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APPRICATION OF SENSOR TECHNIQUES TO ELECTRIC POWER SYSTEMS

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1. INTRODUCTION

The electric power field demands the economical supply of the most stable and high quality electric power possible. To this, improvement of reliability and efficiency by the high degree operation and maintenance technology of each electric power system device is important. Preventive maintenance technology detects the symptoms of equipment disorders from the outside and predicts conditions which can occur in the future and makes advance maintenance possible. The sensors for detecting these equipment abnormalities should be capable of diagnosis in the operating state. Fuji Electric vigrous develops and makes practicable the preventive maintenance sensors and diagnosis systems for rotary machines, transformers, switchgear, and other electric power system equipment.

Fuji Electric technology for the application of sensors to electric power system equipment is introduced here.

2. KINDS OF SENSORS

Since there is no time for maintenance, detecting equipment abnormalities just before trouble occurs is meaningless and a signal which shows the symptoms of an abnormality quickly and positively must be detected and maintenance time secured. This technology is also extremely beneficial in daily maintenance and inspection, especially in maintenance of unmanned facilities.

Table 1 Electric power system equipment trouble symptomatic phenomena

Trouble item	Symptomatic phenomena
Insulation performance	Partial discharge, abnormal sound, decomposed gas, oil leakage, oil level drop, gas leakage, gas pressure drop, leakage current rise, moisture absorption, abnormal odor
Conduction performance	Abnormal temperature, decomposed gas, poor contact arc, magnetic field distribution, pressure rise, smoke
Mechanical performance	Abnormal vibration, abnormal sound, deformed construction, abnormal operation, material deterioration, abnormal torque

The method which diagnoses abnormalities of equipment during operation is performed by sensing abnormal vibration and discharge, abnormal sound, overheating, and other signals generated from equipment which are different from normal by means of sensors.

Table 1 shows examples considered to be symptomatic phenomena of electric power system trouble. Whether or not technology which senses these symptomatic phenomena quickly and positively can be developed is the key to preventive maintenance. There are also cases where abnormality diagnosis is performed with not only one signal, but by combining with multiple sensors or analyzers.

Related to preventive maintenance technology, for quick recovery if trouble should occur, fault location technology is also important.

3. EXAMPLES OF APPLICATION TO TRANSFORMER

(1) Auto analyzer of gas in oil

When local overheating or discharge occurs in an oil immersed transformer, gas is generated by thermal decomposition of the insulating paper or oil. Analysis of gas samples a small amount of the oil in the transformer during operation and analyzes the dissolved gas and is an effective means of diagnosing the degree of trouble. *Fig. 1* is a device that samples and analyzes oil automatically. Gas of nine components of H_2, N_2, O_2, CH_4, CO, CO_2, C_2H_4, C_2H_6, and C_2H_2 is analyzed and printed out at approximately one hour by a two column type gas chromatograph. Moreover, the abnormality cause can be deduced by combining the analyzed result with an expert system.

(2) LTC drive torque sensor

Development into fatal damage can be prevented by installing a torque sensor to the drive shaft of the motor drive mechanism of the on load tap changer of a transformer and detecting mechanism bite and damage (idling) and other switching abnormalities at tap switching. This sensor has four strain gauges making up a bridge circuit installed to its shaft and performs detection by converting the amount of twist (surface shear stress) corresponding to the shaft torque to an electric quantity. LTC drive torque and its construction sensor are shown in *Fig. 2* and *Fig. 3*.

