Analogue Field Level Generator for Hybrid Magnets*

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Synopsis

An analogue field level generator has been developed for various measurements which need an analogue signal proportional to the magnetic field at the center of hybrid magnets. The accuracy of the generators has turned out to be within ±0.4%, which can be made more accurate up to within ±0.05% after a careful recalibration.

I. Introduction

For the measurements of the upper critical field H_{c2} in superconductors, an analogue voltage signal which is proportional to the applied magnetic field is usually needed. In these experiments the analogue voltage signal is put into the abscissa of an X-Y recorder and a voltage signal from a superconductor will be put into its vertical axis. H_{c2} is determined from the magnetic field dependence of the voltage signal from the sample which is proportional to the sample resistance. There might be many other experimental quantities, for whose measurements such an analogue signal is needed.

In the case of hybrid magnets(1), the coil constants of the outer superconducting magnet(SM) and the inner water-cooled magnet(WM) are usually different with each other. Moreover, the signal levels(2,3) from the DC current terminal(DCCT) of each power supplies which indicate the current level of each magnets are also different with each other.

We have, therefore, developed an analogue generator which generates a signal proportional to the magnetic field level at the center of the hybrid magnet from input signals which come from DCCT's

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Table 1. Coil Constants and Operating Currents of the Hybrid Magnets

HM	SM	G_S (T/kA)	I_S (A)	WM	G_W (T/kA)	I_W (kA)
HM-1	SM-1	8.249	1456	WM-1a WM-1b	0.8662 0.7638	22.5 22.3
HM-2	SM-2	5.458	1470	WM-2	0.7381	21.4
HM-3	SM-3	10.308	780	WM-3	1.1113	11.5

of power supplies for outer superconducing and inner water-cooled magnets.

II. Principle, circuit diagram and construction

The central field B of the hybrid magnet is given by the following expression[4],

$$B = G_{SM} \cdot I_{SM} + G_{WM} \cdot I_{WM} , \qquad (1)$$

where $G_{SM}(G_{WM})$ and $I_{SM}(I_{WM})$ are the coil constant and the current of the superconducting (water-cooled) magnet, respectively. Table 1 shows these parameters for our three hybrid magnet systems; HM-3, HM-2 and HM-1. Figure 1 shows a schematic circuit diagram of the power supplies[2,5] for outer superconducting magnets. DCCT of these power supplies gives a signal of 1 to 5 V for zero to each rated current.

For the water-cooled magnets we have two high power electric sources[3,6] with 4 MW capacity each (total 8 MW : 350 V, 2x11.5 kA). These power sources give DCCT signals of 0 to 10 V for zero to each rated current(11.5 kA each). We have developed, therefore, an analogue computing circuit as shown in Fig. 2 which generates an analogue voltage signal following to eq.(1) for each hybrid system.

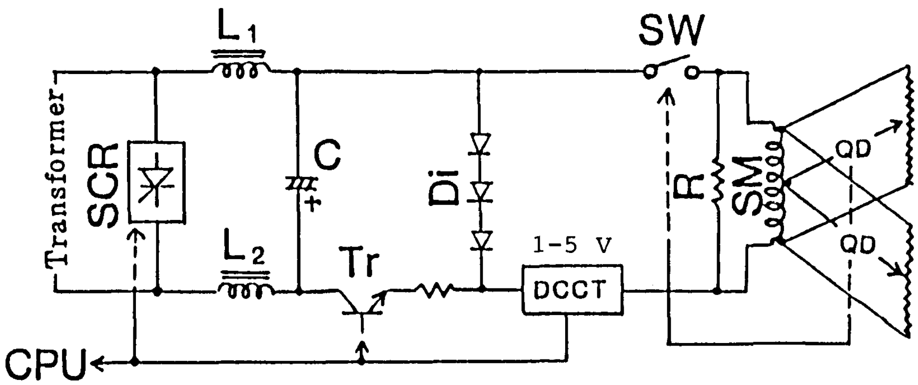

Fig. 1. Schematic Circuit Diagram of Power Supplies for the Superconducting Magnets.

Since a very high voltage up to about 1,000 V would come from the outer superconducting magnet at the occasion of a magnet quench, input signal from DCCT of a power supply for SM is first put into an isolation buffer amplifier and then followed by an impedance converter (741 type IC). In the case of the high power electric sources for WM's, two DCCT signals of 0-10 V each are first impedance converted since the output impedance of them is very high (about 10 kΩ or more). After such first operation described above, three signals are analogue computed exactly following eq.(1) to generate the following voltage signal,

$$E = 0.1 \times B \ , \qquad (2)$$

where E(Volts) is the output signal of the generator and B(Tesla) the magnetic field generated by a hybrid magnet. For the signal isolation, two IC's of LM331 were used, and total six conventional 741 type IC's were used for the impedance conversion and analogue computing for each generator. The output signal of the generators was monitored by a compact digital multimeter(DMM), Iwatsu Electric Corp. Type SC-7401. All signals from DCCT's were put into the generators via a very compact terminal box. A picture of two generators is shown in Fig. 3 together with the DMM for monitoring.

