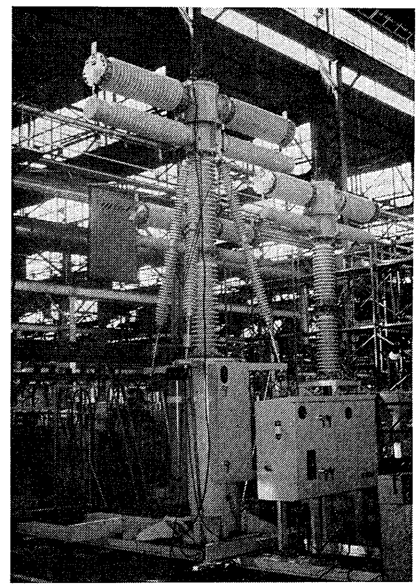

Fig. 1 (a) 300 kV 4,000 A 50 kA 3 cycle, 168 kV 4,000 A 40 kA 3 cycle puffer type F-Schalter with oil-hydraulic operating unit

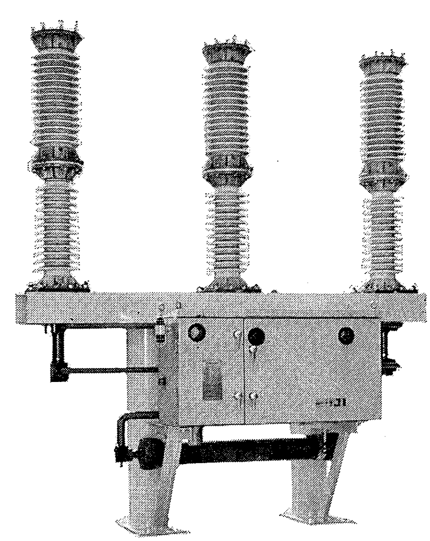

Fig. 1 (b) 72/84 kV 2,000 A 31.5 kA 3 cycle puffer type F-Schalter with oil-hydraulic operating unit

Long since, the oil-hydraulic operating units developed in Europe have been used for porcelain type oil or gas circuit-breakers, but in Japan, connections between oil-hydraulic techniques and circuit-breaker techniques are rare and this field has been delayed. However, in the course of increasing the capacity of the single-pressure type SF_6 gas circuit-breaker with its simple construction, the necessity of compact oil-hydraulic operating unit has been confirmed.

At the same time, the noise has become a social problem and improvements have been demanded in respect to the pneumatic operating units of circuit-breakers. Fuji Electric, since two years before co-operating with local oil-hydraulic manufacturers, has started the research and development on the first oil-hydraulic operating units for circuit-breakers in Japan and at the same time has also been engaged in the research and development on a new type large capacity single-pressure type arc quenching chamber.

As will be described later, there are double-pressure and single-pressure type in SF_6 gas circuit-breakers. In general, the double-pressure type is applicable to large capacity and high speed breaking and the single-pressure type is not. Concerning the series combination of these two types, each company now has its own policies and there is no common policy. Fuji Electric has been proving that the single-pressure type can cover the region of the double-pressure type by the development of the oil hydraulic operating units, with the realization of the 50 kA circuit breaker.

II. TRANSITION OF GAS CIRCUIT-BREAKER

1. Transition of Gas Circuit-Breaker

In SF_6 gas circuit-breakers, there are two types: the double-pressure type with two pressure systems, and the single-pressure type which has only one pressure. Initially, each manufacturer started with series using the double-pressure type, as the techniques of the previous air blast circuit-breakers were applied easily. Because the arc quenching of this type is done by a blast between the contacts, using the high pressure which is increased beforehands by a gas compressor. Other reasons were that it was so easy to analyze breaking performance of this type the capacity of which could be raised rather easily, and that the arcing time was the same or less than that of the air blast circuit-breakers since the pressure difference of the blast gas at the time of opening was made great.

In the double-pressure type, there are various operating systems including the system of "closing by air and opening by spring," "closing by spring and opening by air," and operation by high pressure SF_6 gas. In all cases the blast gas used for arc quenching is created by a gas compressor so that the operating units need only operating force sufficient to operate the contacts at the required speed.

The double-pressure type has many advantages appropriate for large capacity high speed circuit-breakers but it also unfortunately has one major disadvantage. That is, because of the two pressure systems, it needs many accessory devices such as a heater to prevent liquefaction of the high pressure gas in winter, a gas compressor, a high pressure gas tank, and in some cases, a blower to make the high pressure gas temperature uniform, a blast valve for the blast of the arc quenching, and many control and monitoring devices for the pressure conditions. The necessity of using so many accessory devices places a heavy maintenance burden on the user.

By nature circuit-breakers are devices which are normally inactive and operate only a few times per year when there is an abnormality in the system. For devices with such an important task, simple and maintenance free construction without any change in performance is required.

Meanwhile, the single-pressure type, which appeared later than the double-pressure type, compresses the SF_6 gas by its own operating force at the time of opening, blasts the gas between the contacts and performs arc quenching. In the original construction of this system, there were several defects. That is, the operating force required for gas compression was large, and it was necessary to insert the contacts more deeply during closing than in the double-pressure type in order to raise the gas pressure to a certain degree before the opening of the contacts and as a result, the opening time became longer and the arcing time also increased because it was necessary to move the contacts to an appropriate position for arc quenching after the contact opening to raise the gas pressure to some extent. And further, for rebreaking of progressive faults caused by surge voltages directly after breaking, the gas compression chamber capacity and the stroke could not be reduced since the blast gas supply could not be stopped rapidly, so means were required to correct these limitations. In the case of short-line faults, breaking capacity of the single-pressure type was about 30 kA per one breaking unit of 70 kV, which was less than that of the double-pressure type.