Fig. 1 Auto analyzer of gas in oil

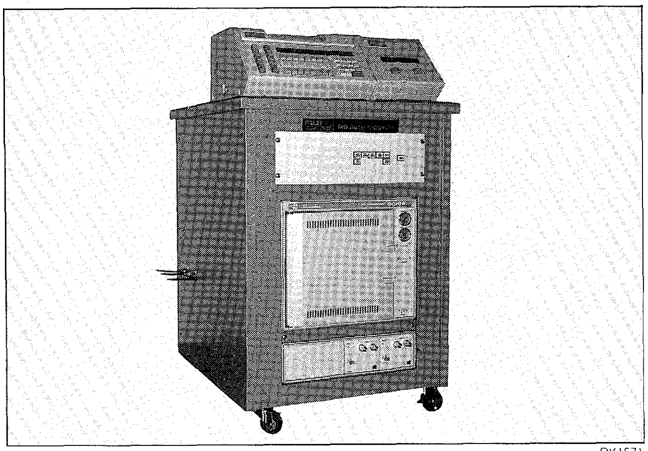


Fig. 2 LTC drive torque sensor

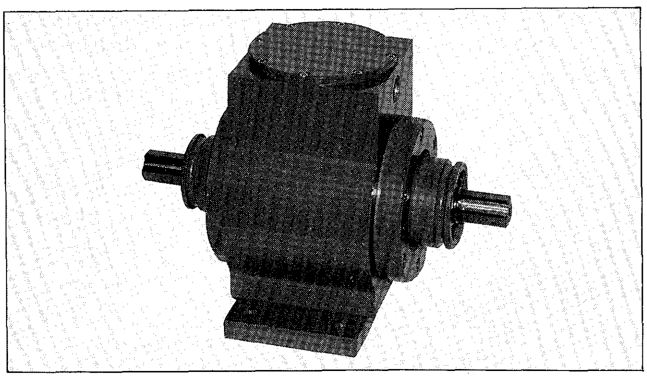
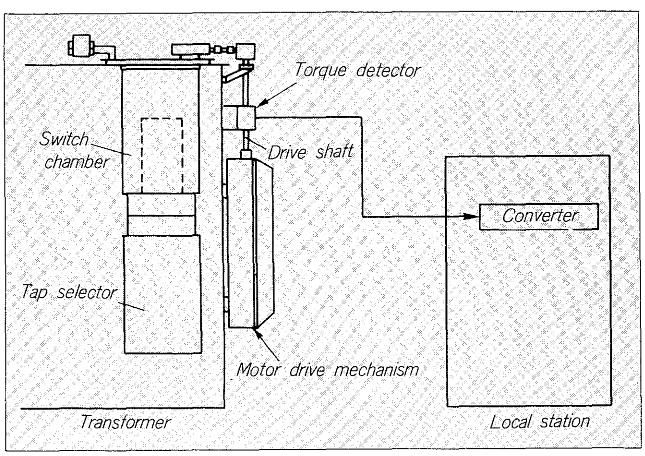


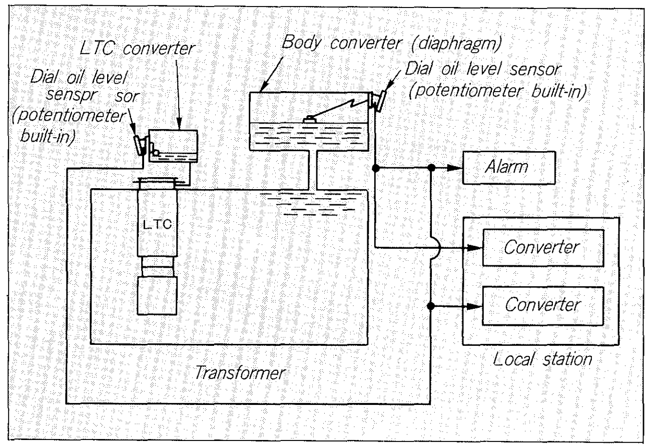
Fig. 3 LTC drive torque sensor construction



(3) Oil level sensor and oil leakage sensor

The oil level sensor detects transformer oil leakage. It consits of dial oil level gauge with built-in potentiometer and a converter which remotely indicates the oil level. The potentiometer is connected to the dial oil level gauge. The resistance value which changes in to the deflection angle of the indicator is converted to an electric signal by a converter. The construction of the oil level sensor is shown in *Fig. 4.*

Fig. 4 Body and LTC oil level sensor construction



There is also an oil leakage sensor which detects very small oil leakage. The sensing element is a cable shape. When about 1cc of oil sticks to it, since the electric resistance rises suddenly, leaking oil can be sensed. The sensor is installed by selecting a place where oil leakage occurs easily.

4. EXAMPLES OF APPLICATION TO CIRCUIT BREAKER AND GIS

(1) Measuring equipment of CB operation time

Many circuit breaker troubles are mechanically abnormal operation. Quick detection of their symptoms contributes greatly to improvement of reliability. However, circuit breakers are normally static and checking the operating characteristics at this time is difficult. This measuring equipment automatically records the control current, switching time, stroke characteristics, etc. and diagnoses abnormalities at periodic maintenance of distribution system circuit breaker.

The equipment is designed as a portable type. The control current can be measured without disconnecting the control line by means of a crank type CT. The current value and continuation time are recorded. Stroke can be measured noncontactless by bar code system. *Fig. 5* is an exterior view of the equipment. The waveforms shown in *Fig. 6* were output instantly at the site by internal printer.

