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FUJI DC CURRENT TRANSFORMER WITH HALL GENERATOR

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I. INTRODUCTION

The Fuji dc current transformer with Hall generator is a dc type utilizing the Hall effect of semiconductor. As will be shown below, this system is superior to previous saturable reactor type dc current transformer, and is suitable for high-precision measurements of large dc currents and outputs in electrolysis and electrometallurgic equipment.

Features

1) Measuring accuracy is high: more than ±0.3%

2) Since the influence of external magnetic fields is small, it is possible to rationally arrange large current buses, which contribute to the improvement of measuring precision and reliability and also impose no limits on the arrangement.

3) The dc current transformer is of the bus through type, i.e. there is a whole passes through the center with dimensions suitable for an aluminum bus to pass through. Since two part construction is used, the dc current transformer can be fitted in place without removing the bus.

4) If overcurrents or reverse currents occur in the main circuit, no abnormal voltages arise in the measuring circuit.

5) The equipment is not limited to current measurements; output measurement is also possible.

Fuji Electric has manufactured various types of dc current transformers (with Hall generators) with ratings ranging between 10 ka and 120 ka, including the 120 ka model delivered to Sumitomo Chemicals, the largest of its kind in Japan. Since the reliability of these transformers is well known, the demand is increasing all the time. Because export demands have also been going up recently, this equipment will be introduced briefly in this article.

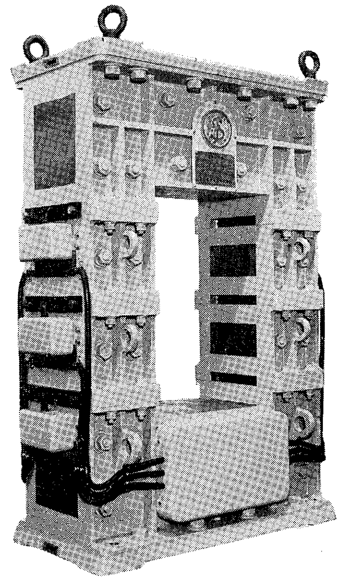

Fig. 1 120 ka dc current transformer with Hall generator

II. HALL EFFECT

Since the Hall effect has already been described in great detail in the literature[(1)(2)] only a simple outline of the main points concerning the FC34 type Hall generator manufactured by Siemens and used in this dc current transformer will be given here.

As can be seen in *Fig. 2,* current I (control current) is flowing through a thin piece of semiconductor. If this piece is placed in a magnetic field of flux density B, a voltage V_h (Hall voltage) appears at right angles to the current and the field, as is shown by the following equation. This phenomenon is known as the Hall effect.

$$V_h = \frac{R_h}{d} \cdot B \cdot I_s \quad \text{.....................(1)}$$

where R_h: Hall coefficient
d : Semiconductor thickness

Hall generators can be made from Ge (Germanium), Si (silicon), InSb (indium · antimony), InAs (indium · arsenic) etc. In order to increase the measuring precision in this dc current transformer, the Siemens FC34 type Hall generator is used. It is made from InAsP (indium · arsenic · phosphorous)

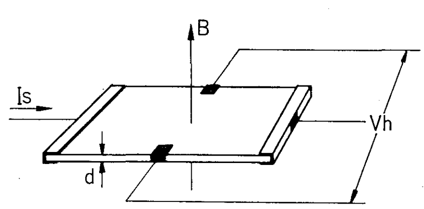

Fig. 2 Hall effect

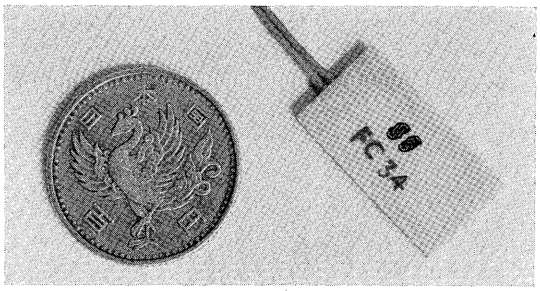

Fig. 3 FC 34 type Hall generator

which has a high Hall coefficient and a low temperature coefficient.

