Novel DC Current Transformer by the Reed Relay's Release MMF

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Abstract - Accurate dc current transformers (DCCTs) are required for high current precision power supplies- Three basic categories of devices are available: devices which uses Ohms law (V=RI) called current shunts, devices which use Amperes law ($\int Hdl = \sum I$), called magnetic current sensors, and devices which uses both, called direct current transformers, DCCT's The novel DCCT (NDCCT) uses Amperes law, and a reed relay (RR) as magnetic current sensor to detect when the primary and secondary ampere-turns would exactly be equal in magnitude and opposite. RR detects the zero flux condition occurring at the outlined balance condition. NDCCT is a clamp-on current probe. Two versions of NDCCT are illustrated, the one as dc current comparator and the other DCCT. By test results on an experimental NDCCT an uncertainty of $1.4 10^{-7}$ on the ratio error at 1 kA of the primary current is achieved.

I. Introduction

Accurate dc current transformers (DCCTs) are required for high current precision power supplies such as those used in particle beam accelerator applications that are operated in the current constant mode [1] and [2] for the CERN's next particle accelerator particle large hadron collider, and in precision current monitor system for the power supplies at SRRC [3] or [4] to measure the beam current and beam life of light sources.
- *Characteristics of dc current measurement devices*. - Three basic categories of devices are available [1]: devices which uses Ohms law (V=RI) called current shunts, devices which use Amperes law ($\int Hdl = \sum I$), called magnetic current sensors, and devices which uses both, called direct current current transformers, DCCTs.
- *Shunts* are differentiated from resistors by the fact that they are exclusively designed to measure current. The majorfactors which affect the precision of a shunt are: the temperature coefficient of transfer impedance, power dissipation, low output signal, and in many applications the need for isolation from the current being measured. - *Magnetic current sensors* comprise devices that measure the magnetic field generated by the current flow. These include: Hall effect current sensors, magnetic modulator devices, and NMR current sensors, SQUID. Current sensors, magnetoresistive devices, and magnetostrictive devices. The major factors affecting the precision of Hall effect current sensors are: temperature sensitivity, linearity, leakage flux sensitivity, and sensitivity to control current, *DCCTs* use magnetic current sensors to extend the frequency range of an AC current transformer down to DC. By using a specific turns ratio, a smaller secondary current, which is galvanically isolated and approximately proportional to the primary current, is generated. This secondary current can then be accurately measured with a low power, high stability shunt to give a scaled readout of the primary current. At SRRC [2], a precision output current monitoring system is installed to monitor the output performance of all the booster/storage ring power supplies. Accurate DC current transformers (DCCTs) are attached to the output. - Current Transductors are fundamental frequency magnetic modulators and members of the magnetic amplifier family. Their basic DC current sensor is a twin core saturable reactor. In which, at zero DC current, the total flux swing approaches the available maximum.

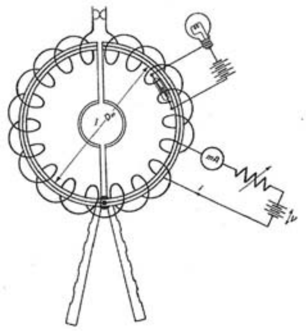

Fig. 1. Schematic diagram of NDCCT as dc current comparator.

Transductor designs vary widely. From the simple to the very complex, see [5]. For a description of the basic series connected current transductor see Geyger [6].

The novel DCCT (NDCCT) uses Amperes law, and a reed relay (RR) as magnetic current sensor to detect when the primary and secondary ampere-turns would exactly be equal in magnitude and opposite. RR detects the zero flux condition occurring at the outlined balance condition. NDCCT is a clamp-on current probe. Two versions of NDCCT are illustrated, the one as dc current comparator and the other DCCT. By test results on an experimental NDCCT an uncertainty of 1.410^{-7} on the ratio error at 1 kA of the primary current is achieved.

II. Basic Principle of NDCCT

The basic principle of NDCCT is to superimpose the primary and secondary ampere-turns of CT on a RR and detect their equality when RR release. The applications of NDCCT as dc current comparator and as Crest Amperemeter-Voltmeter are illustrated in the following.