The technology of this equipment is applicable not only to distribution system circuit breakers, but also to high voltage circuit breakers. Partially, it is being applied to a GIS diagnosis system.

(2) Partial discharge monitoring system

This equipment is for preventing insulation accidents beforehand. It monitors the partial discharge which is a symptomatic phenomena of insulation breakdown. When it is generated, partial discharge is accompanied by pulse

Fig. 5 Measuring equipment of CB operation time

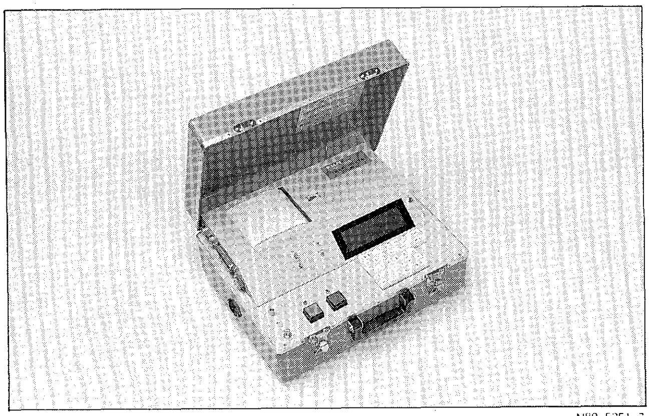


Fig. 6 Printed waveform example

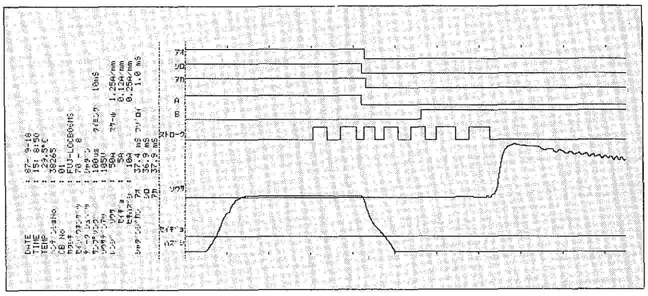


Fig. 7 Construction of GIS partial discharge sensing section

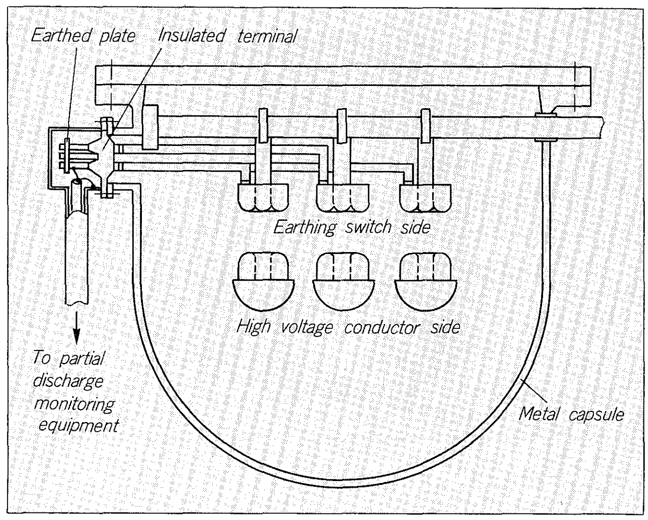


Fig. 8 Relationship between discharge electric charge and output level by practical measurement of monitoring equipment

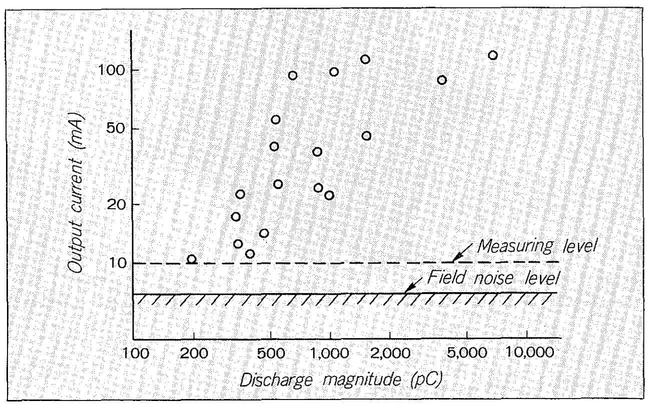
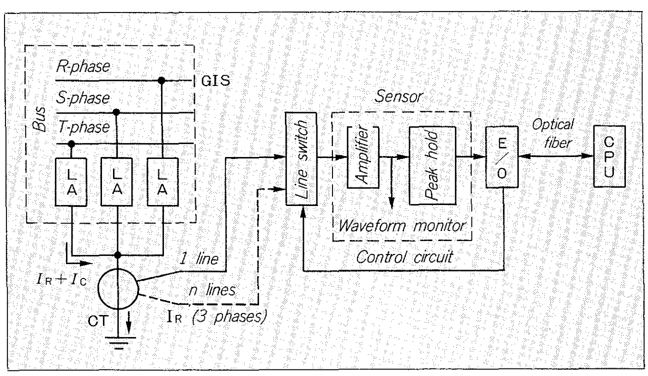