The FC34 type hall generator characteristics are as follows:

Rated control field	1 wb/m^2
No-load Hall voltage	360 mv (for a magnetic flux density of 1 wb/m^2)
Control current	200 ma
Straight line precision of Hall voltage more than	$\pm 0.2\%$
Temperature coefficient	$-0.04\%/°C$ (Hall voltage) 0.19%/°C (internal resistance)
Internal resistance	6Ω (control side) 3.5Ω (Hall side)

III. MEASURING THEORY

1. Current Measurement

As is shown in *Fig. 4*, a magnetic circuit is produced by the 2 opposing U-shaped yoke cores and a Hall generator is inserted in each of the 2 air gaps.

When the main circuit current I flows to the opening in the yoke, the relation between the main circuit current I, the gap magnetic field strength H_g, and the yoke field strength H_{Fe} is as shown below:

$$H_{g1}\cdot\delta + H_{g2}\cdot\delta + H_{Fe}\cdot l_{Fe} = I \quad \text{..................(2)}$$

δ : Gap length

l_{Fe}: Length of yoke core magnetic circuit

The iron core is made from silicon steel sheets with cold rolling directional properties, low hysteresis and high magnetic permeability. Construction is such that almost all magnetomotive force generated by the main circuit current is concentrated in the air gaps. Therefore, equation (2) can be simplified as follows:

$$H_{g1}\cdot\delta + H_{g2}\cdot\delta = I \quad \text{....................(3)}$$

In terms of air gap magnetic flux, $B = \mu_0 H$ (B: magnetic flux density, μ_0: permeability of the air) and therefore equation (3) can be expressed as:

$$B_{g1} + B_{g2} = \left(\frac{\mu_c}{\delta}\right)\cdot I \quad \text{....................(4)}$$

When the control current of the Hall generators inserted in the air gap is held constant, equation (4) gives the following, since the Hall voltage is proportional to the magnetic flux density in accordance with equation (1).

$$V_{h1} + V_{h2} = \text{constant} \times I \quad \text{.................(5)}$$

Therefore, the main circuit current is proportional to the sum of the Hall voltages. In this way the main circuit current can be measured by measuring the Hall voltages.

2. Output Measurement

For output measurement, the current measuring circuit given in section 1, is used with no changes made in the other parts. When the Hall generator control current is proportional to the main circuit voltage V instead of to the constant current, equation (5) can be expressed as follows:

$$V_{h1} + V_{h2} = \text{constant} \times I \times V$$
$$= \text{constant} \times W$$

Therefore, output power (W) can also be measured by measuring the Hall voltage.

IV. MEASURING CIRCUITS

1. Current Measuring Circuit

The current measuring circuit is shown in *Fig. 5*. R_1, R_2 and R_3 are temperature compensating resistors (Refer to IV.-2) which are located in the terminal

