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OIL-HYDRAULIC OPERATING UNIT FOR SF_6 GAS CIRCUIT BREAKER

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I. INTRODUCTION

It is not recently that oil hydraulic techniques have been applied to circuit breakers and used as a drive medium. It dates back to mid 60's.

In Japan, oil is used as the arc quenching medium, but it has hardly any concern with oil hydraulic engineering and seems to be slightly lacking on the application side. Recently, oil hydraulics is receiving fresh attention as a drive medium. This is owing to the following requirements.

1) Reinforcement of the response and operating ability in keeping with increase in speed and capacity of the single pressure type circuit breaker.
2) Conciliation of operating functions in keeping with increase in reliability of SF_6 gas sealing and grade up of maintainability based on this.
3) Measures for low noise, and so on.

To cope with these requirements, Fuji Electric has been aiming at oil hydraulic operating mechanism since a few years ago, developed a purely domestic product for the first time in Japan and announced 72~300kV, 31.5~50kA, single-pressure type gas circuit breakers employing oil hydraulics. Various trial manufacture experiments, on-the-site tests, and actual performance tests have been performed and the company has so far produced more than 130 units including those having 3 years of operating experience and those under production.

In the background of the development and delivery experiences, this paper gives an outline of the oil hydraulic operating mechanism in continuation with the previous report, as well as a description of, specially, problems concerning reliability of apparatus requiring attention from the point of view of actual performance and measures for solving these.

II. FEATURES OF FUJI OIL HYDRAULIC OPERATING MECHANISM

1. Constructional Features

1) 210kg/cm^2, the most widely standardized and stable pressure used in Japan, is used as the hydraulic pressure source, therefore, there is high reliability.

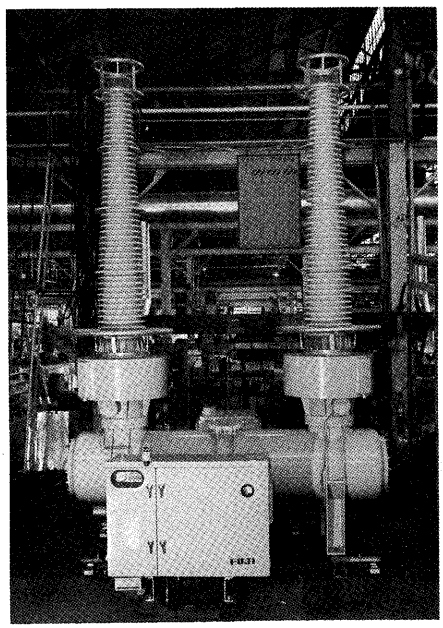

Fig. 1 240/300kV, 50kA, 2,000/4,000A SF_6 gas circuit breaker

2) Domestic components conforming to the JIS and other domestic standards are used and number of each component has been kept to a minimum assuring high reliability and easy maintenance.
3) All single units are block type so that piping has been thoroughly reduced and all connections use O ring seal system, therefore, there is no problem of leakage.
4) Moveable parts are immersed in oil and are not exposed to the air, thus there is no worry of rusting and safety is high.
5) Since high quality aircraft hydraulic oil is used, deterioration is small and there is no problem of public hazard.
6) The construction provides for measures against hazards and safety against fire.
7) The cushion is contained inside the cylinder, the construction is simple and shock is less.
8) The accumulator is specially developed to sufficiently withstand use at −35°C.
9) Common use of parts throughout the system.

2. Performance Feature

1) Small size and large capacity, both opening and closing are accomplished by hydraulic power, therefore, operating power is large and response is good.
2) Since it employs sealed construction, it is low noise and is best suited as a low-noise circuit breaker.
3) Can be immediately operated if operating power source is available. Compressor is unnecessary.
4) Equipped with functions to satisfy domestic and foreign standards.
5) The drive mechanism possesses a self-hold function to keep the original position of valve even if the oil pressure drop accidentally except when operating.
6) Automatic detecting circuits are appended to detect loss of the N_2 gas contained in the accumulator, malfunction of oil hydaulic pump and oil leakage.
7) To cope with troubles in the oil pump or auxiliary AC power source, an emergency use DC pump is separately provided so that the operation can be continued by simply a one-touch operation.
8) Two openings and closings are possible even when the auxiliary AC power is disconnected. (these figures can be increases by increasing the capacity of the accumulator or of the pump.)

3. Maintenance and Inspection Features

1) Since the packing is in touch with the oil, its life is far longer as compared with its use in compressed air. Moreover, since a metallic valve seat seal is used, there is no problem of deterioration.
2) Greasing and oiling are unnecessary.
3) Since a compressor is unnecessary, items concerning maintenance of compressor have been completely eliminated.
4) The operating valve and pump unit are housed together inside the control box for the ease of disassembly, inspection and maintenance.
5) All the operating valves, etc. of the pump unit employ block coupling system thus making maintenance and inspection extremely easy.
6) Oil pumping up time is short (approximately 5minutes) unlike a compressor which requires a long pumping up time of about 4~5 hours, thus remarkably reducing the time required for making preparations for operation.

