Reliability Improvements in the Operating Mechanism and Control Circuit of the Gas-Insulated Switchgear

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1. Introduction

Public requests for a stable supply of electrical power has risen in recent years. Because electricity is an intrinsic part of all social and manufacturing activities, even an instantaneous interruption of service has a profound effect.

The switching apparatus serves as equipment which controls the transportation and distribution of electric power.

Because all components such as circuit breakers, disconnecting switches, earthing switches, buses, etc. are enclosed in SF_6 gas, the gas-insulated switchgear (GIS) is not influenced by the external environment. Therefore, the reliability of this switching equipment is greatly improved over the conventional open air type.

However, according to results of an investigation into GIS faults, faults are still comparatively frequent in the operating mechanism and the control circuit, which operate switches including the circuit breakers and disconnecting switches.

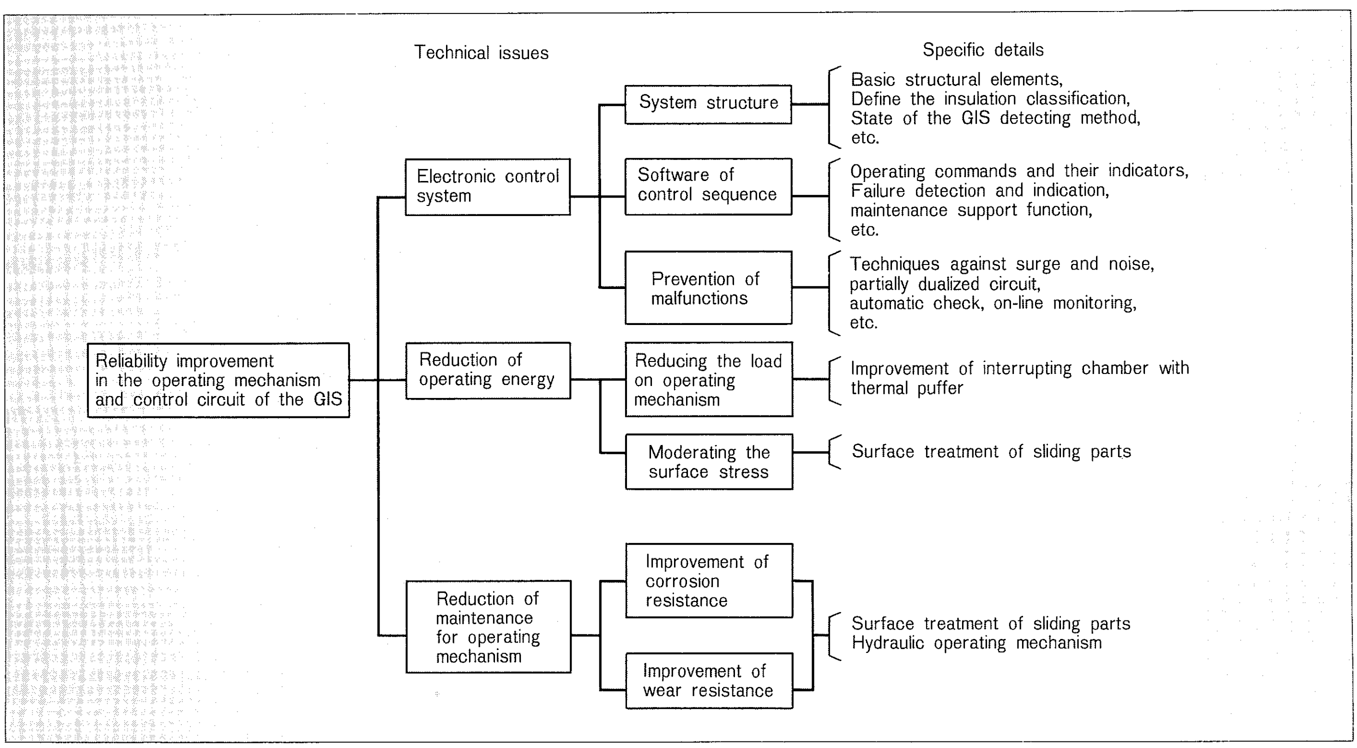
Fuji Electric is working on the technical issues shown in **Fig. 1** to improve reliability of the control circuit and the operating mechanism of the GIS.

In this paper, electronic control equipment put into use following a reliability improvement plan of the control circuit is introduced. Moreover, our technical efforts to reduce operation energy and to decrease maintenance of the operating mechanism are described.

