PERFORMANCE OF TRANSDUCTORS FOR PRECISION HIGH-CURRENT MEASUREMENT AND CONTROL*

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Summary

In order to find transductors suitable for the requirements of the ZGS, four commercial transductors were compared with a precision coaxial shunt. The results of these measurements, which determine the stability, linearity, hysteresis, frequency response, output ripple, coefficients of temperature and line voltage, and effects of magnetic stray fields, are reported.

Introduction

For precision high-current dc power supplies, the signal sources are either shunts or transductors. Shunts have been built with a stability that exceeds 0.001% and a pass band from dc to tens of kHz. However, for good signal to noise ratios shunts usually dissipate several kilowatts of power, and they are also electrically connected to the power circuit. In comparison, a transductor dissipates negligible power, has an output signal ≥ 10 V, and provides isolation from the power supply. However, the performance of commercial transductors has not been as good as that of shunts. In some instances performance data on transductors has been difficult to obtain. These tests were conducted to provide another source of information on the performance of several different commercially available transductors.

Measuring Circuit

General

Measurements were made on four transductors.

1) Brentford CT 3/10
2) Foeldi CT 3000-10
3) Daytron CT 4000 (adjusted for 10 V - 3000 A)
4) Transrex CT 5000-10

The transductors were placed in boxes which were temperature controlled with lamps, and the air temperature inside each box was sensed with a thermistor. The thermistor output was amplified to control the lamps, providing temperature stability inside each box of $\pm 0.5^{\circ}$ C. Thermocouples were used to monitor the air and body temperatures of each transductor together with the temperature of the shunt. The shunt was kept at a constant temperature by its own cooling system. These temperatures were continuously recorded on chart paper each time data was taken. The electronics for the Brentford and Foeldi transductors are contained in their housings, and their temperature changed as the transductors temperature changed. The electronics for the Daytron is separate and was placed in an oven at 65° C $\pm 2^{\circ}$ C. The Transrex electronics was placed in a separate box--the temperature was not controlled but was monitored on the recorder. This temperature did not change more than $\pm 1^{\circ}$ C during the tests.

For three of the four units, the voltage for the electronics is single phase, 60 Hz. This voltage was monitored on a Fluke meter and kept constant to ± 0.05 V. The voltage for the Transrex electronics is 480, 3 phase and could not be controlled.

The transductors were connected in series in a straight line so that errors due to bus fields were negligible. A magnet with a resistance of 25 mΩ and a time constant of 0.1 s was used as a load for a Transrex 5000 A supply.

The transductors were compared with a precision coaxial shunt. The shunt and transductor outputs were measured with Fluke meters with an uncertainty of ± 5 ppm. Five or ten measurements were taken per point and the average was used as the correct reading.

The percent error between the transductor and shunt was calculated in the following way:

$$\% \text{ Error} = \frac{\dfrac{\text{transductor (I)}}{\text{shunt (I)}} - \dfrac{\text{transductor (STD)}}{\text{shunt (STD)}}}{\dfrac{\text{transductor (STD)}}{\text{shunt (STD)}}} \times 100$$

Test Results

Stability and Output Ripple

The stability measurements were made over an eight hour period at bus currents of 1800 and 3000 A. During these measurements, the ambient temperature of the transductors was maintained at 40° C. The peak-peak output ripple of each transductor was recorded. The results of these measurements are shown in Table I. The lowest and highest ratios of the transductor outputs to the shunt outputs were used to calculate the maximum deviation over the test period. A 1-1/2 hour warmup time was allotted before measurements were begun.

Linearity and Hysteresis

For the linearity and hysteresis measurements, the current through the transductors was varied from 300 to 3000 A and back to 300 A in 300 A steps. This procedure was repeated twice. The temperature of the transductors increased by less than 1.5° C introducing a negligible error. The graph in Fig. 1 shows the typical results. The two runs were averaged, and the ratio of the transductor to the shunt at 3000 A was taken as zero error.

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Frequency Response

For the frequency response measurements, three, 2 V batteries each delivering 210 A for 8 hours were connected in parallel and placed across a 5.7 mΩ load. A 10 kW Ling power amplifier and transformer were used to modulate the dc current from 28% to 2.8%, depending on the frequency of the modulating signal. A Hewlett Packard wave analyzer was used to select and measure only the frequency component of interest. The frequency response curve shown in Fig. 2 is normalized to the dc output value of each transductor. The frequency response of the Brentford, Foeldi, and Daytron transductor is similar with maximum variation of less than 5% occurring above 9 kHz.