Fig. 9 Composition of arrester leakage current monitoring equipment



current and electromagnetic waves, sound, light, etc.

Generally, of these, the pulse current is normally measured. However, for continuously monitoring at the site, pulse noise enters from the high voltage bus or ground lines and discriminating between it and partial discharge is very difficult. The method which measures the electromagnetic wave generated from the discharge with an antenna is affected by the electromagnetic noise in space. However, the affect of this electromagnetic noise inside the equipment of GIS surrounded by a metal capsule is extremely small. Therefore, since earthed wire of the earthing side moving electrode of the earthing switch in the GIS is isolated from the metal capsule and led to the outside, discharge can be detected by making it an antenna. *Fig. 7* is the construction of the sensing section. A probe is installed to the earth end of the earthing switch (earthed plate not disconected) and measurement is performed by detecting the high frequency pulse component of several tens of MHz.

Fig. 8 shows the detected level by practical measurement.

(3) Arrester leakage current monitor

Deterioration of the nonlinear element in an arrester is judged by monitoring its resistance component leakage current. However, usually, since a capacitance component current much larger than the resistance component leakage current flows at the same time, innovation is necessary to separate the resistance component current. The system shown in *Fig. 9* eliminates the linear capacitance component current and allows monitoring of only the nonlinear resistance component current economically and at high sensitivity by extracting the current signal for three phases.

(4) Fault locator of GIS

When insulation, thermal, or mechanical deterioration, etc. occurs inside a GIS and leads to a short circuit fault, a fault location can quickly be performed by detecting the light generated by the arc current at internal trouble.