2. GIS Electronic Control System

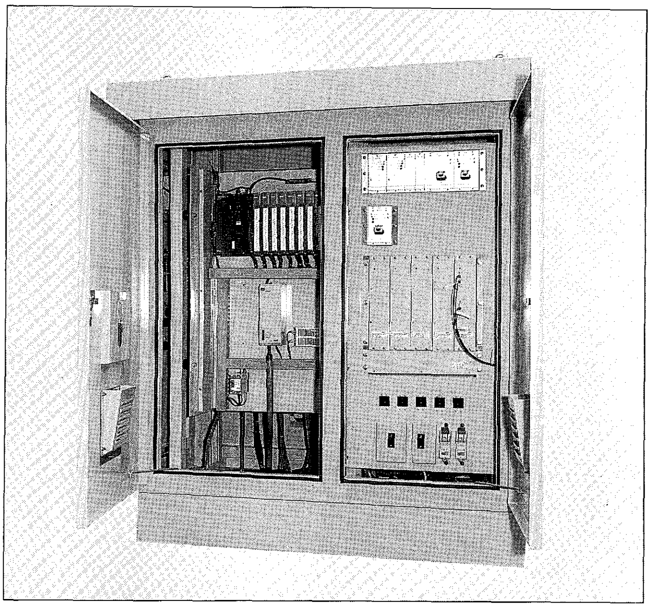
In the control circuit of the GIS, faults which originate due to poor connection of relays with mechanical contacts

Fig. 1 Reliability improvements in the operating mechanism and control circuit of GIS



are frequent. If mechanical contacts are superseded by electronics, the reliability of the control circuit can be improved.

Fig. 2 Outerview of the electronic control system box



Conventionally, there was fear of putting electronic equipment near the high voltage circuit because of surge and electromagnetic noise. Moreover, hardware engineers specializing in high voltage and high power were unfamiliar with the software.

However, electronics have been recently applied to power systems; for instance, digital protective relays and substation equipment supervisory systems have already been put into use.

In the control circuit of the GIS, conventionally composed of relays, mechanical contacts were eliminated and substituted with the sensors and electronic equipment described above. A control box (cabinet) equipped with electronic control equipment is shown in **Fig. 2**.

Securing reliability and the practical use of the system were considered in both the hardware and software when developing the electronic control system. Moreover, emphasis was placed on protecting against surge and noise in verification tests.

2.1 System configuration and features

System configuration of the electronic control system applied to the 84 kV GIS is shown in **Fig. 3**. Programmable controller (PC) is used as control and monitoring circuits, logic circuits comprised of semiconductors are used as