Coefficients of Temperature

Temperature coefficient measurements were made at 1800 A and 3000 A. The ambient temperature of the transductors was set at 40° C and then 60° C for each current. This temperature range was selected because it represents the typical operating conditions for our transductors. For these tests the electronics for the Transrex unit was held constant at 55° C ± 1° C. For the Daytron unit, if the electronics package is kept at the same temperature as the transductors, the temperature coefficient is 200 ppm/° C. Typical results for these measurements are shown in Table II.

Line Voltage Coefficients

Line voltage coefficients were obtained for three of the four transductors at bus currents of 1800 and 3000 A. The line voltage was lowered by 9% and raised by 8%. During these tests the voltage was held constant to ± 0.01 V. The results of this measurement are shown in Table III.

Effects of Stray Magnetic Fields

The effects of stray magnetic fields parallel and perpendicular to the axis of the transductors were obtained at a bus current of 1800 A. Cables were placed on either side and 11 in. away from the center of the transductors, connected in series in a straight line. A current of 2200 A created a calculated magnetic field of 15.74 G at the midpoint between the cables. The effects of this test on the output voltage are tabulated in Table IV. The cables were then placed so as to create a magnetic field perpendicular to the transductor axis. No measurable effects were obtained with this configuration.

Acknowledgments

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Table I

Stability and Output Ripple

I		Brentford	Foeldi	Daytron	Transrex
1800	%/8 hrs	0.0019	0.0018	0.013	0.0011
	ripple (p-p)	116 mV	112 mV	170 mV	70 mV
3000	%/8 hrs	0.0013	0.004	0.035	0.0035
	ripple (p-p)	120 mV	112 mV	180 mV	72 mV

Table II

Temperature Coefficients

I		Brentford	Foeldi	Daytron	Transrex
1800	ΔT	19.17° C	18.89° C	19.72° C	19.45° C
	ppm/° C	1.1	0.76	11.8	0.59
3000	ΔT	19.16° C	20° C	19.44° C	19.85° C
	ppm/° C	2.05	6.07	6.9	0.73

Table III

Line Voltage Coefficients

I		Brentford		Foeldi		Daytron	
1800	ΔV/V (%)	9.2	8.3	9.2	8.3	9.2	8.3
	ppm/% V	0.5	1.5	1.9	1.0	3.5	0.7
3000	ΔV/V (%)	9.3	8.8	9.2	8.8	9.2	8.8
	ppm/% V	21	3.9	4.7	9.8	21	10.3

Table IV

Coefficients of Stray Parallel Magnetic Fields

	Brentford	Foeldi	Daytron	Transrex
Current	1800	1800	1800	1800
ppm/gauss	6	4.5	44	19