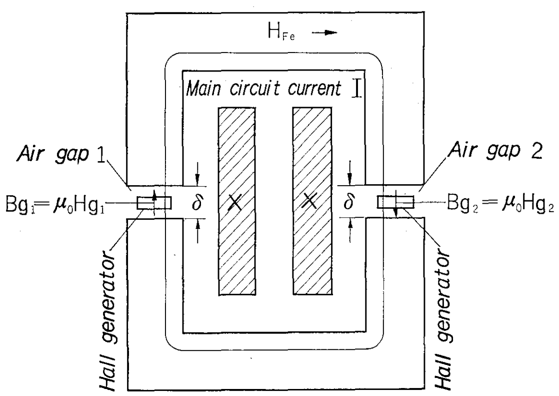

Fig. 4 Measuring principle of dc current transformer with Hall generaor

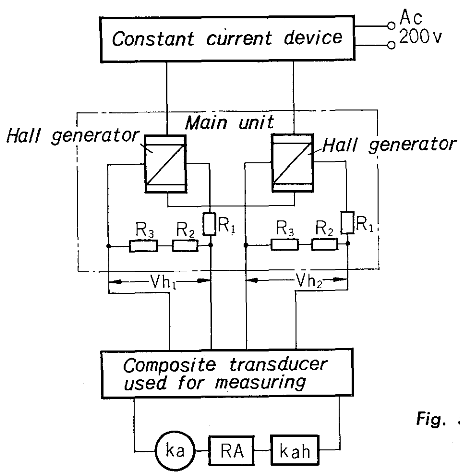

Fig. 5 Current measuring circuit

box fixed to the upper part of the main unit. The voltage outputs of Hall generators 1 and 2 are combined in the composite transducer used for measuring and the transducer output is proportional to the sum of the 2 Hall voltages. In this way, various types of ammeters, ampere-hour meters, or relays can be operated by the dc current transformer. It is standard when the main circuit current $I=100\%$, the transducer output is 50 ma and when $I=0\%$, 10 ma, and the maximum load resistance is 450 Ω.

2. Summary Current Measuring Circuit

When measuring the sum of multiple system currents used for parallel driving of current rectification devices which are found in large numbers in electrolysis equipment etc., several dc current transformer units can be supplied which control current by a single constant current device as shown in *Fig. 6*. Current measurement is accomplished by measuring the current of each dc current transformer with primary transducers. It is possible to measure the sum of all the system currents by means of the summary transducer.

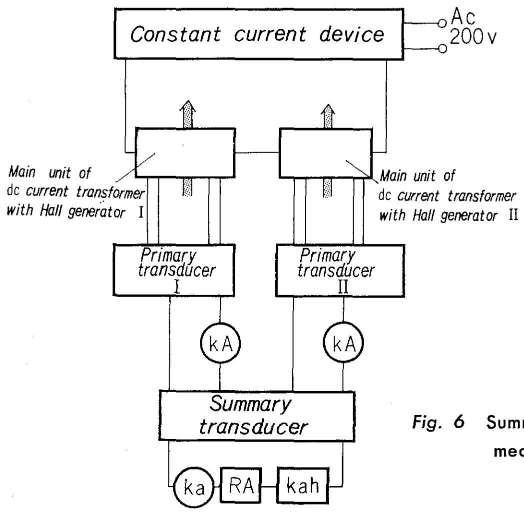

Fig. 6 Summary current measuring circuit

3. Output Measuring and Output/Current Measuring Circuit

The output measuring circuit is shown in *Fig. 7* and the output and current measuring circuit in *Fig. 8*. Instead of the constant current device used in the current measuring circuit the output measuring circuit employs a transducer for measuring voltage which supplies current proportional to the main circuit voltage as described in III–2.

In the output and current measuring circuit, an output Hall generator and a current Hall generator are installed in a single Hall dc current transformer. As described above, the output measuring circuit contains a transducer for measuring voltage which supplies control current proportional to the main circuit voltage and the current measuring circuit contains a constant current device.

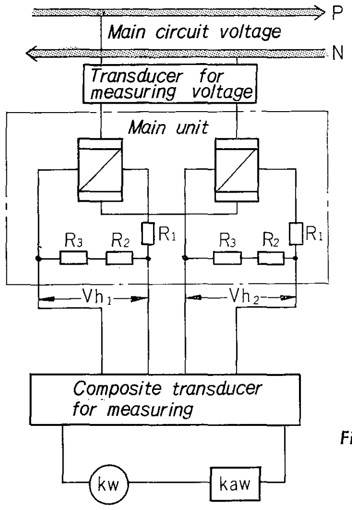

Fig. 7 Output measuring circuit

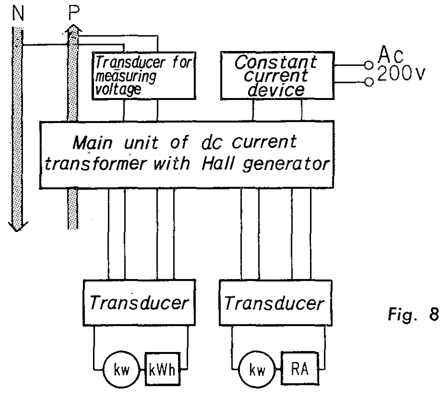

Fig. 8 Output and current measuring circuit

V. STRUCTURE OF THE DC CURRENT TRANSFORMER MAIN UNIT AND STANDARD TYPES

1. Structure of Dc Current Transformer Main Unit

To insure high precision measurement, dc current transformers with ratings up to 30 ka contain 2 yoke iron cores; those between 40 and 80 ka contain 4; and those between 90 and 120 ka contain 6. Hall generators for either current measuring or output measuring are inserted in each of the air gaps which pass through these cores. These Hall generators are connected as mentioned in the various measuring circuit descriptions in section IV.