Fig. 3 System configuration

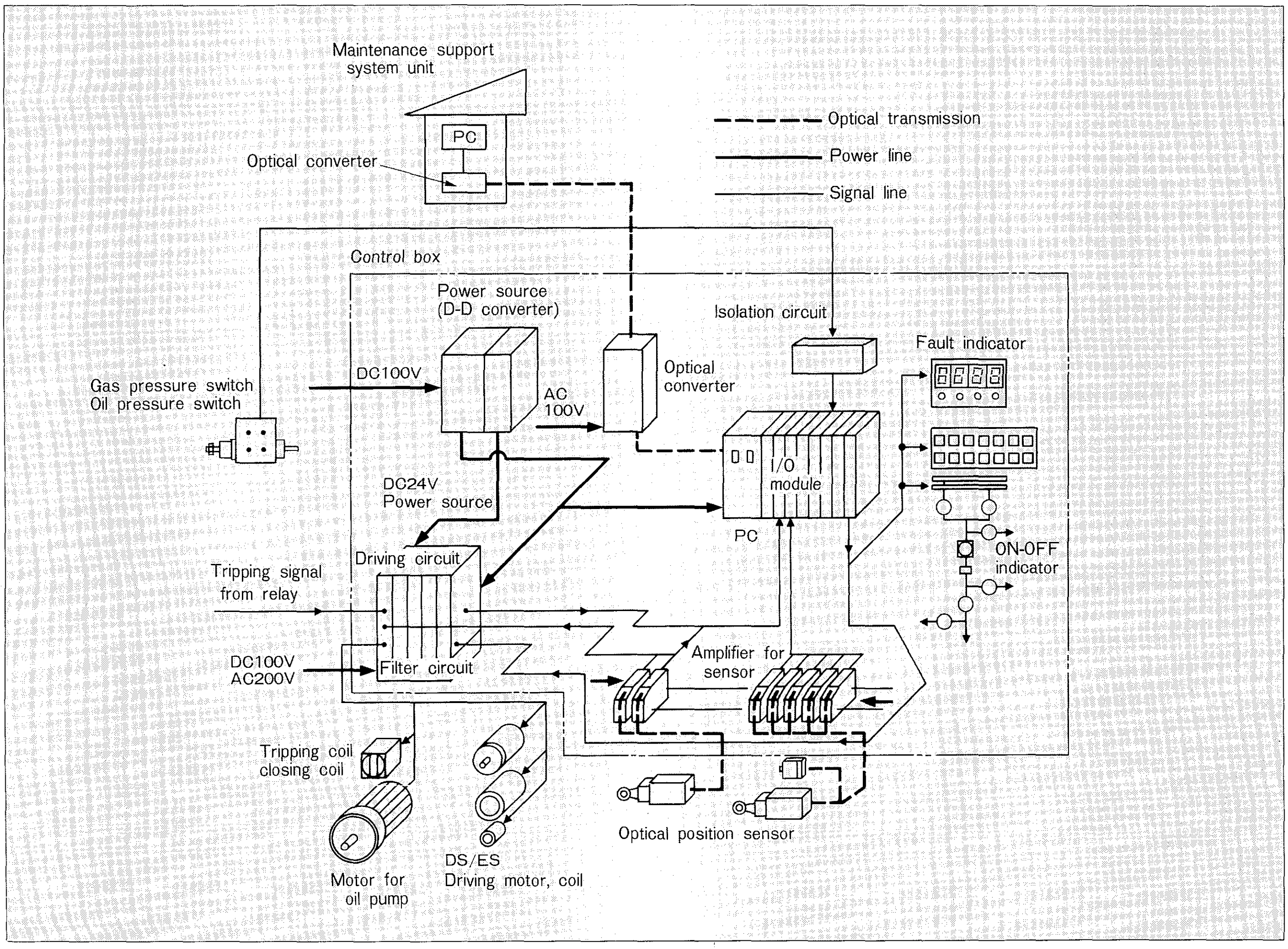


Fig. 4 Control circuit of openning operation for circuit breaker

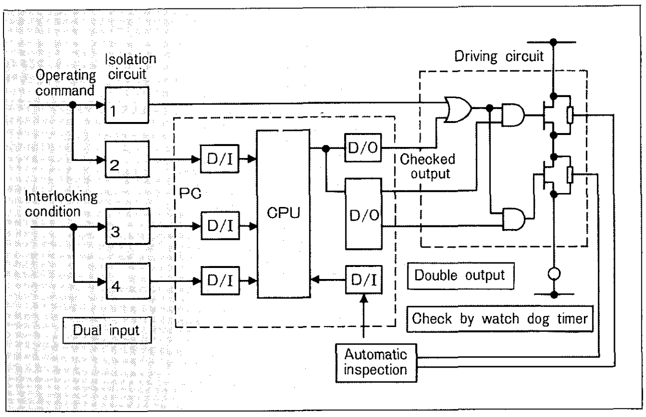
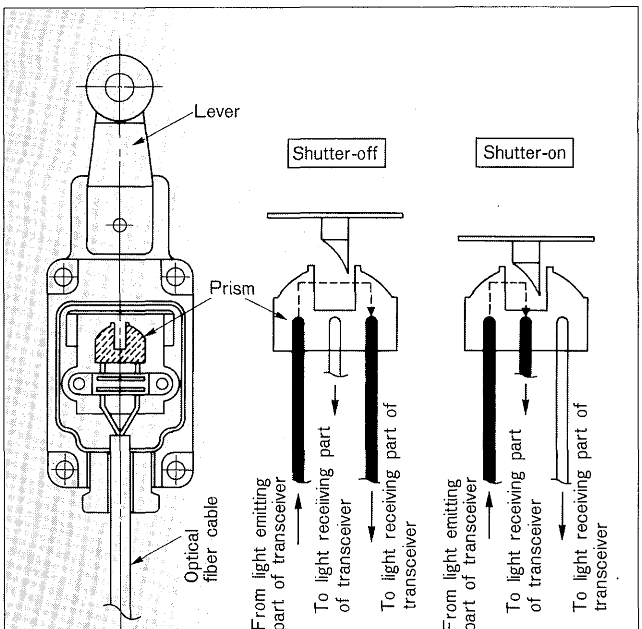