4. Quality Control Features

1) A large number of actual performance assurance tests are performed to assure high reliability.
2) Individual parts have been subjected to highly precise characteristic tests in accordance with exclusive test standards.
3) Inspection system using freon or SF_6 gas is employed for detecting oil leakage.

III. CONSTRUCTION AND OPERATION OF OIL HYDRAULIC OPERATING MECHANISM

1. Composition of Apparatus

The oil hydraulic operating mechanism consists of 4 elements, a pump unit as the pressure generating device, an accumulator basic having the function of instantaneously transmitting oil pressure and preserving the energy, an operating valve to accomplish the operating duties assigned to the circuit breaker and to control, and an oil cylinder to drive the circuit breaker contact. The oil hydraulic circuit for all circuit breakers consists of a combination of these 4 elements.

In the entire breaking system of 72~300kV, there is one set of pump unit for one circuit breaker. The pump unit has a capacity in accordance with the pumping up time required for the operation, and other constituent parts are all common.

The accumulator and operating valve are also one each for each phase or one each for one circuit breaker depending on the breaking capacity and whether or not a single-phase reclosing circuit is present. However, in either case same parts are used for all the systems.

Specifications of the oil hydraulic cylinder slightly differ with the operating speed and required capacity of the breaker contact, but the basic construction and shape of each part is the same permitting full interchangeability. There are two systems of coupling the oil cylinder with the breaker contact. In one system, a cylinder is provided in each phase and directly connected to an insulated rod and in the other system, it is connected through a link for changing the stroke. However, in either case since the oil hydraulic section and the gas section are connected through the shaft of the oil cylinder, the parts are not exposed to the air and the construction is oil sealed as well as gas sealed. *Fig. 2* and *3* show two examples of oil hydraulic circuit based on the operating system. *Fig. 2* shows the directly connected type oil cylinder 3-phase simultaneous operation and *Fig. 3* shows the case of single phase reclosing type. The 240/300kV 2-cycle circuit breaker employs the latter construction.

In the case of the single-phase reclosing system, since interphase gap is long, back pressure at the time of operation can not be neglected. For this reason, oil drain is first stored in the auxiliary tank and then transmitted to the oil tank of the pump unit. In either circuit, all circuits except the air suction port of the oil tank are of sealed construction. Moreover, all but the pipe connecting each unit employ the internal coupling system (coupled inside the block) and external piping is not used. *Fig. 4* and *5* show an exterior view of the 72/84kV insulator type circuit breaker and the layout of the oil hydraulic parts inside the control box. As can be clearly seen in *Fig. 5*, the hydraulic parts and electrical apparatus are housed separately in the control box permitting handling ease and at the same time providing preventive measure against fire. *Fig. 6* shows the pressure set values of this oil hydraulic system. The pump up characteristic of the 72~120kV class 3-phase simultaneous operating type circuit breaker is shown in *Fig. 7*. The time required to attain the rated pressure from the start is only about 5 minutes, permitting drastic reduc-