Under such conditions, we repeately performed many experiments in order to improve the arc quenching capacity of the single-pressure type F-Schalter. As a result, an increase of the operating force at the breaking was required and in this case, the most appropriate method was the use of an oil pressure of 200 kg/cm². And the new series of F-Schalters were developed on the basis of experience with the former series.

2. Experience with Fuji F-Schalters

Since January, 1969, almost 500 F-Schalters had been manufactured, but among these, 400 were of the single-pressure type. After delivery, there were almost no troubles reported for the single-pressure type and stable practicability was proven as almost never before.

The particular points to consider for gas circuit-breakers are:

Penetration of water: filter control

Countermeasure dissociated gas: selection of materials

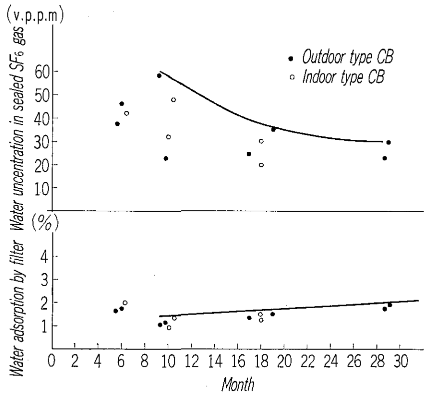

Fig. 2 Inspection data for 72/84 kV F-Schalter

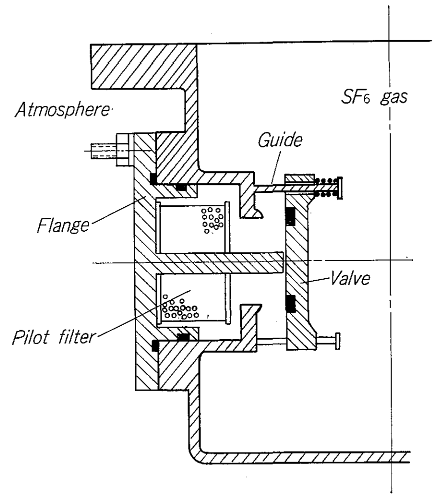

Fig. 3 Sectional view of pilot filter

***Table 2* Series of new F-Schalter with oil-hydraulic operating unit**

Mode		BAP 207	BAP 211	BAP 318	BAP 318	BAP 322		BAP 327	
Rated voltage	(kV)	72/84	120	168	204	240		300	
Rated current	(A)	1,200, 2,000, 3,000		2,000, 4,000					
Rated breaking current	(kA)	31.5		40		40	**50	40	**50
Breaking capacity	(GVA)	3.9/4.6	6.5	12	14.1	17	21	21	26
Rated closing current	(kA)	80		100		100/125			
Rated restriking voltage	(kV/μs)	0.75		1.0					
Insulation class (JEC)	(No.)	70	100	140		170		200	
Rated break-time	(cycle)	3							
No load make-time	(sec.)	0.15							
Rated SF_6 gas pressure	($kg/cm^2 \cdot g$)	5							
Rated operating oil pressure	($kg/cm^2 \cdot g$)	190～200							
Rated control voltage	(V)	DC 100/110							
Rated operating sequence		*A		*A • R					
No. of breaking unit pole		1		2					
Gas blast system		Single flow		Double flow					
No. of operating unit		1		3					
Weight	(kg)	2,570	2,850	8,800		9,200		9,400	
Outline dimension (mm) (Refer to Fig. 4)	A	1,500	1,900	3,000		4,000		5,000	
	B	3,420	4,400	—		—		—	
	C	4,157	4,810	5,954		5,827		6,007	
	D	755	1,060	3,100		3,520		3,520	