Fig. 5 Optical sensor with self-diagnosis



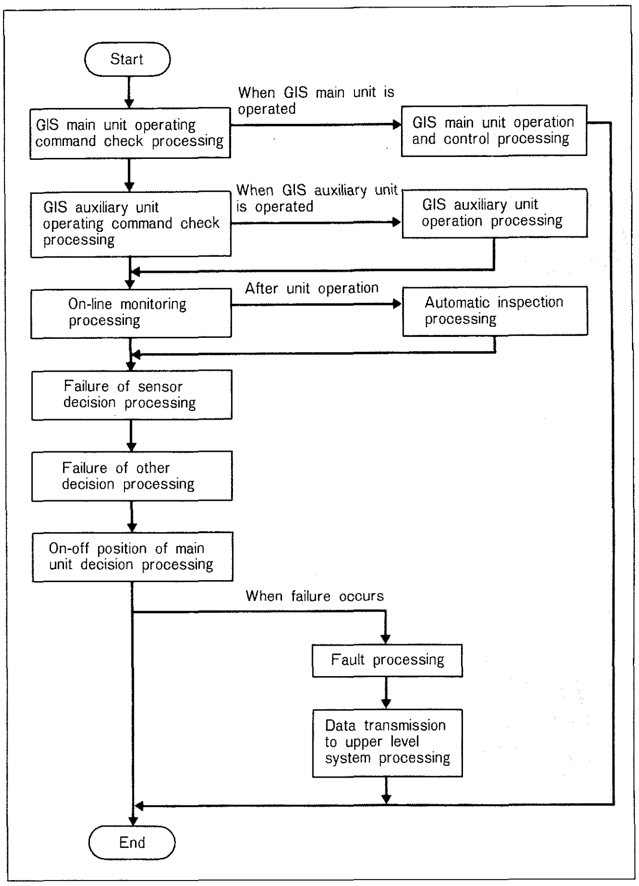
When the optical sensor is normal, 1R and 2R are always opposite conditions. then diagnosis is possible by monitoring both of 1R and 2R

driving circuits which amplify the output from the PC, and sensors are used for detecting states. One feeder of the GIS is composed of one system.

(1) Insulation classification definition

Electronic control equipment of the GIS is powered by 24 VDC supply. However, the system must withstand the lightning impulse voltage of 7 kV (to earth) corresponding to circuit classification 2 of JEC-210. Therefore, by defining the insulation classification, isolation of the system is performed, preventing surge and noise from invading the electronic control equipment from the outside. In practice, isolation is performed by using D-D converters for systems operating on 24 VDC, filter circuits for the systems of drive circuits and optical transmissions to the outside, as shown in **Fig. 3**.

Fig. 6 The flow of control software



(2) Dual circuits

There is a method of using dual circuits to increase the reliability of the entire system. However, dual circuits are used only for critical paths to keep costs down, but automatic inspection and monitoring function are enhanced, securing overall reliability.

Signals which comprise the operation commands of the switches and the interlock conditions are the most important among the signals controlling the GIS. The flow of the signal from input to output in the control circuit for opening the circuit breaker is shown in **Fig. 4**. The operating command is input dually, and switching elements of the last stage of the current control operate when the signal from the PC and the signal not from the PC agree. Moreover, the outputs are also dual, and PC malfunction, etc. are also monitored at the same time by the WDT (watch dog timer). When the two inputs disagree, the operation is forced into the interlock condition.

The two elements of the last stage are connected in a series, and each device operates in parallel and has been made dual to protect the system from faulty operation due to failure of one electronic element.