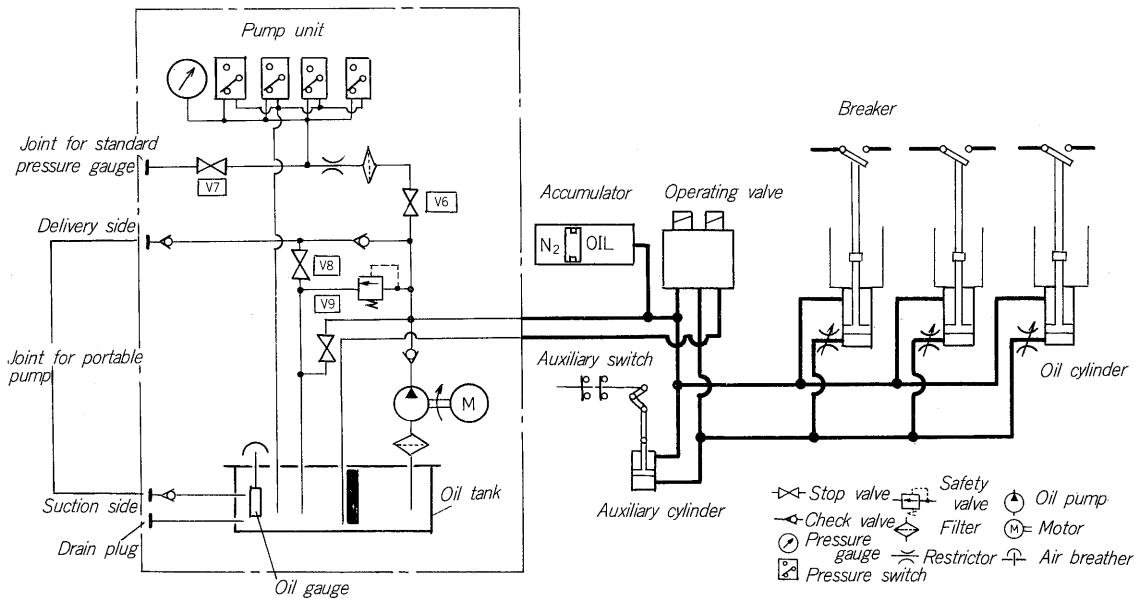

Fig. 2 Oil-hydraulic circuit of SF_6 gas circuit breaker (3 poles simultaneously operating type)

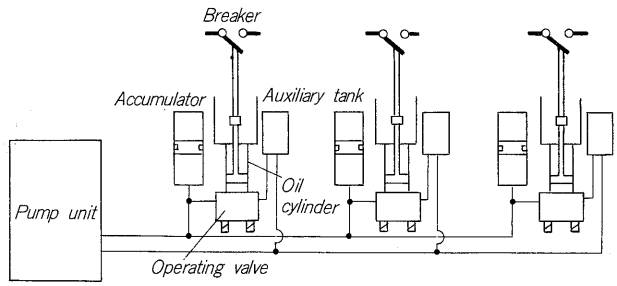

Fig. 3 Oil-hydraulic circuit of SF_6 gas circuit breaker (each pole separately driven)

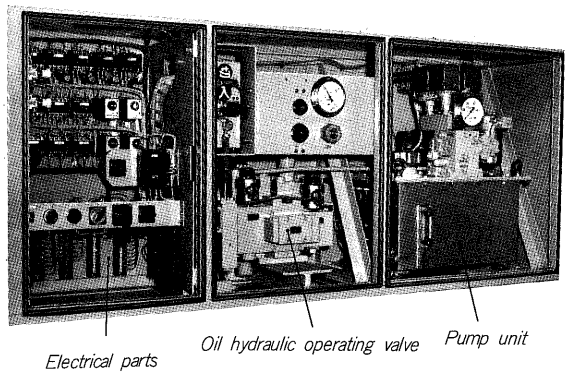

Fig. 5 Oil-hydraulic operating unit

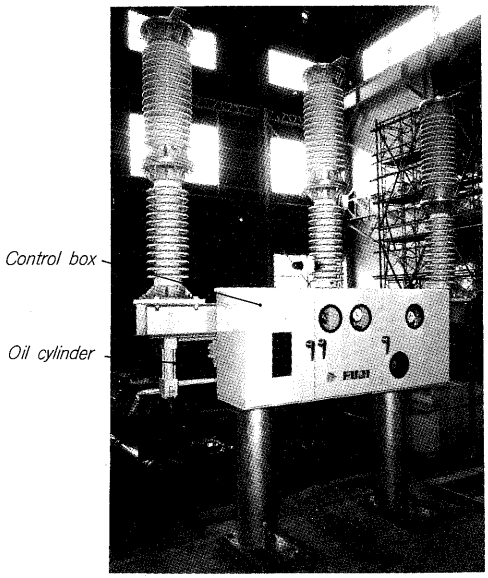

Fig. 4 SF_6 gas circuit breaker (72/84kV, 31.5kA)

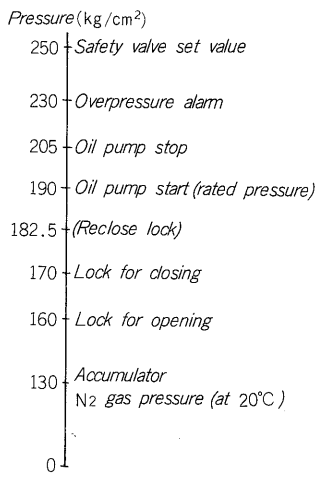

Fig. 6 Oil pressure control valves

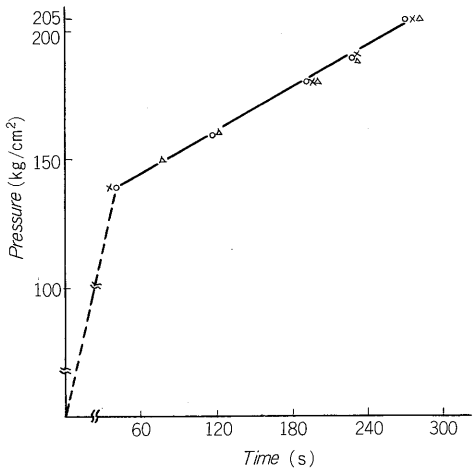

Fig. 7 Pump-up time

tion in the time required for making preparation for operation.