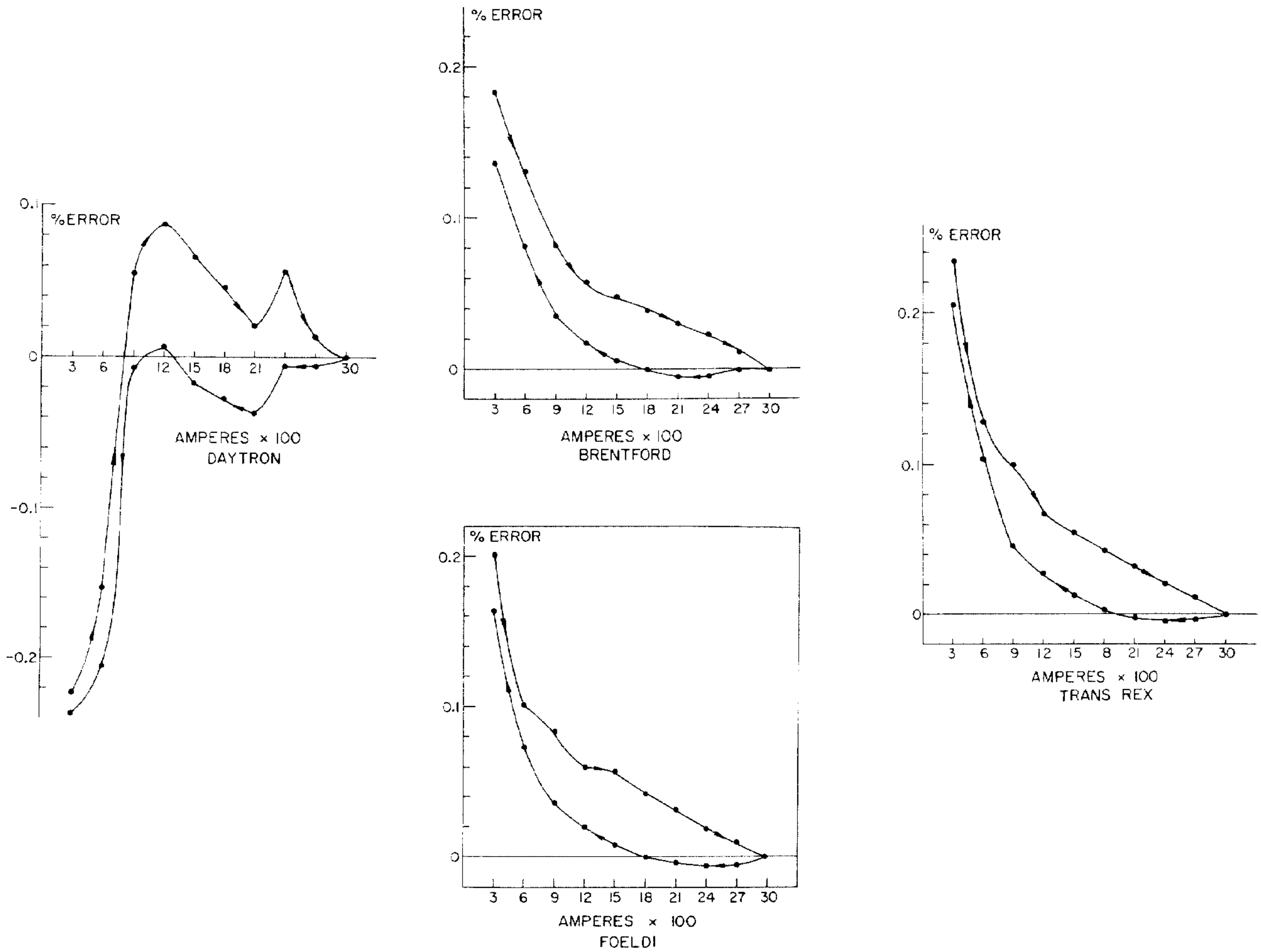

Fig. 1. Linearity and hysteresis.

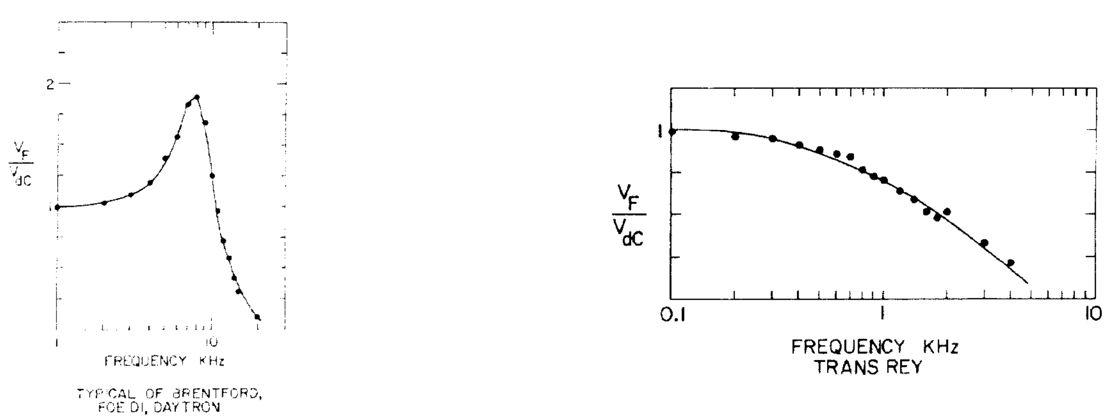

Fig. 2. Frequency response.