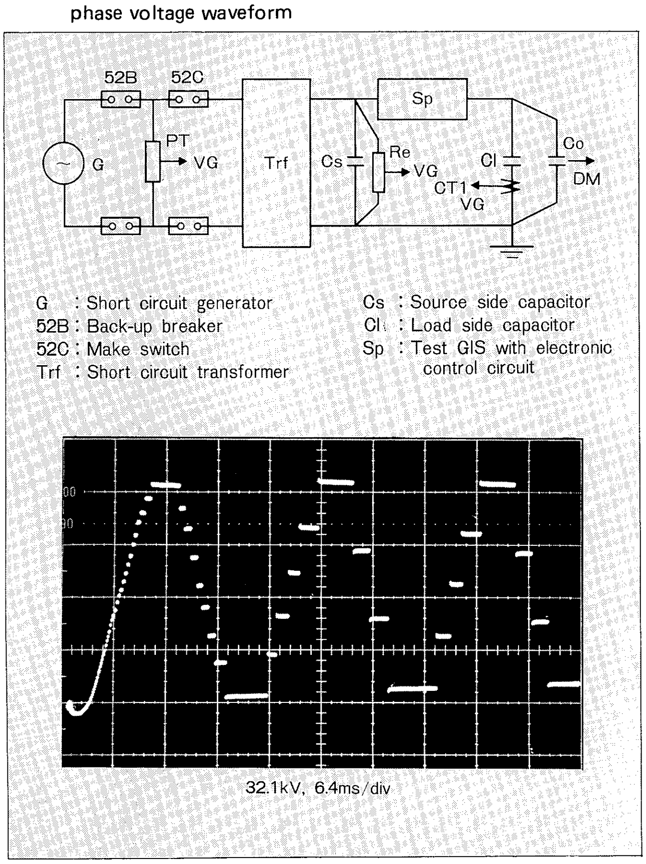
(3) Application of optical sensors with self-diagnosis

Auxiliary and limit switches used to detect the state of the switches were substituted for the optical position sensors shown in **Fig. 5**. This eliminates electrical contacts and the influence of noise at the same time. This sensor has in addition two light detectors for each emitter. Sensor

Table 1 Verification test items and test conditions

Items		Test conditions
Environmental test	High and low temperature test	Mechanical operating tests at −25°C and 55°C
	Heat-cycle test	Mechanical operating tests before and after a series of heat cycles (15 cycles +20°C→−20°C→−10°C→+60°C→+50°C kept at each temperature for two hours)
Surge tolerance test	Rectangular wave test (Fast transient SWC test)	Pulse width: 1μs, Rise time: 1 ns, Voltage: 3 kV
	Damped oscillatory wave test (Oscillatory SWC test)	Voltage of first half wave: 3 kV, Frequency: 1 MHz
	High speed switching test of the inductive circuit	Application of noise by random and high speed switching of an inductive circuit for 2 min.
	Electromagnetic compatibility (immunity) test	Application of noise by a transceiver 5W/150 MHz, 400 MHz, 900 MHz
Control supply voltage regulation test		Switching on and off of supply voltage
		Instantaneous drop in supply voltage
		Slow rise, slow fall of supply voltage
Short-circuit test		Interruption of the rated short-circuit breaking current by the circuit breaker
Small capacitive current breaking test		Interruption of small capacitive current by the disconnecting switch
Long term charging test		Verification of the stability of the system by long term charging and periodical switching operation

Fig. 7 Small capacitive current breaking test circuit and load-side phase voltage waveform



malfunction is always monitored by the PC by means of the diagnostic logic shown in the figure.

(4) Control software

Figure 6 shows the flow of the control software. Only decision processing for the presence of the switching unit's operation commands and for sensor malfunction is performed. It is controlled to operate the relevant switches when the switch operation command input is received.

In this way, the program's scanning time is shortened. Response time has also been shortened by employing a configuration in which only the applicable programs respond when commands are input and malfunction occurs.

On-line monitoring and automatic inspection processing, shown in the flowchart, are performed for the drivers and detect disconnection of the circuit and malfunction of semiconductor devices. The failure decision processing judges and processes abnormalities in power supplies, gas pressures, and oil pressures in addition to the optical sensor shown above in item 3.

(5) Improvement of functions

Because this system has sensors for control and a PC with an arithmetic unit, the maintenance support function can easily equipped to monitor the states of each unit of the GIS and the control system.

In addition to the above-mentioned malfunction detection of the drivers and sensors, operating time and the number of operations of the circuit breakers, disconnecting switches and earthing switches, and operating frequency of the oil pump are all measured. These results can be transmitted to the maintenance support system through an optical transmission.

Moreover, to promptly respond to failure, the location of the failure is displayed with a failure code.

The main features for securing reliability and practicability of the electronic control system were introduced above. In addition, countermeasures are taken to prevent malfunction due to surge and noise by isolating the signal cables from the operating and control cables, isolating the input and output signals with the use of photocouplers, and preventing spurious output by putting a delay program in the control software.