2. Principles of Operation

The pressurized oil obtained from the pump unit is stored in the accumulator within a fixed pressure range at all times and a large amount of the oil is supplied to the oil cylinder at the time of operation. The pressurized oil is also supplied to the rod side of the oil cylinder at all times. The oil cylinder is differential type and the circuit breaker is closed and opened entirely oil hydraulically. That is, when pressurized oil is supplied to the side opposite to the rod side, the cylinder performs the closing operation and when this pressurized oil is discharged to the oil tank through the operating valve, the cylinder performs the opening operation. Thus the oil hydraulic cylinder is operated in accordance with the operation of the circuit breaker by switching of the various valves contained inside the operating valve. That is, the operation is performed by simply feeding the oil to or removing it from the side opposite to the rod side, thus greatly simplifying the principle of operation.

3. Oil Hydraulic Parts

1) Pump unit

The unit is divided into 3 blocks as shown in *Fig. 2.*

(1) An oil tank and a pressure generator consisting of an oil gauge, an air breather, an oil pump, a filter and a motor.

(2) A pressure operating block comprising a safety valve, a stop valve, a throttle valve, a filter, etc.

(3) A pressure monitoring block consisting of a pressure gauge and a pressure switch.

The parts can be assembled and disassembled independently, blockwise or pumpwise.

Each part employs the cartridge system for the ease of maintenance and inspection. For example, in case of trouble, the pressure switch block can be independently removed without affecting the other systems. Thus blockwise replacement is possible. Aircraft hydraulic oil (MIL-H-5606) of high quality, less temperature dependence and good viscosity characteristic is used as the working oil. The oil does not contain any harmful matter that could have a bad effect on human body.

As mentioned above, the oil hydraulic circuit is of sealed construction so that foreign matter, etc. can not enter and mix with the oil. However, for the sake of safety, a filter is mounted at the air intake port. Moreover, a 10μ filter (cartridge type) is also used on the suction side of the pump in order to prevent beforehand pump troubles caused by entry of foreign matter into the high pressure system. A long lasting and easy to handle gear pump of simple construction is used as the oil pump.

Moreover, there is no fear of the apparatus being damaged in the event of abnormal pressure rise in the circuit because the system is protected by means of a safety valve. As compared with other valves, the safety valve used in this system is a directly operated type valve of simple construction and good sealing effect. Among the other pressure control apparatus, specially the pressure switch is an important part for which many things have to be considered regarding its use and selection of the type. In this oil hydraulic system, a throttle for preventing the pulsating motion is used on the primary side in order to prevent misoperation of the pressure switch contact due to the pulsating motion at the time of operation and this, together with the measure taken to prevent electrical misoperation, provides a perfect safety measure.

For block coupling, the pump unit employs the O ring and bolt system and external piping for the high pressure system is not used. An exterior view is shown in *Fig. 5.*

2) Accumulator

There are two representative types, the bladder type and the piston type. When using for circuit breaker use, the quality of piston packing must be such that the sealing effect is destroyed at high as well as low temperatures and the packing must be long lasting. In this sense, the piston type is ideal and does not have the defects of permeation of N_2 gas, ageing, durability, etc. of the bladder type. With the piston type, the capacity can be adjusted to optimum according to the work of the circuit breaker by simply adjusting the length of the tube without any need to change the internal construction. Therefore, since the construction is consolidated and simplified, there is no disparity of maintenance due to difference in the capacity.

3) Operating valve

A cross sectional view of the operating valve is shown in *Fig. 8* and an exterior view in *Fig. 9.*

This operating valve employs the simplest circuit satisfying the performances given in the specification, consists of an opening solenoid valve, a closing solenoid valve, a pumping stop valve, a servo valve and a main valve (total 5 valves), and is combined by block construction. An operating valve for the 2 cycles circuit breaker is obtained by employing a high-speed tripping solenoid valve and the basic configuration of both the operating valve for the 2 cycles circuit breaker and for the 3 cycles circuit breaker is identical.