Fig. 10 Sensor output waveforms example

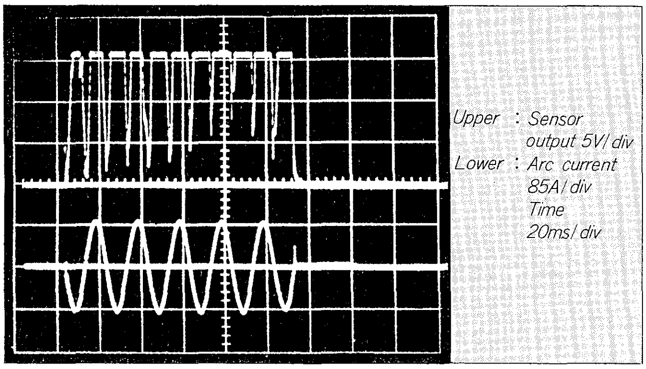


Fig. 11 Fault locator for GIS

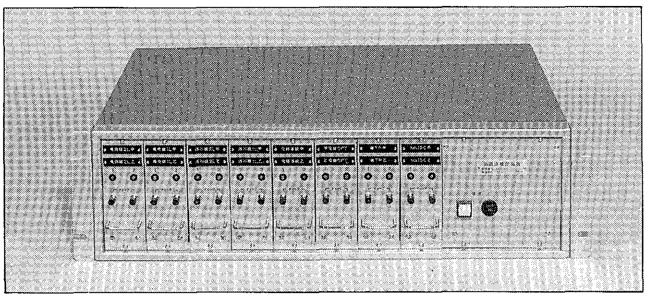


Fig. 12 Field telemetering system concept

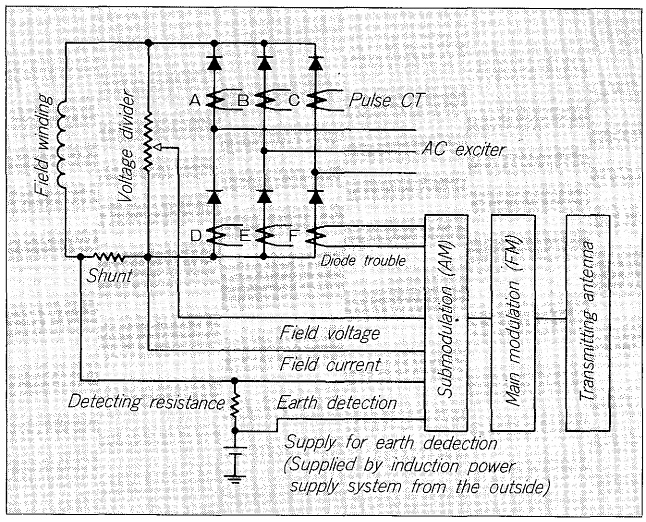
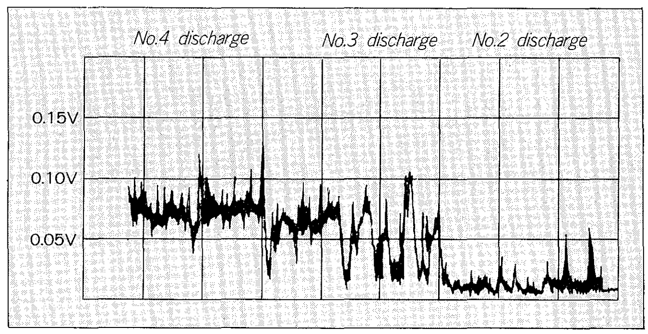


Fig. 13 Discharge number and output voltage coefficient by antenna



The light is passed through a glass window and is detected and is guided by an optical fiber and is finally extracted as an electric signal by O/E converter. The sensor output waveforms are shown in *Fig. 10.* In this case, the sensitivity changes with the position of the detection window and the magnitude of the short circuit current to earth. However, by using the light reflected by the internal coating, detection up to the low range of the short circuit current to earth is possible and therefore use in even high resistance earthing systems is possible.

There are circuit breakers, switches, and other devices which generate an arc. However, erroneous judgment can be prevented by output in AND condition with the protection relay drive signal. An exterior view of the equipment is shown in *Fig. 11.*

5. EXAMPLES OF APPLICATION TO ROTARY MACHINE

(1) Field telemetering system

This system is a brushless exciter telemetering system. As shown in *Fig. 12,* the detection amounts are field current, voltage, field short circuit, and diode trouble detection. These field amounts are converted to a low level signal voltage by converter and are transmitted to the outside contactlessly with FM as the main carrier wave.

Regarding diode trouble detection, to simplify the transmission system, a new system which added secondary output of pulse CT was used. In other words, when the diode is normal, the sum of the CT secondary output voltage becomes zero. However, since an output is generated when the diode is faulty, this is used as a trouble signal. The modulation frequency can be reduced to 1/6 by using this system.

(2) Brush discharge detection

The brush discharge of a rotary machine is a important operating state monitoring item. When it is generated, accelerated deterioration, commutator surface demage, abnormal brush wear, abnormal temperature rise, etc. may occur and develop up to the faulty system operation. To detect this brush discharge, systems which detect the discharge electric wave by condenser system and antenna system were studied. The correlation coefficient of the discharge number and output voltage waveform by antenna system is shown in *Fig. 13.* In all cases the discharge number and output voltage correlation coefficient is good and it is practicalized in remote monitoring of discharge generation at commutator and slip ring.

(3) Rotor health checker

When a layer short-circuit occurs during operation of a cylindrical generator, an error is produced in the rotor temperature and a so-called thermal unbalance which produces vibration caused by this is generated. This rotor winding layer short-circuit can be detected by inserting

Fig. 14 Layer monitor search coil induced voltage waveform (three-phase short-circuit state)