III. Test and results

Three generators for HM-1, HM-2 and HM-3 were constructed. There are three potentiometers with ten turn high precision type to be adjusted for each generator. HP-1 (see Fig. 2) determines the signal

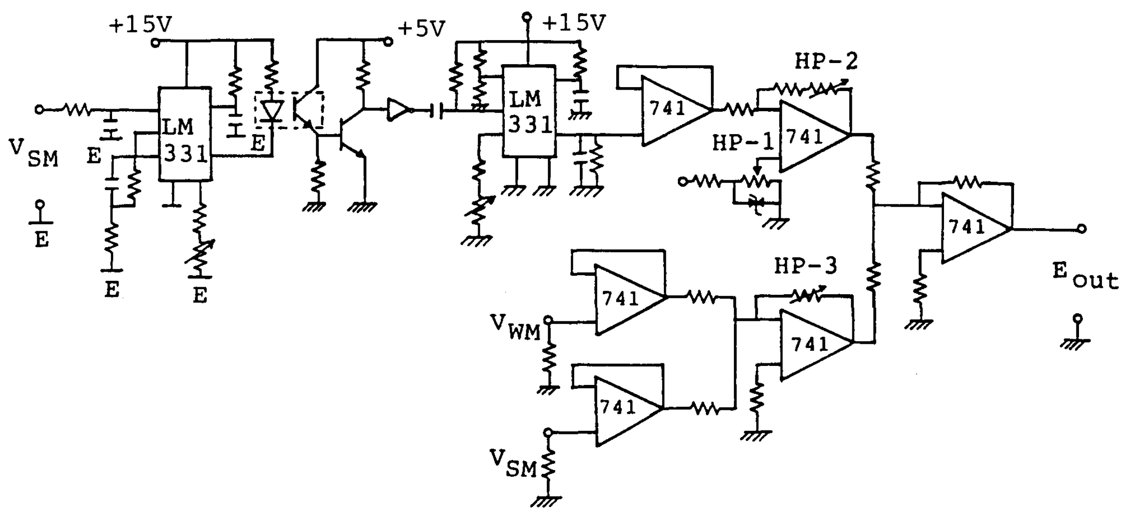

Fig. 2. Circuit Diagram of the Analogue Field Generator.

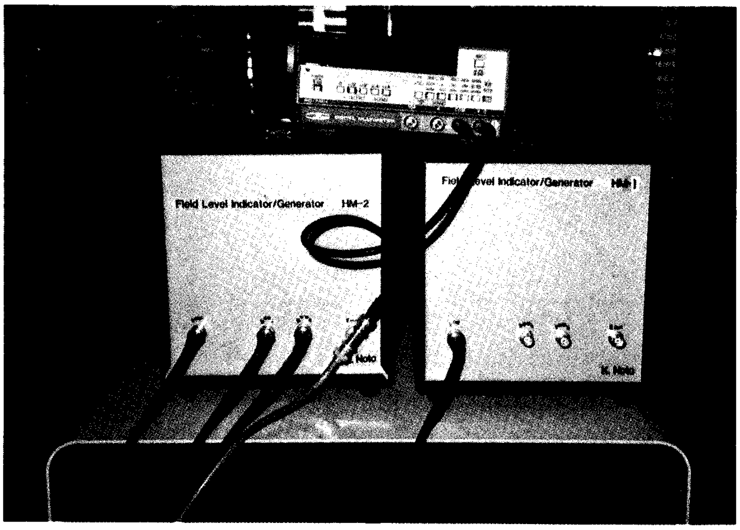

Fig. 3. Picture of the Analogue Field Level Generators.

level of subtraction, that is, $V_E \cong 1$ V from the signal of DCCT from the power supply for SM. HP-2 sets the value of G_{SM} and HP-3 that of G_{WM}. These three potentiometers of each generators were first adjusted at zero, maximum field of SM, and maximum field of HM. HP-1 was adjusted at zero field to determine V_E so as the output voltage to be equal exactly zero. HP-2 was adjusted at the maximum field of outer SM, where the current of inner WM was zero, to set G_{WM} giving an output, $E_{out} = (1/10)B_{SM}$. At the maximum field of HM, HP-3 and thus G_{WM} was adjusted to give $E_{out} = (1/10)B_{HM}$.

The generators were used after an enough time warm-up every time longer than 1 hour. Figures 4 and 5 show the output voltage and its deviation of the generator for HM-2 against the magnetic field after a few months operation from the first adjustment. As can be seen in Fig. 5, the accuracy is about ±0.4%. This accuracy is not very high, but is satisfactory for the usual H_{c2} measurements, since the exact field level is always checked on the recorder chart during the measurements. Moreover, it is expected that more accurate than ±0.05% adjustment might be possible judging from the linear deviation from the abcissa and the small scattering of data at high fields in Fig. 5. Figure 6 is an example of H_{c2} measurements in a practical multifilamentary Nb_3Sn conductor(7). H_{c2} was determined from the onset point of the sample resistance.