* A : O—(1 min.)—CO—(3 min.)—CO

R : C—(θ)—CO—(1 min.)—CO. θ : reclosing time

** under development

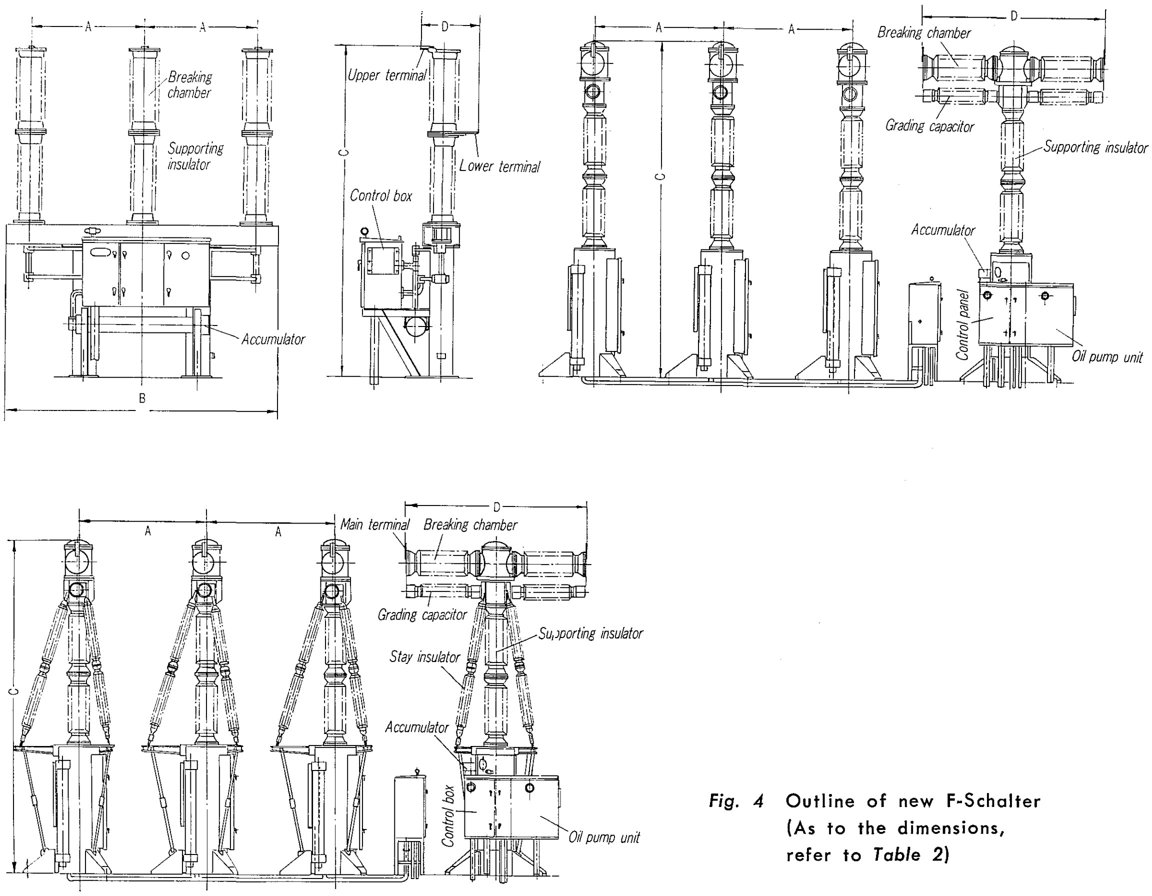

Fig. 4 Outline of new F-Schalter (As to the dimensions, refer to *Table 2*)

Prevention of gas leaking
All of these points have been described before, and now the results of regular inspections on some of the delivered circuit-breakers are being gained. From these results, the water absorption conditions are as shown in *Fig. 2*. Thirty months after the start of operation, the amount of water in the gas remained at less than 30 v. ppm and there is a sufficient margin for 180 v. ppm at a dew point of $-20°C$. The filter had not changed since the beginning and has shown that in practice, the absorption of water can be disregarded. Since the life of the filter drops at about 15% of water absorbed, it can be considered from the present that the filter will last for more than 20 years.

Since the absorbed water should be monitored quantitatively by the measurement of the weight of absorbed water in the filter, a pilot filter was attached to each of the some single-pressure type F-Schalters delivered previously as shown in *Fig. 3* and a survey has been conducted by measuring the amount of absorbed water by this filter without removing the SF_6 gas.

Concerning the supplement of SF_6 gas because of gas leaking to the exterior, there are no F-Schalters which have been added the gas except in 1 or 2 cases of supplement because of faults at the soldering parts of piping by the initial products. It can therefore be said that these are good results for the single-pressure type F-Schalter which has only a small amount of gas sealed originally. There have been no packing deteriorations or resulting gas leaking over the last five years and there has also been no gas leaking due to hardening of the packing in cold regions.

In surveys concerning odors or color changes in the arc quenching chamber in order to inspect for dissociated gas, no such things have been found and there have been no changes in materials, etc.

Concerning the history of each breaker after manufacture and delivery have been monitored with control cards.

III. NEW F-SCHALTER SERIES

1. Series and Features

The F-Schalter series with oil-hydraulic drive is shown in *Table 5*. There are two types of arc quenching chamber. The F-Schalters rated at 120 kV and below use the one breaking unit pole of the single-flow type chamber shown in *Fig. 5*. And the F-Schalters rated at 168 kV and above use the two breaking unit poles of the double-flow type chamber shown in *Fig. 6*.

Special attention has been placed on the inter-

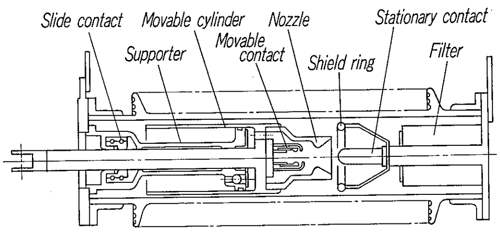

Fig. 5 **Single-flow type breaking chamber**

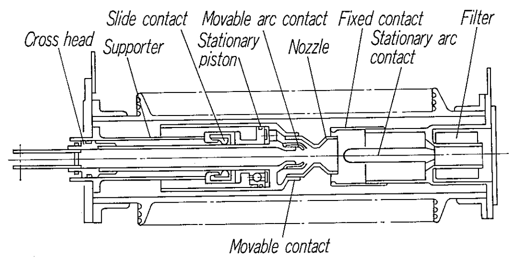

Fig. 6 **Double-flow type breaking chamber**

changeability of parts and the separate control boxes which contain the electrical system and the oil pressure pump unit etc. are of two standard types, the one for 120kV and below, and the other for 168 kV and above. All of the tests were performed in accordance with JEC–181 and other standard, and all characteristics were guaranteed including the one for short-line faults. The circuit-breakers shown in *Table 2* are all for break-time of three cycles but a report on two cycles breakers for extra high voltages is planned in near future.

The features of the series are as follows:

1) Compactness, large capacity and complete unit system.
2) Lower noise level not achieved previously.
3) Immediate operation is possible only with control and operating power source. No compressed air generator required.
4) All of the main moveable parts are covered.
5) The dynamic seals (valve seats, etc.) of the operating unit are all metal seals which do not deteriorate.
6) All of the packings, etc. are in contact with oil or gas and they have a longer life than those used in compressed air.
7) The oil-hydraulic system is especially constructed to prevent oil leaking, the number of pipes are reduced as much as possible and highly reliable methods are used in the joints.
8) Even with the failure of the auxiliary power supply, the breaker itself can close and open twice and manual-pumping for oil-hydraulic operating unit is possible by the easy connection of a hand pump.