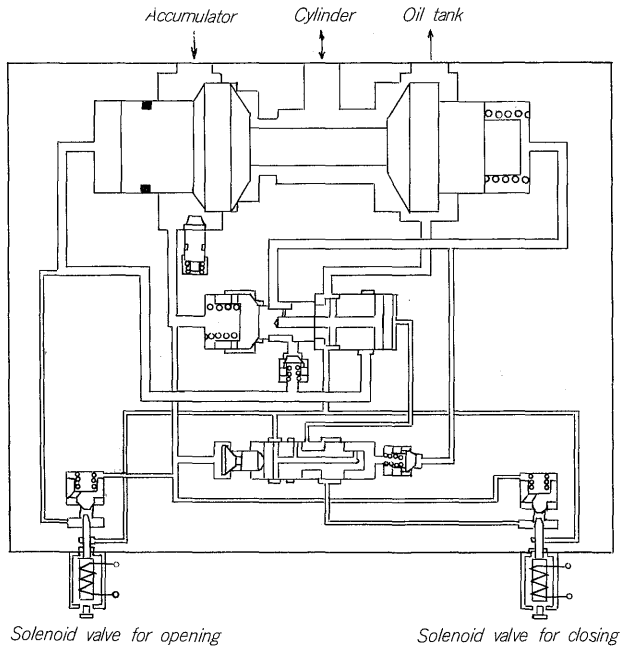

Fig. 8 Construction of operating valve

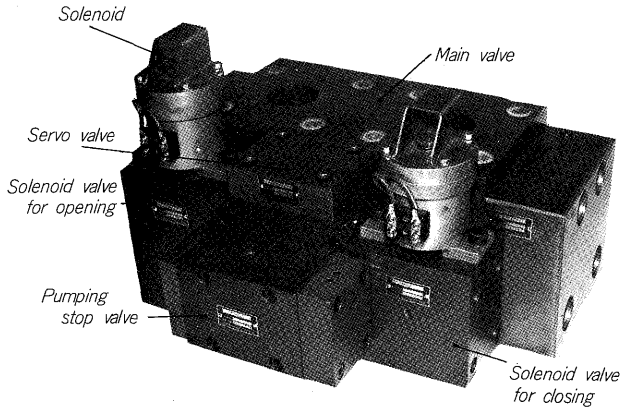

Fig. 9 Operating valve

Each valve employs poppet construction to reduce internal oil leakage. Moreover, the construction is also resistant to change in viscosity with temperature. The operation start time of the cylinder and speed, that is, moving characteristic of the circuit breaker contact depend on the main valve's operating time and the diameter of its opening. For high speed, the valve is extremely small type, fluid resistance of the pilot is reduced and at the same time load of the solenoid valve is made small, and a special stable type valve is used so that the main valve can be driven with minimum volume flow. At the time of opening operation, the signal of the solenoid valve cancels the retaining force of the main valve, the balance is upset and immediately after the operation starts in a few milliseconds, the main valve runs itself and external force becomes unnecessary. Moreover, the main valve has a self-hold mechanism to maintain the existing position. Even when the oil pressure drops except when it drops due to the operation in the opening or closing state, the position prior to the drop in pressure can be surely maintained. From the performance point of view, the point to be paid attention to regarding these valves are durability of the metallic seal, strengthening of the sealing ability, and elimination of foreign matter. For this purpose, selection of material, precision of dimensions and hardness, control of spool gap, control of cleanness of the working oil by means of a filter or some other cleaning device are necessary. However, it won't be an exaggeration if we say that if the original oil hydraulic apparatus is very durable as described before and production is controlled at a constant level, durability in actual system will be semi-permanent.

4) Oil cylinder

The oil cylinder is so-called differential type and consists of a tuning device to adjust for operational differences, a piston drive section, a cushion mechanism, a rapid start device, and an SF_6 gas seal mechanism. The circuit breaker use oil cylinder differs from an ordinary one in that since the speed is remarkably high, a breaking device is necessary at the end of the stroke to instantaneously relieve the mechanical shock and on the other hand, because of the high speed of the circuit breaker, initial start has to be very quick. Moving characteristic of the cylinder is closely related to the operating valve and bears a direct effect on the arc quenching ability of the circuit breaker.

Fuji Electric performed various experiments concerning this in the trial manufacture stage and developed an optimum simplified configuration for circuit breaker use, which is being applied in actual practice. At the same time, a computerized operation analysis program including the entire oil hydraulic system and the breaking section has been developed to check compatibility with the test results.

An exterior view of the oil cylinder (72~120kV use) is shown in *Fig. 4*. The moving part is not expose to the outside but is driven inside the oil so there is no need of oiling and safety is improved.

IV. ACTUAL PERFORMANCE

There are various problems concerned with the reliability in actual performnace.

As already explained, most of the circuit breaker troubles lie with the operating mechanism, therefore, Fuji Electric has established more than 100 verification test items in the development stage and has systematically performed actual test. An outline of this has already been published, but his chapter describes the necessary points concerning the matters experienced with regard to the actual problems involved in operating and in the characteristic tests after delivery at the site. Moreover, an outline of the corrective measures is also given.