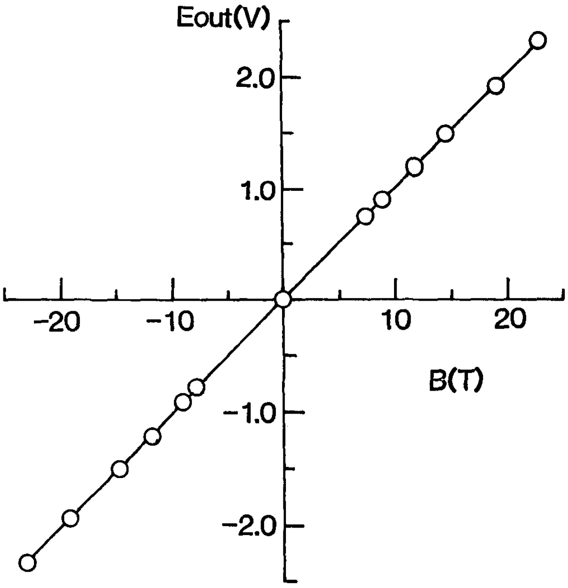

Fig. 4. Magnetic Field Dependence of the Output Signal of the Analogue Field Level Generator.

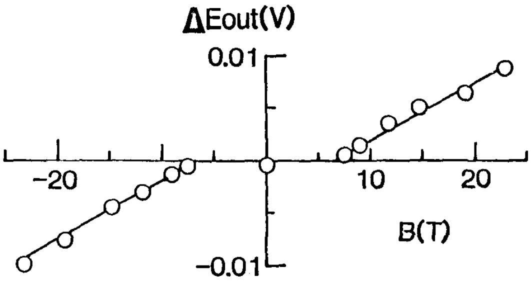

Fig. 5. Deviation of Output Signals Against the Magnetic Field for the Analogue Field Level Generator.

IV. Summary

In summary,

(1) an analogue field level generator has been developed for the measurements of the upper critical field measurements.

(2) The accuracy of the generator turned out to be about within ±0.4% of the maximum field of our hybrid magnets.

(3) The accuracy is thought to be made better than within ±0.05% judging from the first calibrated data.

(4) This generator is thought to be useful also for many other measurements, for which such an analogue signal proportional to the magnetic field at the center of hybrid magnets is needed.

(5) This generator might be applicable also for many hybrid type superconducing magnets often developed recently.

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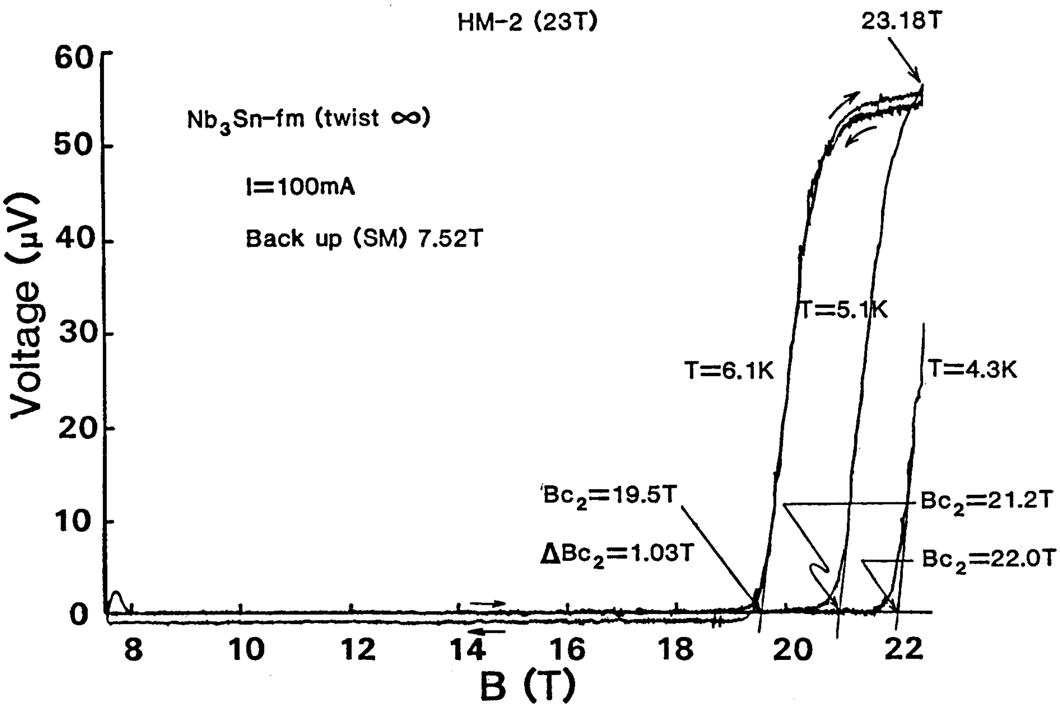

Fig. 6. An Example of H_{c2} Measurements by Use of an Analogue Field Level Generator.

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