2. Construction

Fig. 7 shows the typical cross section of F-Schalter with two braking units poles. *Fig. 8* shows

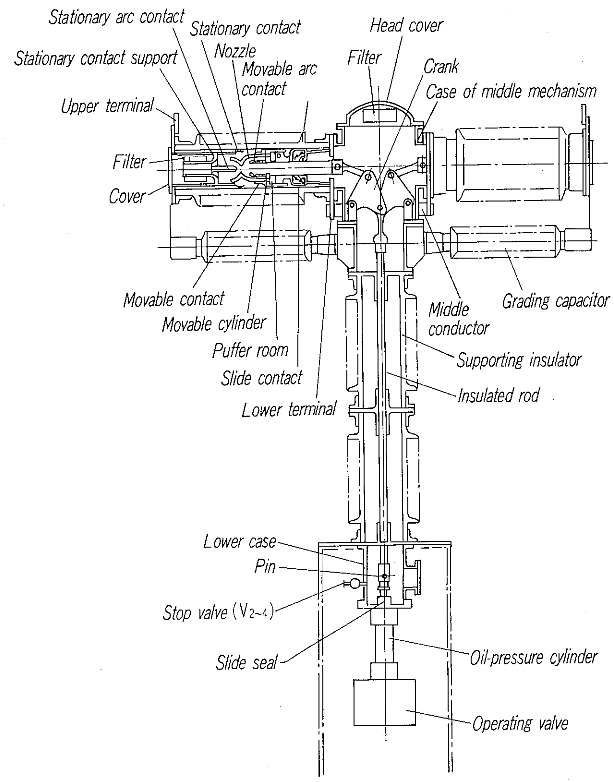

Fig. 7 **Sectional view of 2-break F-Schalter**

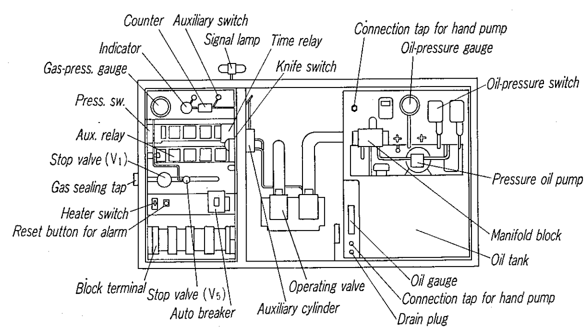

Fig. 8 **Explanatory view of the control box (under 120 kV)**

the internal arrangement of the separate control boxes for the F-Schalter rated at 120 kV and below and *Fig. 9* shows the one for 168 kV and above. *Fig. 10* shows an inner view of the frame for 168 kV F-Schalter.

In the sectional diagram in *Fig. 7*, the operating force reaches the right and left arc quenching chambers from the oil pressure cylinder in the frame via the insulated rod in the support insulator and the top middle crank. When the insulated rod moves upwards, a breaker closes and when it moves downwards, a breaker opens.

In the F-Schalter, each pole of which consists of two breaking units, grading capacitors are arranged in parallel with each breaking unit.

The oil system of 200 kg/cm² and the gas system of 5 kg/cm² are connected in the lower case in the

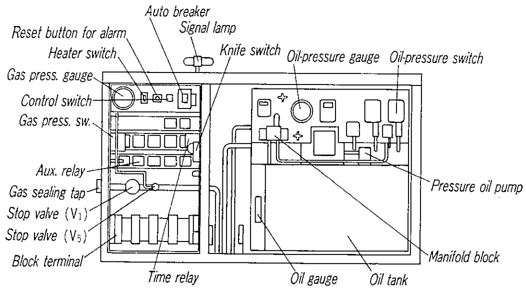

Fig. 9 Explanatory view of the control box (over 168 kV)

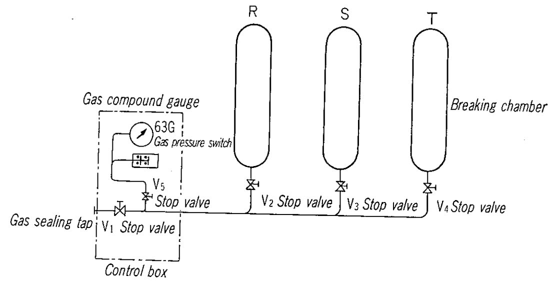

Fig. 11 SF_6 gas system

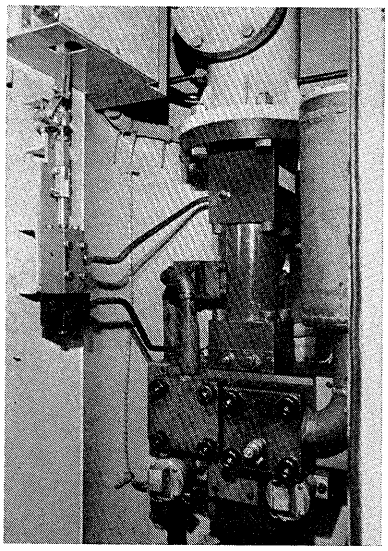

Fig. 10 Innerview of 168 kV F-Schalter frame

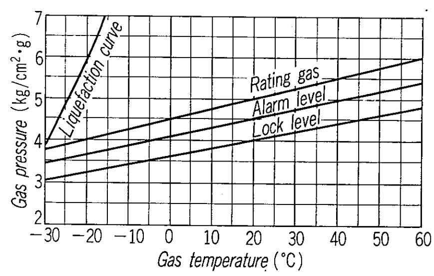

Fig. 12 SF_6 gas pressure control

frame via a two-directional slide seal. The development and production of this part was particularly cautiously made. After continuous operation of 1,000 times, only less than 1 cc. of oil entered into the gas side, and since this oil is actually taken tnto the oil storage part having the capacity of fifty or sixty cc. located in a part of the seal mechanism, no oil enters into the gas side in practice.

