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DCCTs for Magnet Power Supplies

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Abstract

This paper describes the operation principle of DCCTs which are used in the magnet power supplies of the TRISTAN main ring.

1. Introduction

The current sensor used in the magnet power supply must be of high precision. In the TRISTAN main ring, high-precision DCCTs comprising 2 Brentford/Hingorani (B.H.)-type DCCTs (direct-current current transformer) are used.

The usual textbooks explain the Kraemer type DCCT, which has a well-known defect: the waveform of the output exhibits "notches" at the peaks of the ac voltage wave. The output therefore has a large ripple of 100 Hz. Although capacitors can be used to smooth out this ripple so as to produce a pure dc component, this sacrifices the response speed.

Dr. Hingorani and Brentford corporation in England developed a modified version of the Kraemer circuit in the early 1960's which eliminated the current notches (refs.1-2). Although any DCCTs of this type are now operational in power supplies, no papers explaining the principle of the B.H.-type DCCT could be found. This paper thus gives both the principle and a procedure for building DCCTs.

2. Brentford/Hingorani-type DCCT

Principle of operation

The B.H.-type DCCT comprises two saturable inductors, four rectifiers and there resistors. The primary and secondary windings are wound on a single core (Fig.1) The core is the key element. A rectangular hysteresis-loop core material is employed to obtain a sharp break between the saturated and unsaturated states. As soon as the flux in the core reaches the saturation region, the impedance of the inductor changes from a high value to a low value. The operation is alike that of the SCR (silicon-controlled rectifier), since the load current can be controlled by firing the saturable core as well as the SCR. The photograph in Fig.1 shows the load voltage. The firing angle can be controlled by the dc current of the primary. The difference between the SCR and a saturable inductor is that the SCR allows the current to pass in only one direction, whereas inductors conduct current in both directions. It is worth noting that the return current is nearly constant. This property depends on the B-H loop, because the characteristics on the integral of the voltage versus the current are almost as sharply rectangular as the B-H characteristics.

B.H.-type DCCTs make use of the flatness of the return current. The circuit in Fig.2 can be regarded as being an equivalent circuit of that shown in Fig.1. The resistor (R) in Fig.1 is equivalent to a mixture of the resistors and diodes in Fig.2. The bypass diodes are connected to the resistors in parallel. The rectifiers are switched alternately; the rectified output across the resistor (RL) is shown in Fig.2. We obtain square pulses. The height is proportional to the primary current. Since the region is wider than 180 degrees, a pure dc output can be made from 2 square pulses by means of a circuit functioning as an AND-gate.

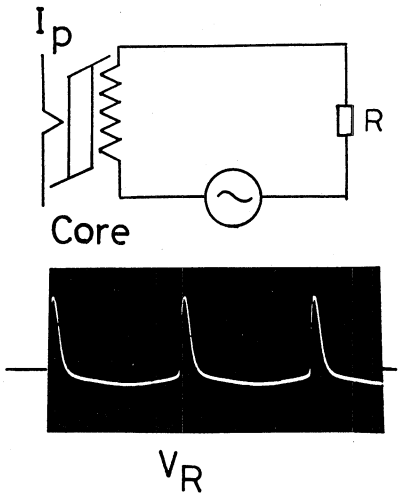


Fig. 1 Circuit with a saturable core

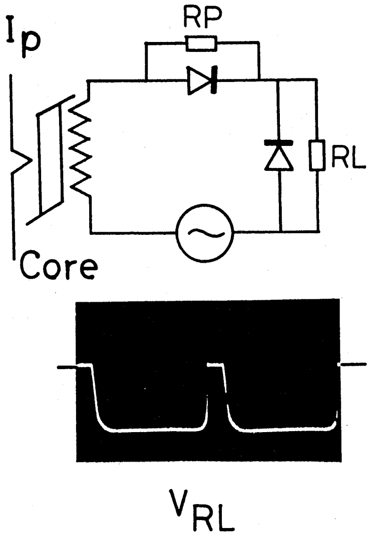
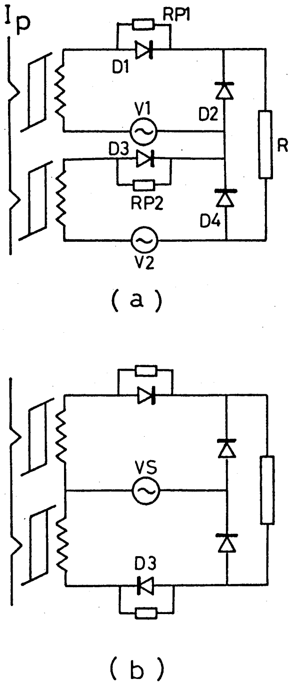


Fig. 2 Equivalent circuit

In Fig.3(a), two saturable cores are combined to supply each square pulse (shifted by 180 degrees) to a common load resistor (RL). The core is periodically magnetized into saturation; the role of the two cores is reversed in the next half-cycle, providing a DCCT. Fig.3(a) is equivalent to Fig.3(b). The circuit arrangement shown in Fig.3(b) is familiar to us.