The yoke iron core is constructed of laminated silicon steel sheets with cold rolling directional properties, low hysterisis and high magnetic permeability. It is held on both sides by the non-magnetic frame and tightened securely with bolts. The tightening bolts are insulated in respect to the iron core with insulation pipe and there is no possibility of lag in magnetic flux due to eddy currents. When automatic control is used, high speed response can be obtained.

The air gap surfaces of the yoke are finished smoothly, and in order to maintain the specified air gap lengths, precisely measured pieces are put between the gaps and tightened to the upper and lower yokes with bolts. In the spacers, fixing pins are provided for

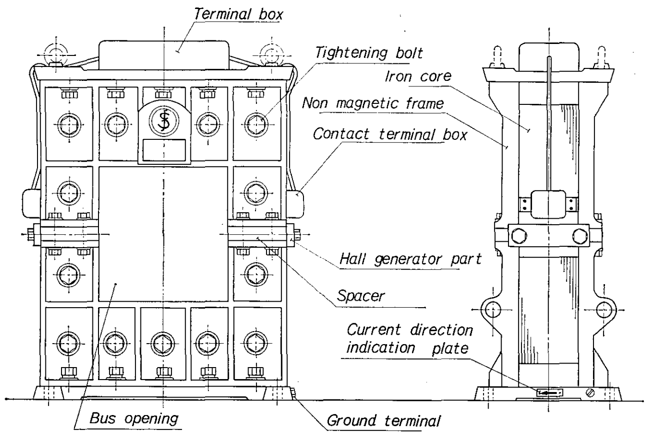

Fig. 9 **Structure of dc current transformer with Hall generator**

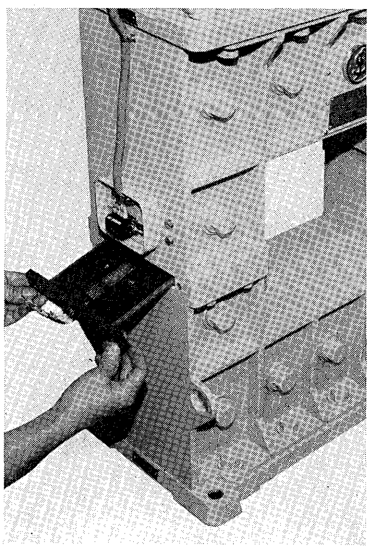

Fig. 10 **Fitting of Hall generator**

alignment so that the air gap dimensions can be maintained correctly during diassembly and assembly of the yoke. Since the main unit is of such stable construction, the high precision of the equipment will not be influenced even if the dc current transformer is taken apart in the field for installation without removing the dc bus.

Main structure in this case, a 30 ka dc current transformer containing 2 iron cores is shown in *Fig. 9*. As shown in *Fig. 10,* the Hall generator is fixed to a support plate and is inserted into the air gap by means of a pull-out type construction. It is best to insert the Hall generators last after the yoke has been completely assembled so that there is no danger of the generator elements being damaged during yoke assembly. (Utility Patent No. 23785/1966)

2. Standard Series

The standard models with ratings between 10 ka and 120 ka are listed in *Table 1*. Dimensions for the bus opening are standard for the permissible size of aluminum bus to be used. A non-standard level-installation type is also being manufactured.