1. Operating Experience

After 2 years of operation in an actual system, general construction inspection and characteristic test of opening/closing time, etc. were performed for the 72/84kV class circuit breaker having an operating history of 1000 times. The results are shown in *Table 1*. As evident from this table, as

Table 1 Mechanical inspection and characteristics (after operating for 2 years)

Item				When Installed	After 2 Years (After 1000 Times of Operation)
Inspection of construction	General construction inspection			Good	Good
	Oil leakage (external, internal)			Good	Good
	SF_6 gas leakage			Good	Good
	Accumulator N_2 gas leakage			Good	Good
	Pressure switch operation test	SF_6 gas use	Low pressure lock (lock/release)	3.9/4.2kg/cm²	4.0/4.3kg/cm²
			Low pressure alarm (lock/release)	4.4/4.7kg/cm²	4.5/4.8kg/cm²
		Oil hydraulic use	Opening lock (lock/release)	160/170kg/cm²	159/170kg/cm²
			Closing lock (lock/release)	170/180kg/cm²	170/180kg/cm²
			Pump operation (operation/stop)	190/205kg/cm²	190/206kg/cm²
			Overpressure alarm (alarm/release)	225/218kg/cm²	225/220kg/cm²
	Safety valve (start)			250kg/cm²	251kg/cm²
Open/close test	Manual operation test (closing, opening operation)			Good	Good
	Minimum operating pressure		Closing operation	125kg/cm²	125kg/cm²
			Opening operation	125kg/cm²	125kg/cm²
	Operating characteristic		Closing time (100% pressure)	87 ms	88 ms
			Opening time	25 ms	25 ms
			3 phase unbalance (closing/opening)	0/0 ms	0.3/0.2 ms
	Accumulator capacity test (CO 2 times)			Good	Good
	Sequence test (alarm circuit, auxiliary relay, etc.)			Good	Good

compared with the results of testing when installed, the results of testing after 2 years show no change, no abnormality at all is found in the characteristic and construction up to details of the oil hydraulic system, and the equipment is confirmed to have sufficient practical performance ability.

2. Vitiation and Deterioration of Oil

Methods of investigating deterioration are mainly classified into at-the-site and laboratory methods. In the former method, the working oil is inspected with naked eye for change in color, extent of impurity, suspendid solids, and offensive odor and judgement is made by comparing with a new oil. In the latter case, a quantitative evaluation is made according to the methods of analysis specified in JIS.

Fuji Electric has performed pursue examinations at fixed intervals (for example, every 1000 hours) of the products after delivery and shelf test by testing circuit breaker and has also been performing quantitative analysis, but no deterioration is seen at present. Compared with an ordinary working oil, the working oil conforming to MIL-H 5606 is manufactured by a very high grade and precise process and is far less liable to deterioration.

3. Fire Preventive Measures

As shown in *Fig. 5*, a precautionary measure is taken by separating the electrical parts by partition walls so that oil may not fall directly on the electrical parts in case of accidental oil spill. A summary of the results of two, three simple test assuming actual oil spill is as follows.

(1) Working oil was sprayed between the contacts of the auxiliary switch and the current was switched on-off, but it did not catch fire.

(2) The heater in live state was covered with a piece of cloth throughly dipped in the oil, but it did not catch fire at all and did not burn even when a flame was brough about 50mm close in this condition.

(3) Did not catch fire even when the heater was immersed in the working oil for 1 hour.

These results confirm that practically there is no problem.

4. Measures in Case of Abnormality

The oil hydraulic operating unit is provided with various electrical and mechanical preventive measures against unexpected abnormalities of the oil hydraulic system. Possible abnormalities and corrective measures are given in *Table 2.*

The emergency use DC pump is used when the oil hydraulic use motor's AC power is cut off or when the AC pump is faulty. The main purpose of the DC pump is to upkeep drop in pressure due to internal oil leakage. The standard capacity is DC 100V, 180W, but it is possible to provide the same ability as that of the AC use oil hydraulic pump by increasing the capacity. Moreover, if required, it is also possible to connect it in parallel with the AC oil hydarulic pump and perform automatic switching. An exterior view is shown in *Fig. 10.*

5. Low Temperature Performance

Low temperature test of the 72/84kV circuit breaker was performed at Nayoro, Hokkaido for about 150 days including the severe winter season from December 1973 to May 1974. The test condition is shown in *Fig. 11.*

During the test, an ambient temperature of −35°C~ −20°C lasted for about one month. As a result of this test, it was confirmed that no abnormality is caused to the oil hydraulic apparatus and the SF_6 gas apparatus in this low temperature condition. This is described in brief in the

Table 2 Measuring in case of abnormality

Abnormality	Auto Detection Circuit	Immediate Measures
Oil leakage	Pressure switch Timer for monitoring pump operating time	Visually determine if it is internal leakage (high pressure → low pressure) or external leakage. Since both the mainbody and operating unit are equipped with an original state self-hold device, a major accident will not occur if left as it is for sometime.
Accumulator N_2 gas leakage	Timer for monitoring pump operating time	After timer's alarm, see the oil level. If the level of oil is found to be low, N_2 gas is leaking. However, since malfunction will not occur soon, add N_2 gas when convenient.
Pump use motor faulty	Internal short: detect by NFB Open circuit: detect by oil pressure drop	Open the door and replace only the motor. Operation can be continued by means of the emergency use DC pump.
Auxiliary power source (AC) fall off	If the cause lies inside the circuit breaker control box, detect by the alarm contact of NFB.	Since the pressure does not drop to 160kg/cm² unless 3~4 hours have passed after the auxiliary power fall off, operation is possible during this time. After this, the original state self-hold condition will occur. A separate emergency use DC pump is provided.