2.2 Verification test

In addition to the GIS test specified by the JEC (Japan Electrical Committee Standard), reliability and practicability tests shown in **Table 1** were conducted to verify the electronic control system. The featured tests related to surge and noise are introduced below.

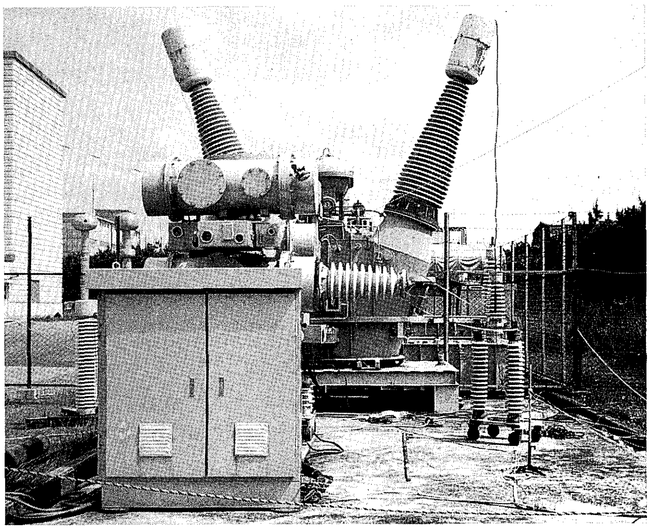
(1) Short-circuit test

It was confirmed that the electronic control system did not malfunction at the BTF100% (100% I terminal fault) breaking test which observed the effects of the short-circuit current passing through the GIS main unit and interrupting the short-circuit current.

(2) Lightning impulse voltage test

After it was confirmed that the electronic control system did not malfunction when a lightning impulse voltage was applied to the GIS, a voltage higher than

Fig. 8 Electronic control circuit box under long term charging test



specified by the standard was applied for the following stress tests:

(a) Flashover to the GIS tank
(b) After giving the operation command, applying a lightning impulse to the disconnecting switch in the middle of operation

We confirmed that no problems occurred in the above tests.

(3) Small capacitive current switching test with a disconnecting switch

When a small capacitive current is switched with a disconnecting switch, a high frequency switching surge is induced by repeated ignitions. The surge voltage is induced at the GIS tank and the control circuit, causing this adverse effect.

The small capacitive current test was performed by using a motor drive as the operating mechanism of the disconnecting switch. **Figure 7** shows the test circuit and load-side phase voltage waveform. This voltage waveform shows that the disconnecting switch breaks the current with repeated ignitions.

Though the applied voltage was 150% of the specified standard value, abnormalities such as malfunction were not observed in the electronic control system.

(4) Long-term charging test

Together with the outdoor exposure test, a fixed voltage was applied to the tested GIS for the term of one year, operated once per day. Stability was confirmed even over the long term. **Figure 8** shows a photograph of the equipment under the long-term charging test.

3. High Reliability of the Operating Mechanism

3.1 Reduction of operating energy

A puffer type interrupting chamber is now used for the circuit breakers of the GIS. The SF_6 gas compressed in the puffer room is blown onto the electric arc, interrupting the current. Because the current breaking efficiency depends on the blowing pressure, moderate puffer pressure is needed to obtain necessary performance. On the other hand, because the puffer pressure acts as a reaction force of the operating machanism, operation energy must be increased as the puffer pressure increases to improve the current breaking performance. Of course, when the operating energy increases, the load on the mechanism increases. Therefore, mechanical strength of the mechanism must also be enhanced.

Fig. 9 New type interrupting chamber

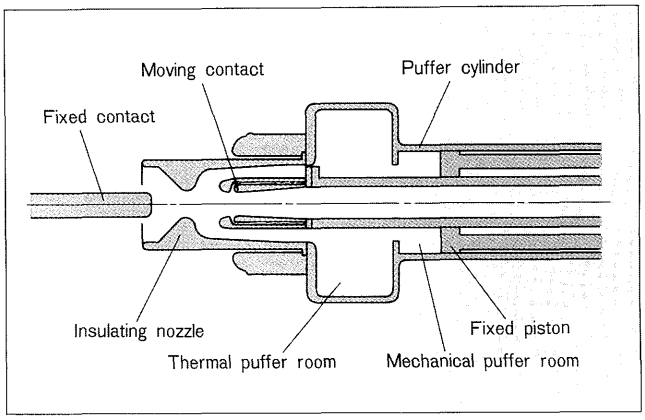


Figure 9 shows the principle of a new type of interrupting chamber, where a thermal puffer room is provided in addition to the conventional mechanical puffer room.