(a)

(b)

Fig. 3 Superposition of saturable core circuits

SPICE analysis

In order to fully understand the operation, computer simulations were performed. The circuit shown in Fig.3(b) was investigated using computer code SPICE. The Jiles and Atherton hysteresis model (refs.3-4) is listed in the library of SPICE. The model is ferrite so that the hysteresis-loop is not rectangular.

Many computer runs were made in order to obtain a smaller ripple waveform. The resulting ripple, even in the best case, was about 30%. This was caused by not-rectangular hysteresis.

Test of DCCT

The DCCT used for tests has two cores with 6000 turns. The core material has a high permeability and a rectangular-hysteresis loop. The inductance was 980 H, which was almost the upper limit of the LCR meter.

(1) The B-H loops in operation are shown in Fig.4.

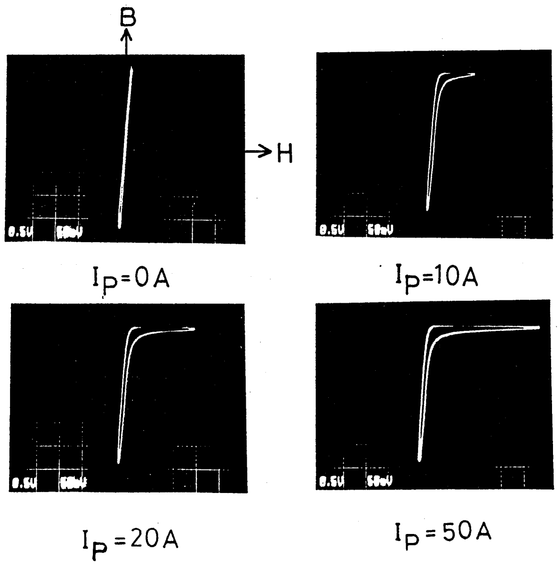


Fig. 4 Oscilloscope presentations of the B-H loop.

(2) The ripple of the output was about 8%. This unwanted ripple component is generated by the width of the hysteresis loop.

(3) A pulsed current was measured using the DCCT and a precision shunt. Fig.5 shows the current waveforms. Although the carrier frequency of the magnetization source is 50 Hz, a short pulsed current can be observed, because a core in the unsaturation state serves as an ordinary transformer.

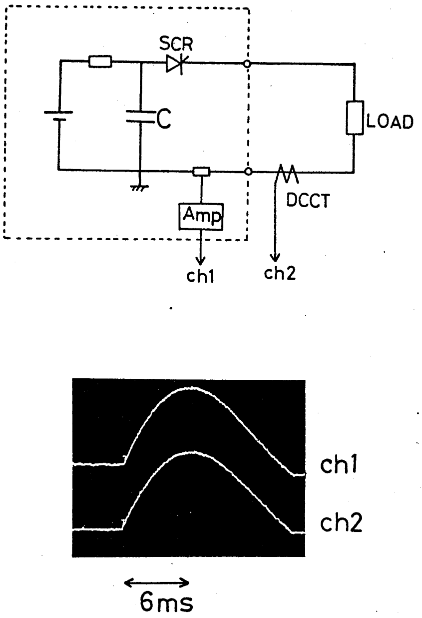


Fig. 5 Pulse response of the DCCT

3. Construction of a high-presition DCCT

The circuit of the high-presition DCCT is shown in Fig.6. There is one primary winding and 3 auxiliary windings. A large dc current for making measurements flows in the primary cable. Four windings for the carrier current are provided in each core; 2 bias windings are provided in each DCCT, which are connected in series. The output of each DCCT is set to the proper operating level by a bias current. The primary cable and compensating winding are wound in opposite directions to each DCCT, and are connected in series. The current to be measured is compensated by the secondary compensating winding current through a high-gain power amplifier with a feedback loop. This control circuit maintains a decrease in the difference between the two DCCTs. The negative-feedback circuit improves the linearity, dynamic range, frequency characteristic, temperature stability, and signal-to-noise ratio. The burden resistor (V_{ref}) converts the compensating current into a voltage signal (V_{out}). The voltage is proportional to the primary dc current.

We constructed a high-precition DCCT. Matched DCCTs were chosen for a pair. Although the ripples of about 8% of the DCCTs were canceled in the input of the amplifier, a slight ripple remained in the output voltage. A spike ripple was caused by diodes when the current was turned off. Above a high amplification, an oscillation of 2～3 kHz occurred, and quickly shifted to the voltage limit.

To obtain high stability, a stabilized ac voltage source and a temperature-controlled oven are required. These performances are well documented in the literature, and fulfill the requirements of the storage ring.

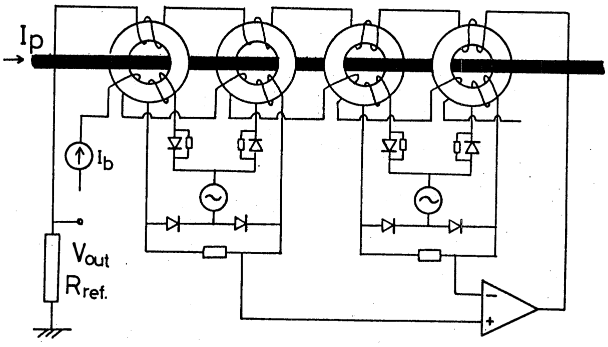


Fig. 6 Circuit of the high-precision DCCT

Acknowledgment

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