The penetration of the gas into the high pressure oil side is so little that it can not be detected and presents no problem at all.

The materials used inside the gas system, the bearings, the surface treatment and the gas sealing method at the flanges are all the same as in the previous series which operate well.

In case of the three-poles common operation type, the operating valves are arranged in the middle of the separate control boxes as shown in *Fig. 8*. The electrical and gas systems are arranged on the left side and the oil-hydraulic system on the right side. The oil pressure system and the electrical system are separated by a dividing wall, so the electrical system will not be effected even when there is oil or mist spray on an accident. The oil-hydraulic pump unit on the right pumps the oil from the lower oil tank into accumulators by raising the pressure and raising it upwards through the filter, and is provided with a pressure control system in the oil-hydraulic system. The electrical system, operating valves and pump units are all interchangeable not only among the same types but also among the different types.

The oil-hydraulic control valves developed for those series consist of five types of valves such as control valves, operating valves, etc. arranged in longitudinal blocks. These are connected together by bolts to form a single unit and since they form a single valve, and have no pipes to connect each other.

Fig. 10 shows the inner view of the frame of a single-pole operating type (ex. 168 kV F-Schalter). The lower case on the lower part of the support insulator, the oil-hydraulic cylinder and the oil-hydraulic control valves form a single unit and there are absolutely no useless pipes.

Fig. 11 shows the gas system. Gas seal detection is performed by a two contact type pressure switch with a temperature compensator. *Fig. 12* shows the gas pressure control system.

The oil pressure is normally set at between 200 and 190 kg/cm², the lock of reclosing is set at 182.5 kg/cm² and the minimum guaranteed pressure for rated operation is 160 kg/cm². Even when the auxiliary power supply is cut off, the breakers can close and trip at least twice by the oil pressure in the accumulators.

Fig. 13 shows the oil pump-up time characteristics.

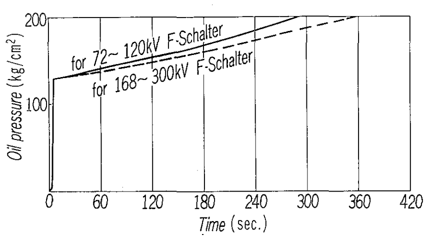

Fig. 13 Pump-up time

When the oil pressure of 200 kg/cm² drops to less than 190 kg/cm², the pump operates to increase the pressure. The pump operating frequency should be normally less than once an hour. In practice, it operates once every 4 to 6 hours.

IV. PRACTICAL APPLICATION

1. Improvement of Maintenance Characteristics

Though it has already been made clear that gas circuit-breakers are excellent in respect to maintenance, the overall maintenance characteristics have been improved by the use of the oil hydraulic operating unit.

1) The compressed air generator becomes unnecessary and an oil pump unit is attached but the inspection intervals for both of these differ as can be seen in *Table 3*.
2) The mechanism is in oil or SF_6 gas so that there is little danger of rust, lubrication defficiencies, etc.
3) The valve seats in the oil-hydraulic operating unit are all made of metal so that they can be used semi-permanently and there are no changes in characteristics due to deformation.
4) *Table 4* shows the standard of inspection. At present, the inspection intervals of three years for ordinary inspections and six years for detailed inspections are the same as those for conventional F-Schalters but in the future, these intervals will be prolonged if the results are favorable.
5) Nitrogen gas is added to the accumulator once every three years or every 2,000 operations.

Table 3 Comparison of inspection cycle for air-compressor system and oil-pump unit

Item \ Classification	Air-compressor system	Oil-pump unit
Exchange of oil	Lubrication oil: every 7 months	Operating oil: every 6 years
Drainage	every 3 months	every 6 years
Adjustment of belt lengthening	every 6 years	—
Cleaning of filter	every 1 year (air filter)	every 6 years (oil filter)
Disassembly inspection	every 6 years	every 6 years

Remarks: Under the supposition that air-compressor system would run 30 minutes per day

Table 4 Inspection table

Kind of inspection	Intervals of inspections	Inspection times	Instruments required
Routine inspection	Daily	—	—
Ordinary inspection	Once every 3 years or every 2,000 operations	≦120 kV: 2 persons 3 hours ≧168 kV: 2 persons 4 hours	Precision pressure gauge (gas and oil), accumulator accessories, SF_6 gas addition device, SF_6 gas cylinder, N_2 gas cylinder
Detailed inspection	Once every six years	≦120 kV: 4 persons 8 hours ≧168 kV: 8 persons 8 hours (except the items for inspection every 12 years)	Precision pressure gauge (gas and oil), accumulator accessories, gas recovery device or vacuum pump & SF_6 gas addition device, hand pump, SF_6 gas cylinder, N_2 gas cylinder, filter replacement tool, contact disassembly tool
Provisional inspections	Rated current interruption: 10 times, Load current interruption: 1,000 times, Small current switchings: 4,000 times, Total operations: 10,000 times; when any of the above are reached or a fault occurs	(Differs according to conditions)	(Differs according to conditions)

2. Verification of the Practicability

In the autumn of 1972, the tests of the new F-Schalters rated at 72/84 kV, 168 kV and 300 kV were started. About 100 items to be verified were decided on the basis of the our practical use standards.