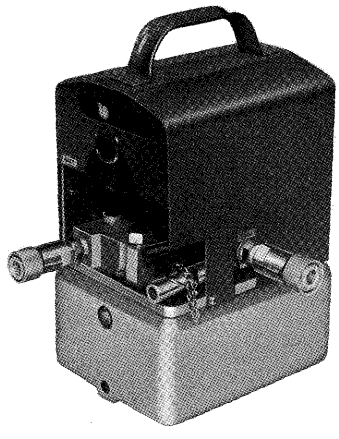

Fig. 10 Portable pump

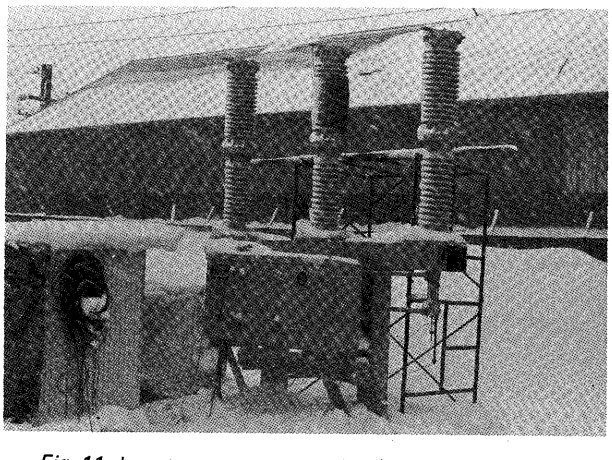

Fig. 11 Low temperature test of 72/84kV circuit breaker

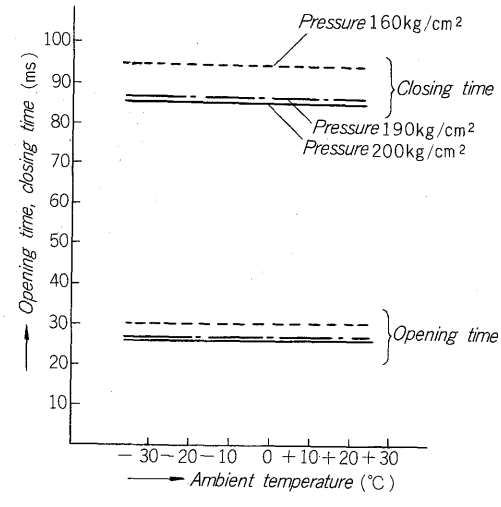

Fig. 12 Characteristics of opening time and closing time versus ambient temperature

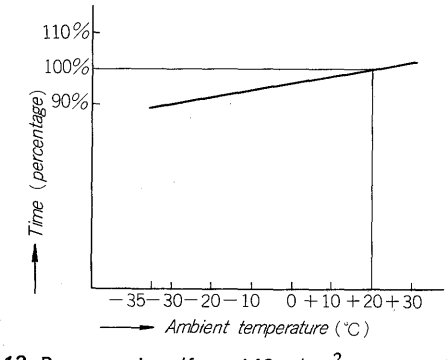

Fig. 13 Pump-up time (from 140kg/cm² to 200kg/cm²)

following. A low temperature test for the SF_6 gas apparatus had already been performed in 1971 at the same place, but this time the test has been performed mainly to test the low temperature performance of the oil hydraulic operating mechanism parts.

1) Opening/closing characteristic

Measurement results of opening time and closing time versus ambient temperature are shown in *Fig. 12*. Temperature dependence of opening time was almost absent. As regards the closing time, slight change in the viscosity was observed, but the change is so small that for practical purposes there is no problem at all. It also became clear that no change occurs in the opening/closing characteristic due to operating pressure.

2) Pumping up time characteristic

Tendency of the pumping up time with ambient temperature at pressures from 140 to 200kg/cm² is shown in *Fig. 13*. As temperature increases, viscosity of the working oil increases and the pump capacity and efficiency also increases and, therefore, the amount of discharge also increases. On the other hand, since the N_2 gas enclose pressure drops with temperature, pumping up time slightly decreases. However, the change within the practical usage temperature range is at the most ±10% which does not have