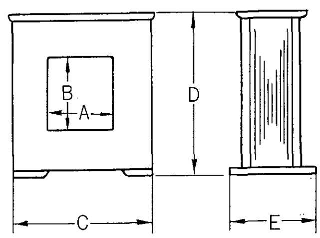

Table 1 **Standard Series of Dc Current Transformer with Hall Generator**

	Current (ka)	Dimensions (mm)					Weight (kg)	Remarks
		A	B	C	D	E		
H 101	Up to 10	160	227	350	596	200	150	Can be used with alminum bus
H 115	Up to 15	160	230	350	598	200	150	Can be used only with copper bus
H 201	Up to 20	160	233	350	604	200	150	Same as above
H 201	Up to 20	320	285	610	800	320	450	Can be used with alminum bus
H 301	Up to 30	320	291	610	806	320	450	Same as above
H 401	Up to 40	320	527	610	987	320	520	Same as above
H 501	Up to 50	320	533	610	993	320	520	Same as above
H 601	Up to 60	320	540	610	1000	320	520	Same as above
H 701	Up to 70	460	539	850	1159	400	1350	Same as above
H 801	Up to 80	460	545	850	1165	400	1350	Same as above
H 901	Up to 90	460	777	850	1397	400	1500	Same as above
H1001	Up to 100	460	783	850	1403	400	1500	Same as above
H1101	Up to 120	460	795	850	1415	400	1500	Same as above

VI. MEASURING PRECISION AND COMPENSATION FOR EXTERNAL MAGNETIC FIELDS

1. Measuring Precision

The measuring precision is equal to the sum of the errors of the dc current transformer main unit, accessories and indication devices. The actual degree of precision is determined by the error of the indication device. The dc current transformer main body error is due to the magnetization characteristics of the iron core, the dc characteristics of the Hall generator element, temperature changes of the Hall voltage due to ambient temperature changes, the influence of external magnetic fields etc. However, because of the previously described silicon steel sheets with cold rolling directional properties used in the construction, and also if the compensation method described below is carried out, a precision of more than $\pm 0.3\%$ can be maintained. The precision of the accessories (constant current device etc.) is more than $\pm 0.2\%$.

Fig. 11 shows the results of actual measurements of the dc current transformer main unit error and also indicates the very high precision above the guaranteed value.

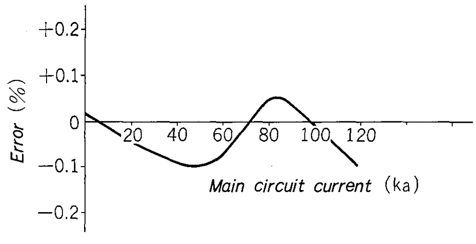

Fig. 11 Error curve of dc current transformer with Hall generator

2. Temperature Compensation

Hall generator temperature error results mainly because of changes in the no-load Hall voltage based on temperature changes in the Hall coefficient.

As was mentioned in section II, the FC34 type Hall generator made from InAsP with a small temperature coefficient is used in this dc current transformer. Although the hall temperature coefficient is $-0.04\%/°C$, Hall voltage compensation to increase the precision is made so that the voltage dividing ratio changes in accordance with temperature changes by means of constantan resistance wire (R_1 and R_2 in *Fig. 5*) with temperature coefficient of almost zero and a copper resistance wire (R_3 in *Fig. 5*) with a positive temperature coefficient inserted in the circuit. Unlike in the thermistor and other methods, this method allows for fine adjustment of the resistance value as well as insuring precision compensation (Utility Patent No. 25712/1962). Using this method the Hall voltage temperature error can be kept below $\pm 0.1\%$ for a temperature range of $25°C \pm 15°C$.

3. Compensation for External Magnetic Fields

Generally, when large currents are being measured, external magnetic fields caused by back currents in the dc bus etc. influence the measurements, resulting in large errors. In previous saturable reactor type dc current transformers, it was necessary to maintain sufficient distances to overcome this influence. Since external magnetic fields are compensated for in this dc current transformer, there are no limitations on distances and rational arrangement of large current buses and accessories is possible.