Previously, it was generally considered that it was satisfactory to completely fulfill the test items specified in JEC-181 or other standards concerning circuit-breakers. However, the concepts have changed for these newly developed breakers and we have pro-

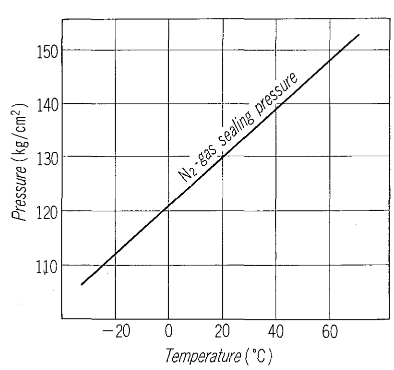

Fig. 14 N_2-gas pressure sealed into accumulator (oil pressure = 0)

Table 5 **Check list for practical use (abstract)**

Classification	No.	Items			Points
Oil-hydraulic operating unit	27	Heat	Heat expansion for piping		Bending and tie bolt stress when a load is applied in the cylinder flange
	28	Earthquake proofing	Shock during transport		Vibration test for pump unit
	29		Application of vibration to device		Vibration test for circuit-breaker
	30		Load stress for piping		Bending the pipe with distance piece in base
	31		Loosening of tightened parts		Check with torque wrench during vibration test with continuous operation test
	32	Oil deterioration	Water	Entry of water in oil tank	Check filter pressure loss after long inactivity
	33			Effect of water on tank bottom	Actual test with water filled
	34		Dust	Pipes, etc.	Check for pipe flushing, welding method, ambient site problems
	35			Valves, pressure switches, etc.	Test for entry of dust after long inactivity
	36		Air	Natural mixing	Check for first operating characteristics after long-time inactivity
	37			Bubbles in tank	Survey by sampling after continuous switching during cold weather
	38				
	39	Life and durability	Pump	Continuous life	Continuous operation test at 250 kg/cm² by 5 pumps
	40		Pressure switch		Durability test with connection of Solenoid valve (10,000 times)
	41		Oil system	Durability	Disassemble after 10^4 operations and detailed inspection (dimensions, deformation)
	42		Intermittent operation	″	Perform intermittent operation at time of long term inactivity test and check characteristics
	43		Packing	Life	Oil deterioration promotion test of O-rings and packing samples at Central Laboratory
	44		Quick coupler	Durability	Operation test (continuous)
	45		Packing	Wear	Check by continuous operation of oil-hydraulic cylinder packing
	46		Synchronizing device	Effectiveness and withstand ability	Check operating characteristics during cold withstand site test before and after continuous operation test
	47		Air removal	Durability rust	Surface of perforated air removal sheet (inactivity test)
	48		Mini-cylinder	Durability of seal construction	Leak test after continuous operation test
	49		Solenoid	Durability	After continuous operation test (deformation check of pins, sheets)

ceeded the verification tests mainly to check the reliability on the running condition. Some of the items are summarized in *Table 5*. Among these, the long term test using a single-pole unit rated at 168 kV has been in progress since the beginning of this year but the others have already been completed.

V. IMPROVEMENT OF THE BREAKING CHARACTERISTICS BY MEANS OF THE OIL-HYDRAULIC OPERATINC UNIT

The breaking characteristics are greatly improved by the use of the oil-hydraulic operating unit. The following points were carefully considered in the development.

1. Improvement of Breaking Characteristics during Large Current

In single-pressure type gas circuit-breakers, the blast pressure increase at the instant of opening is related to the opening time, etc. and is generally a comparatively low value. For this reason, the arc handling capacity due to enthalpy flow shall be improved during the large current period, and influence during the large current period must be reduced as much as possible not to remain up to the current zero point, and the flow must be recovered in such a way that the gas blast is performed effectively at the current zero point. Therefore, such a construction that the effective blast area in the nozzle becomes large in a short time must be adopted and the blast pressure should be high.

Fig. 15 shows a comparison of the blast pressure increase and the stroke characteristics between the conventional spring breaking system and the newly developed oil hydraulic system. The value of the blast pressure increase is approximately 2.2 times that of the conventional type, and the movable contact speed is also increased by 50%.

As the arc handling capacity due to enthalpy

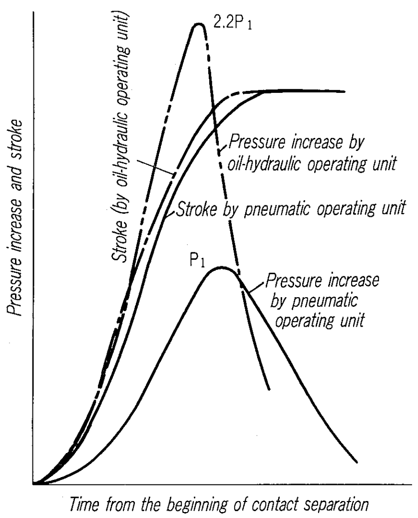

Fig. 15 Comparison of no load characteristics

flow is proportional to the pressure increase values, it has been improved greatly by the adoption of the oil-hydraulic operating unit. And the fact shows that the flow surface of the cooling gas is large and sectional area of arc is conversely small, and so an improvement of the breaking characteristics near the current zero point is gaind.

The energy flow within the nozzle becomes greater at the downward side because it is injected by the arc. Therefore, sufficient consideration was also paid to the section area of the downflow side of the nozzle throat.

2. Improvement of the Breaking Characteristics near the Current Zero Point

Near the current zero point, minimizing the effect during the large current period the arcing time constant τ, must be smaller and the arc loss N_0 must be larger.