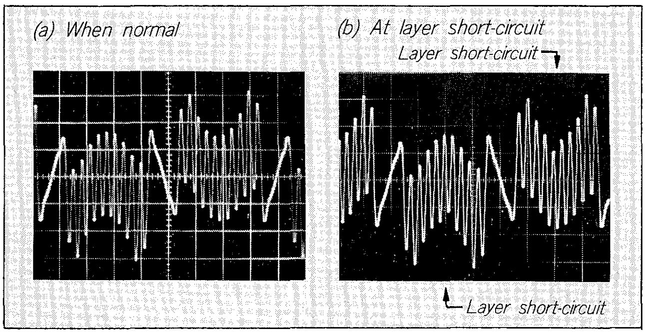
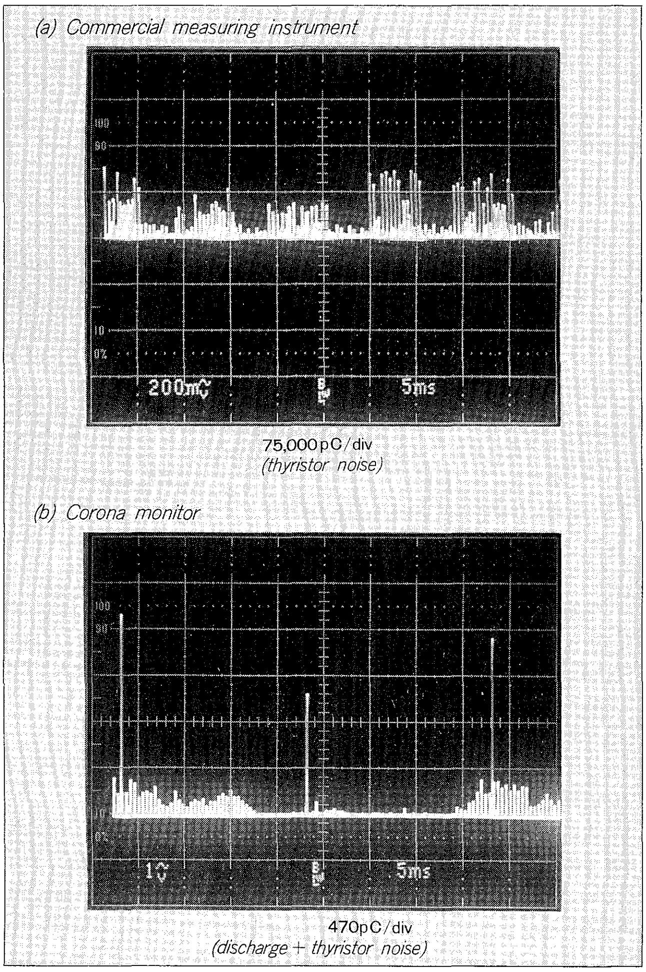


Fig. 15 Comparison of partial discharge detection performance



a search coil into the air gap and measuring and judging the magnetic flux distribution in the diameter direction of the rotor.

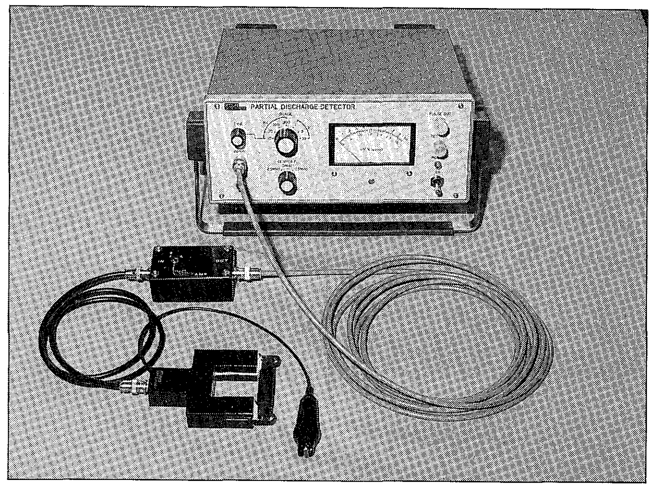
The search coil inducted voltage waveform by diameter direction flux when a normal generator was rotated in the three-phase short-circuit state is shown in *Fig. 14*(a) and the waveform at a layer short-circuit is shown in *Fig. 14*(b). Since the inducing magnetic force is reduced at the layer short-circuit point, the induced voltage lower than from the adjacent slot.

(4) Corona monitor

Partial discharge generation at an operating high voltage rotary machine can be monitored by installing a pulse CT to the earthing wire of the high voltage rotary machine and detecting the partial discharge. However, thyristor equipment is often used in the field and when detection from the earthing wire is attempted with a commercial measuring instrument, only the thyristor noise is detected as shown in *Fig. 15*(a).

Fig. 15(b) is the result of testing performed by tuning the pulse CT to near several MHz. The thyristor noise is reduced approximately two figures and discharge can be detected. *Fig. 16* is the several MHz tuned type corona monitor developed by Fuji Electric.

Fig. 16 Corona monitor for rotary machine



6. CONCLUSION

Recent Fuji Electric sensor application technology in the electric power field was intorduced above. Preventive maintenance technology for equipment will become increasingly important in the future. The higher degree sensors and systemization including an artificial intelligence technology are desired. Fuji Electric is amply satisfying this demand and is vigorously advancing sensor application technology research and development to contribute more in the preventive maintenance field.