The pressure in the thermal puffer room rises due to the heat of the electric arc during periods of high current. The risen pressure in the thermal puffer room simultaneously causes the blowing pressure as the current decrease to zero. According to this principle, the operating energy of the 84kV circuit breaker, was remarkably reduced when compared with conventional systems.

It is possible to apply the same principle to the disconnecting switch, which has closed loop current switching duty, and the earthing switch, which has an electrostatically- or electromagnetically-induced current switching duty. Then, reduction of operating energy is expected for the disconnecting switch and the earthing switch.

3.2 Maintenance-free operating mechanism

The following requirements must be filled so that the operating mechanism will operate smoothly over a long period.

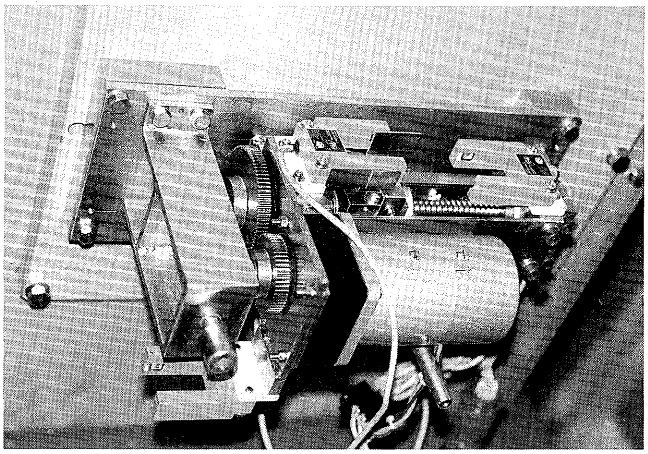
First, the sliding parts must have enough resistance to wear for the specified number of times of operation. Second, they must resist rusting and otherforms of corrosion during the operation period (conventionally 20 years or more).

To satisfy these requirements, the following measures were adopted.

3.2.1 Hydraulic operating mechanism

The hydraulic operating mechanism used for the circuit breaker has a manufacturing record of about 25 years, but is now arranged in a block structure without the use of pipes. Moreover, all sliding parts are stored in oil to simplify the structure. Therefore, there is no atmospheric influence

Fig. 10 Motor drive model under mechanical enduarance test



and no fear of rust generation. Further, the oil acts as a lubricant and resistance to abrasion is improved. As a result, lubrication is not necessary, and a significant extension of the inspection period is achieved.

In the future, this maintenance-free state will be further advanced, cumulating in rotionalizing the inspection of such items as oil volume and pressures.

3.2.2 Motor drive mechanism and motor-spring drive mechanism

The motor-spring drive mechanism or motor drive mechanism is applied to the disconnecting switch, the earthing switch and the low operating energy type circuit breaker. The transmission of mechanical force in them is performed with the use of gears, feed screws or cams. In general, grease is applied to these sliding parts to prevent abrasion and corrosion.

However, grease deteriorates with age and due to pollution from its environment. As a result, there is the possibility of malfunction originating in uneven operation, jarring of the mechanism, grease adherence, etc. Though it is possible to prevent this through maintenance, this acts against the general aim of a maintenance-free mechanism.

Therefore, we are working on technical developments to make the main sliding parts greaseless.

The sliding parts are made greaseless with a self-lubricating method by adopting the latest surface treatment technology in addition to changing the friction mechanism and reducing surface stress.

A friction abrasion test using the test pieces, a surface analysis of the coating film, a salt spray test among others were all conducted as basic tests.

The above-mentioned surface treatment was applied to the apparatus of the motor drive mechanism shown in **Fig. 10** based on these basic test results. Then, a mechanical endurance test was performed in this greaseless condition, and durability was confirmed.

A verification test of the operating mechanism of the motor-spring drive is also scheduled.

4. Conclusion

Our work on the technical problems for the reliability improvement of the operating mechanisms and the control circuits, which frequently malfunction in the switchgear, were described.

The electronic control system already put into use has begun operation in the field. Moreover, problems concerning the operating mechanism were solved by the basic tests, and are now in the verification stage using the actual equipment.

Lastly, high reliability of the GIS is expected by improving these control circuits and operating mechanisms.