The arcing time constant which is more important in respect to the breaking characteristics is proportional to the sectional area of arc and it is desirable to have the sectional area of arc near the current zero point as small as possible.

In the case of large current breaking, the arc time constant τ is expressed as follows in relation to the sectional area of arc. "A" is a constant determined by the type of gas and the construction.

$$\tau = A \cdot \frac{\omega I_m}{\sqrt{p}\left(\frac{q}{p} \cdot Vp\right)^{3/2}} \quad \cdots\cdots\cdots\cdots(1)$$

where ωI_m: gradient at the breaking current zero point when there is no arc

p: pressure

q: speed of flow

Vp: pressure gradient

The value of τ increases in proportion to the gradient of breaking current and when the pressure increases, it decreases by the ½ power, and also depends on the geometrical form of the nozzle.

The restriking voltage increase rate dV/dt when the restriking voltage increases in a comparatively linear manner such as in a short-line fault breaking can be shown approximately as follows:

$$\frac{dV}{dt} = \frac{1}{2} \cdot \frac{N_0}{\omega I_m \cdot \tau^2} \quad \cdots\cdots\cdots\cdots(2)$$

Considering this, the breaking characteristics can be greatly improved by making τ smaller, even slightly. As is shown in *Fig. 15*, the pressure increase in the breaking chamber in case of the oil hydraulic drive is twice as much as that in case of the conventional drive and the breaking characteristics have been greatly improved.

VI. TEST RESULT

1. Operation Test

In the oil-hydraulic operating unit, change in the air temperature causes the changes of viscosity of the operating oil and so the effects on the operation characteristics should be confirmed. For this reason, operation test was performed using the oil which had the same viscosity at normal temperature of the operating oil at the upper and lower temperature limits as specified by JEC. The results showed that there was absolutely no problem at the upper limit of 40°C and also at the lower limit of −20°C, there was no deviation among the three-poles operations but at the low temperature, the opening time was extended by about 12% (3.5 ms) and the closing time by about 11% (12 ms). However, the ratings are still satisfied.

Since the amount of oil required for one operation changes slightly in accordance with the temperature changes, it is necessary to decide the accumulator capacity by the maximum amount of oil required at low temperature operation. However, it was proven that the accumulator has sufficient capacity for two closings and openings each at −20°C.

Because of the non-compressability and inertia of the oil, there might be changes in the contact speed and the stroke curve during high speed reverse operation such as during reclosing. The results of the confirmation test concerning this point were exactly the same as during ordinary operation. This indicates that the changeover speed of the operating valves is sufficiently high.

For details concerning the operation characteristics, refer to the article "Newly Developed Oil-Hydraulic Operating Unit for Circuit-Breakers."

2. Temperature Test

Fig. 16 shows an example of the temperature test results.

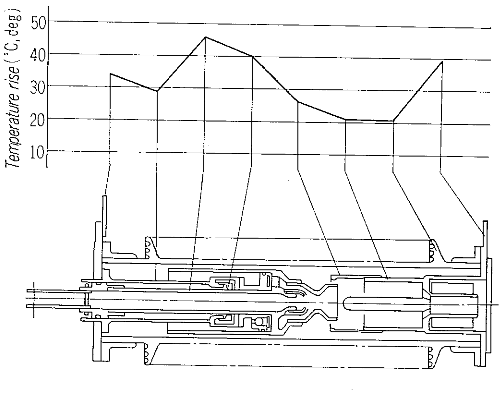

Fig. 16 Test results of heat-run (4,000 A, 60 Hz)

Table 6 Flash over test results

	Item	Dry Positive polarity	Dry Negative polarity	Wet Positive polarity	Wet Negative polarity
72/84 kV	Main terminals to earth	higher than 480 kV	higher than 620 kV	higher than 510 kV	higher than 570 kV
	Between main terminals of same phase	higher than 480 kV	higher than 620 kV	higher than 510 kV	higher than 570 kV
168/204 kV	Main terminals to earth	higher than 1,270 kV	higher than 1,300 kV	higher than 1,300 kV	higher than 1,270 kV
	Between main terminals of same phase	higher than 1,270 kV	higher than 1,300 kV	higher than 1,300 kV	higher than 1,270 kV

(Wave form $1 \times 40 \mu s$)

3. Insulation Test

Table 6 shows the results of the flash over test. In the single-flow breaking chamber, the metal ring type electrodes are provided on the fixed contact side and the potential distribution between the contacts has been improved. By this means, the uniformity of both the positive and negative polarity

Table 7 Flash over test results (0 kg/cm²·g)

Item	72/84 kV	168/204 kV
Main terminals to earth	50 Hz 97 kV 1 min. not flashed over	50 Hz 236 kV 1 min. not flashed over
Between main terminals of same phase		