A. DC Current Comparator

The configuration of NDCCT as dc current comparator is shown in Fig. 1, it is composed of a clamp-on toroidal core. The primary current's (I) conductor is brought at the center of the core by a properly configured rubber plane. The secondary winding of N wires is wound on the core. Series connected with the secondary coil are both an adjustable supplier of the secondary current (i) and RR (one-pole form A (opened) contact). RR is put on the inner diameter of the core. A bulb with series connected a supplier is parallel connected with RR. With D_m the inner diameter of the core the primary ampere-turns on RR are, H= $I/\pi D_m$. With i the secondary current the secondary ampere-turns are, h=$Ni//\pi D_m$. With I $\neq$0 and i=0 H actuates RR that lights the bulb. i is hand increased up to switch off the bulb. With the experimental NDCCT, h = H. Then I= Ni.

B. *NDCCT*

Fig. 2 shows the configuration as dc CT. Omitted, for simplicity, the rubber plane and the switch on the secondary coil. RR is series connected with, i, a high value resistor, R, and a dc voltage supplier and milliampermeter (mA) of i. A capacitor C is parallel connected with the series of R and mA. With I $\neq$0 and i=0 H actuates RR, i increases up to have h=H (namely, I=Ni. This holds for the maximum value i_m of i at which RR release and not with the mean value $\bar{i}$ by mA) at which RR release i zeroes and the cycle newly starts. At each cycle C reaches the maximum of the voltage at its terminals and then discharges on mA $\bar{i} \propto i_m$. With T the realize time of RR the ratio error, η, is, $\eta = \dfrac{i_m - \bar{i}}{i_m} = \dfrac{T}{2RC}$. In our prototype of a DCCT, T=0.5 ms, with R= 1 MΩ, and C=10 μF, $\eta<210^{-7}$).

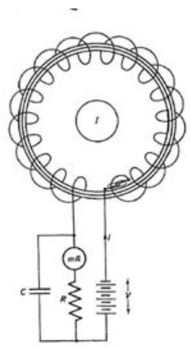

Fig. 2. Configuration of NDCCT as dc CT

C. Crest Ampere-meter-Voltmeter

Aconductor of three thin twisted wires is wound on a RR the under test current supplies the primary winding with series connected a diode. The secondary network is the same as in Fig. 1; the compensating current I_c supplies the third winding (see in the following). I is a periodic current, RR is activated at each half a period. When i $=I_{kreast}$ RR release

- *Detection of the ratio* $\frac{i_m}{\bar{i}}$ *and Compensation of the Activating Current* - i_m is detected by the current comparator configuration. At the configuration as NDCCT with the same I $\bar{i}$ is measured in place of i_m. $\frac{i_m}{\bar{i}}$ Is evaluated with an uncertainty nearly equal the resolution with which i_m and $\bar{i}$ are measured and I is maintained at the same value. We denote with I_o the minimum value of I that actuates RR. I_o is the current's error = $\frac{I_o}{I}10^6\ ppm$. In fact when RR releases, H-h< I_o instead of H-h=0. A small conductor is fastened on the one of I and is supplied with the compensating current $I_c \cong I_o$. The current's error is $I_o^{'}=I_o-I_c\cong 0$. I_c has to be maintained constant during the whole test. We had $I_o^{'}$=0.14 mA with I= 1kA and $I_o^{'}$= 10 pA in the crest value measurement, see the Section Test Results. By this compensation i is nearly a dc without any ripple. - *Residual and External Fields* - NDCCT operates at a nearly zero field, then, is imperious to residual and external field affecting the majority of DCCT's.