External magnetic field compensation is carried out in the following manner. As shown in *Fig. 4,* one Hall generator is placed in each of the 2 (or 4, or 6) air gaps and the sum of all the Hall voltages becomes the output of the composite transducer. Therefore, the influence of external magnetic field due to back current etc. is mutually cancelled out and becomes very small. *Figs. 12* and *13* show the results of experiments on the compensation effect. *Fig. 12* shows a case where there is a back current near the generator. When the distance between the dc current transformer with Hall generator and the back current is shortened, the magnetic flux density B_{g1} in air gap (1) on the far side decreases in respect to the back current, while the magnetic flux density B_{g2} in air gap (2) near the back current increases. The mean value of both magnetic flux densities $(B_{g1}+B_{g2})/2$ is approximately constant and compensation is assured. *Fig. 13* shows a case where there is an iron body near the generator. In contrast to the above case, the magnetic flux density in air gap

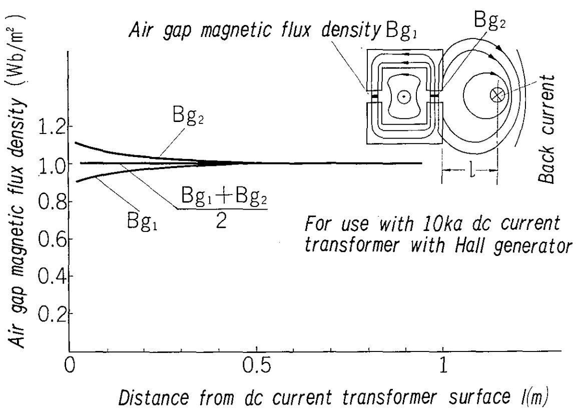

Fig. 12 Compensation for external magnetic field

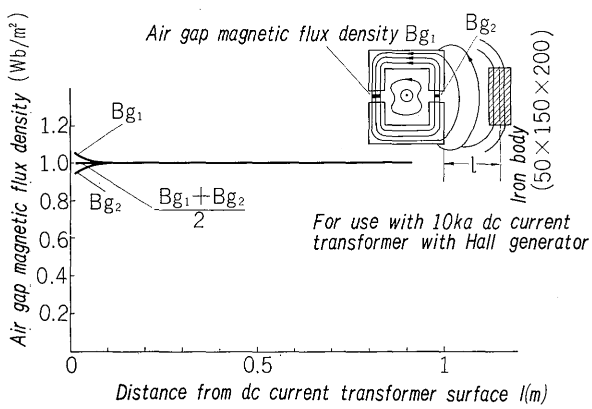

Fig. 13 Compensation for external magnetic field

Table 2 **Supply List of Dc Current Transformers with Hall Generators**

Rating of Dc Current Transformer with Hall Generator	Purchaser	No. of Units	Year Manufactured	Application
120 ka	Sumitomo Chemical Co.	1	1962	Output and current measuring
50 ka	Fuji Electric (Testing equipment)	1	1963	Current measuring
30 ka	Showa Denko K. K.	6	1964	Current measuring
30 ka	Tsurumi Soda Co.	1	1966	Current measuring
30 ka	Sumitomo Metal Mining Co.	1	1966	Current measuring
20 ka	National Rayon Co.	3	1963	Current measuring
20 ka	Nippon Light Metal Co.	9	1967	Output and current measuring
20 ka	The Japan Carlit Co.	1	1967	Current measuring
15 ka	Kanto Electrochemicals	12	1965	Current measuring
10 ka	Taiwan Alkali Co.	1	1962	Output measuring

(1) on the far side increases in respect to the iron body, while it decreases in gap (2) near the iron body. The mean value of the flux densities $(B_{g1}+B_{g2})/2$ is also a constant and compensation is assured.

As can be seen from *Figs. 12* and *13,* effective compensation can be achieved even when the back current or iron body is very near the generator.