Table 8 Results of interrupting test

Circuit-breaker	Items of test		Operating sequence	Test circuit	SF_6 gas pressure	Test results (for one breaking unit): Test voltage (kV)	Breaking current: kA	Breaking current: DC component (%)	Arc time (~)	Restrikig voltage: Rate of rise (kV/μs)	Restrikig voltage: Peak value (kV)	Remarks
BAP 2 (Single-flow)	Bus terminal fault	100% *I*	O–1M–C′O–3M–C′O	Weil synthetic	4	122.6	32.5	18.7~56.8	0.8~0.9	1.16	242	Peak value of making current 92 kA
	Multiple fault	78% *I*	〃	〃	〃	122.6	32.5	18.7~56.8	0.8~0.9	1.16	242	
	Out of phase fault	25% *I*	O–3M–O	〃	〃	159.6	8.0	12~14.5	0.75~1.1	0.78	315	
	SLF	90% *I*	〃	〃	〃	72.4	28.5	11~20	0.75~0.85	7.67	143	
	Leading small current	30%, 100% I_C	O × 12 times	Single phase direct S & S synthetic	4	87	34A 105A	—	0.15~0.45	—	—	
	Inductive small current	30%, 100% I_C	O × 12 times	Single phase direct	6	104	7A 20A	—	0.1~0.60	—	—	Over voltage: less than 130%
BAP 3 (Double-flow)	Bus terminal fault (40 kA)	100% *I*	O′0.35S-C′O-1M-C′O	Weil synthetic	4	93.4	41.5	4~60	0.45~0.80	0.97	185	Peak value of making current 107 kA
	Bus terminal fault (50 kA)	100% *I*	〃	〃	〃	120.1	50.5	12~55	0.55~0.90	0.96	239	
	Multiple fault	78% *I*	〃	〃	〃	93.4	41.5	4~60	0.45~0.80	0.97	185	
	Out of phase fault	25% *I*	O–3M–O	〃	〃	136	10.3	5~14	0.80~0.81	0.56	240	
	SLF (40 kA)	90% *I*	〃	〃	〃	68.7	37.0	3~5	0.75~0.85	5.37	136	
	SLF (50 kA)	90% *I*	〃	〃	〃	65.6	45.0	0~16	0.65~1.1	5.05	132	
	Leading small current	30%, 100% I_C	O × 12 times	Single phase direct S & S synthetic	〃	89	56A 160A	—	0.07~0.57	—	—	
	Inductive small current	30%, 100% I_C	O × 12 times	Single phase direct	6	77.1	6A 20A	—	0.07~0.60	—	—	Over voltage: less than 150%

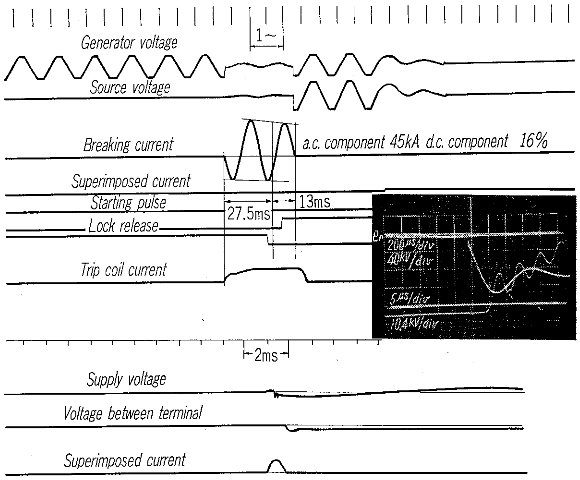

Fig. 17 **Oscillogram of 300 kV 50 kA SLF**

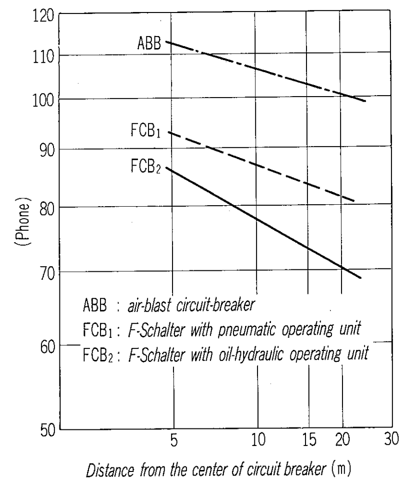

Fig. 18 **Operating noise of 84 kV-circuit breakers**

of the withstand voltage between the contacts has also been improved. *Table 7* shows the flash over test results assuming that the pressure of the SF_6 gas dropped to atmospheric pressure.

4. Breaking Test

The results of the breaking test are shown in *Table 8*. *Fig. 17* shows the oscillogram for 90% short-line fault breaking test by the F-Schalter rated at 300 kV and 50 kA.

5. Noise Test

The main advantage of the F-Schalter with oil-hydraulic operating unit is the low noise level. Naturally, the noise level can not be lowered sufficiently simply by using oil pressure. The noise level could be greatly reduced by making the moving parts light, and dampening the shocks during speed reduction by means of an oil pressure cushion provided in the oil hydraulic cylinder.

Fig. 18 shows the noise level characteristics of the new 70 kV class F-Schalter in comparison with the conventional air-blast circuit-breaker and the gas circuit-breaker with pneumatic operating unit. The noise level is about 10 phons lower than in the conventional models, and the frequency component is shifted to the lower frequency region. Therefore, there was almost no noise which weighs our mind although in front of the breaker (refer to *Fig. 19*).

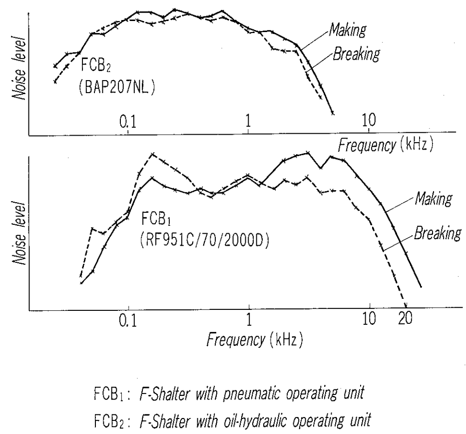

Fig. 19 **Frequency analysis of operating noise**

VII. CONCLUSIONS

This article has given the basis for the development and the performance of the newly developed single-pressure type F-Schalter gas circuit breaker with the oil-hydraulic operating unit. As the first manufacturer applied an oil-hydraulic operating unit produced in Japan to the single-pressure type gas circuit-breakers, we intend to continue the investigations of the basic and practical characteristics of these breakers in the future.