III. Test Results

An experimental NDCCT has been developed. - A. *Prototype's Rated Data*:
- *RR* in the A form (single pole opened) maximum, *operating, time* about 0.5 ms and *rated voltage* 100 V, *contact resistance* about 150 mΩ, operating *temperature range*, -55÷+70 °C, *shock resistance* 100 g - 11ms, *vibration resistance* (duration 6 h), 10 g, 10 ÷ 1500 Hz, maximum operating frequency 550 Hz, *expected life* for switching at 0.25A/40 V dc, over 510^8 operations, encapsulated *in a plastic package* (acting as a thermal shield), overall dimensions, 3×5×15 mm.
- *Core and windings* - D_m =133 mm, *N=230* in the form of CT and N=50 in the form for crest measurement.
- (C) *Scheme of the circuit to testing CT*- A schematic diagram of the circuit used in testing NDCCT is illustrated in Fig. 3. R_l = 10 mΩ with parallel connected a seven decades resistor. n_k is the settling of the decade with step of 10^k Ω with k=0÷6. Is, $\frac{I}{i}=\frac{R_2}{R_1}\left[1+\sum_0^6 n_k 10^{-(k+2)}\right]$. At k=6 the resolution of the test is to 10^{-8}.

The test has been repeated with I in the range 100 A÷10 kA. It was $I_o^{'}$=0.14 mA. During the test at I= 1 kA sensitivity equaled the resolution 10^{-8} and ratio error <1.410^{-7} and at I=10 kA, ratio error <1.410^{-8}. In the use as crest ampere meter, $I_o^{'}$=10 nA and the ratio error undetectable to 2 MHz. *Reliability* has been detected by energizing NDCCT with I=1150 A and i_m =5 A all along one month. The RR has shown to be imperious to temperature influences in the temperature range 20-110 °C. The waveform of i at different values of R as been detected, see in Fig. 4 a) and b) the waveform of i with C= 10 μF and respectively R= 1M Ω and R= 133k Ω. The time scale is 1 ms/div.

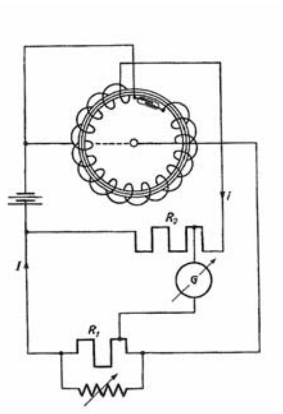

Fig. 3 Schematic diagram of the circuit used in testing NDCCT as CT

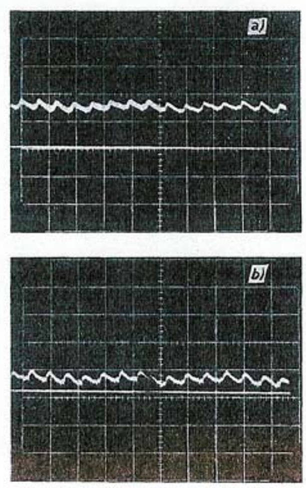

Fig. 4. Waveform of i with C= 10 μF and respectively (a) R= 1M Ω and (b) R= 133k Ω. The time scale is 1 ms/div

IV. Conclusions

A new dc current transformer (NDCCT) by a RR has been successfully investigated designed and experienced. By test results it clearly appears that the illustrated NDCCT quite satisfy the requirements of high, class, and reliability required by industrial applications to the extreme environmental temperature. Moreover its construction (if compared with the usual techniques of DCCTs [1, 2] is highly simple cheap and reliable. Therefore these highly significant and valuable characteristics justify the clam of the usefulness of NDCCT by a RR in industrial applications appears. High accuracy is generally attained at the cost of increased time and effort. There is the necessity for combining high accuracy with the simplicity that makes for reliability. NDCCT performs this finality.

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BIOGRAPHY

FRANCO CASTELLI was born in Milan, Italy. He received the M.S. degree in electrical engineering from the "Politecnico di Milano", Milano, in 1958. He worked one year at C.G.E. (Compagnia Generale di Elettricità), Milan, in the servomechanism field. In 1961 he joined the Polytechnic of Milan as Assistant Professor of Electrical Measure-ments. He was awarded the "Angelo Barbagelata" premium in 1965 and the "Lorenzo Ferraris" premium in 1967 on the basis of the publications on electrical measurements.

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MARCO FAIFER was born in Bormio (Italy) on July 28, 1978. In 2003 he received his M.Sc. degree in Electronic Engineering at the Politecnico of Milan. Currently he is an assistant professor of Electrical and Electronic Measurements at the same University. His scientific activity is mainly concerned with the DSP techniques, the development of industrial sensors and the devices for High Voltage measurements.