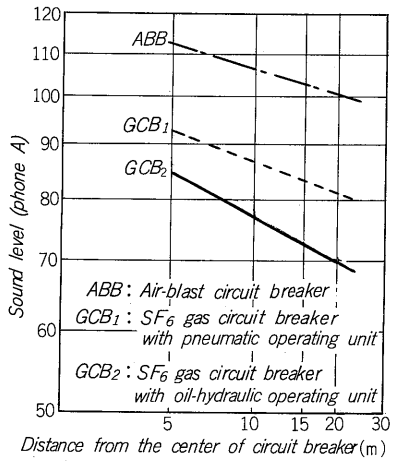

Fig. 14 Operating noise of 84kV circuit breakers

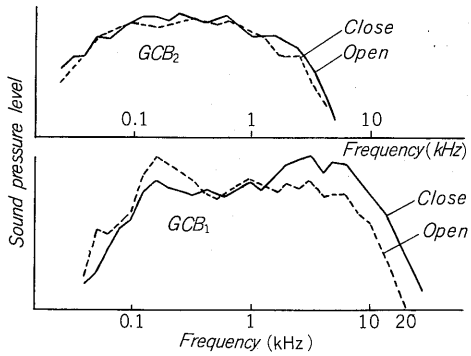

Fig. 15 Frequency analysis of operating noise

an adverse effect on the operation and the performance is sufficiently good for practical purposes.

3) Capacity of heater inside control box

As a result of measurement of temperature inside the control box using 2 kinds of heater, a 180W and a 440W, it is confirmed that even when the ambient temperature drops to −35°C, the temperature inside the box can be maintained above 0°C by means of the 440W heater. Moreover, it also became clear that there is no need of providing any special low-temperature precautionary measures in the interphase piping and that there is no problem for practical purposes.

4) Other performance tests

Intermittent operation test in severe cold, pressure switch operation confirmation test, continuous opening/closing test, investigation for external leakage, investigation of packing, etc. were performed, but in all cases no problem was encountered. Moreover, the results of SF_6 gas leakage investigation, measurement of the amount of moisture penetration, and measurement of insulation resistance also did not reveal any abnormality.

5) Conclusion

The above on-the-site test results confirm that for both the oil hydraulic apparatus and the SF_6 gas apparatus the change in the characteristics with temperature over a temperature range of from −35°C to −20°C is very small and performance at low temperature is sufficiently good.

6. Noise Characteristic

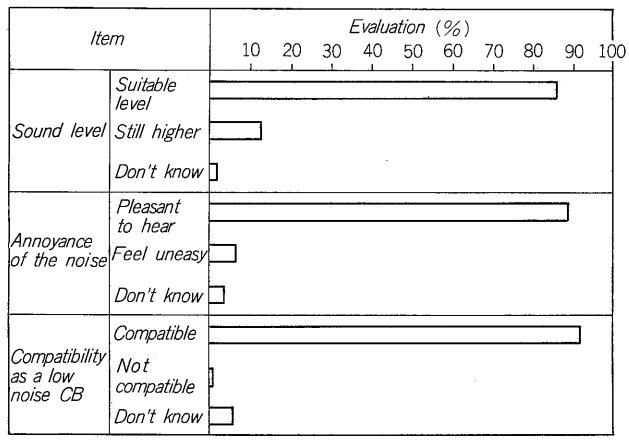

Fig. 16 Evaluation of operating noise

Fig. 14 shows a comparision of the operating noises of the oil hydraulically operated GCB, air operated GCB, and ABB. In the former two cases noise preventive measures of silencer, etc. have been taken, but the oil hydraulically operated GCB does not employ any special noise preventive measures. Obviously, since the circuit is a sealed configuration, there is no explosive exhaust noise of high frequency as in the case of the air operated apparatus, but the frequency is remarkably low as shown in *Fig. 15* and the sound is heard almost like that of closing an automatic door of a car. That is, the sound produced in not unpleasant like a noise.

In the case of the operation by air, essentially, depreciation effect's limit (approximately 20phons) can be said to exist. Isolation by sound-proof walls, sound-proof enclosures can also be considered, but this can not be said to be a basic preventive measures and is economically not good. Noise also has subjective elements and can not always be represented only by noise level. *Fig. 16* shows the result of an investigation through opinionaire by about 200 observers, when the circuit breaker was publicly displayed, concerning operating noise of the oil hydraulically operated circuit breaker. As a result, the oil hydraulic operation can be said to be best suited for low noise circuit breakers.

V. CONCLUSION

A summary of oil hydraulic mechanism concerning its an outline of the construction and operation, and results of the practical performance tests by Fuji Electric are given.

Since social impact for the accident of a circuit breaker is large, practical performance of the operating mechanism is more important, it can not be visualized the same as an ordinary industrial machine. Regarding external oil leakage, it can be said to require a control of the same order as that required for an aircraft. Though it is not a long time since our oil hydraulic circuit breakers were introduced in the market, more than 130 units of circuit breakers qualifying the requirements of the time have already been delivered. In future also, we hope to receive valuable suggestions from the users, perform further tests and inspections and do our best to stabilized the quality.