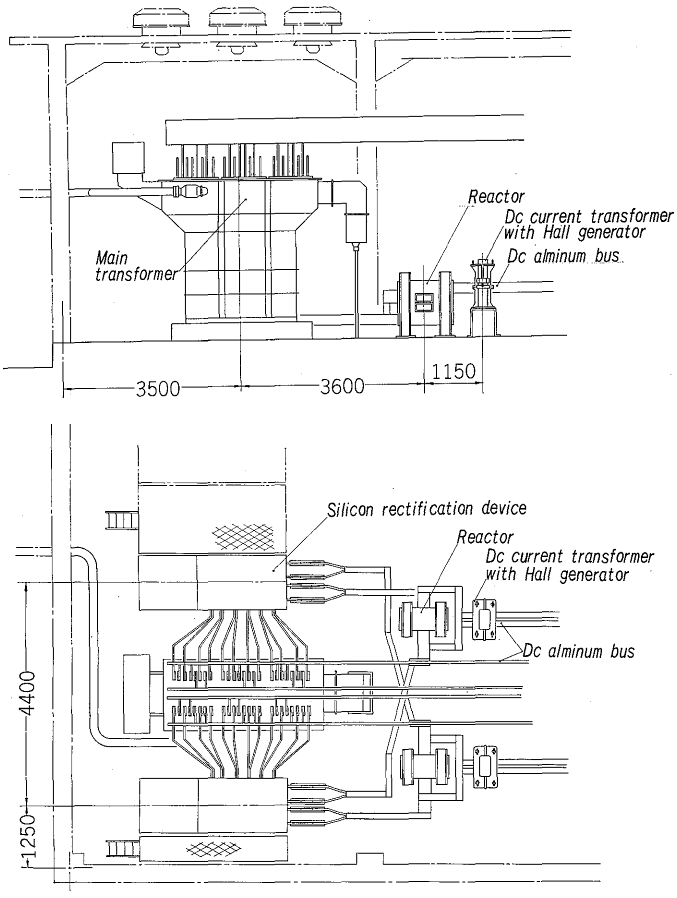

Fig. 14 Arrangement of bus bar and dc current transformer with Hall generator

VII. BUS ARRANGEMENT

Fig. 14 shows the arrangement of the buses and the dc current transformer with Hall generator in case of the silicon rectification device. *Fig. 15* is an actual photograph of the same arrangement. Although the bus spacer is rather short and a reactor with large magnetic leakage flux situated very near it, almost no error arises.

VIII. PREVIOUS PRODUCTION

Fuji Electric has produced various types of dc current transformers with Hall generators with ratings between 10 ka and 120 ka, including the 120 ka model delivered to Sumitomo Chemicals, the largest of its kind in Japan. These dc current transformers have been utilized in all types of equipment including soda and aluminum electrolysis equipment. A supply list is shown in *Table 2.* Also, about 10 devices are now being manufactured, excluding those for export.

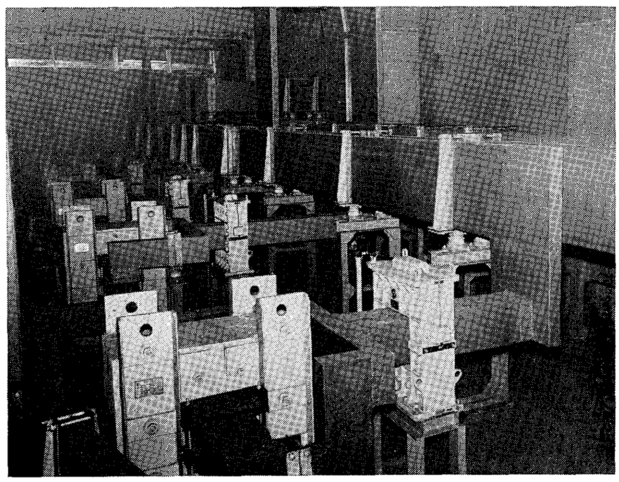

Fig. 15 Bus bar and dc current transformer with Hall generator

IX. CONCLUSION

A brief introduction to the Fuji Electric dc current transformer with Hall generator has been given above. Since this dc current transformer with Hall generator has superior characteristics such as high precision, no influence from external magnetic fields, etc., Fuji Electric hopes that this equipment will fulfill customer's expectations.

References

(1) Friedrich Kuhrt: Siemens Z. Heft 8 (1954)
(2) Siemens Hall-Effect Devices for All Problems of Modern Electronics <Siemens Bestell-Nr · 1-6300-012-1>