AN AUTOMATIC DC CURRENT COMPARATOR RESISTANCE BRIDGE

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ABSTRACT

The principle of the Direct Current Comparator has been around for some 30 years, however, very little work has been done towards automation. This paper describes a bridge for measuring resistance ratios in the range of 0.001 ohms to 10,000 ohms using a microprocessor controlled automated DC Current Comparator with IEEE-488 to an uncertainty of better than 0.1 ppm from 1 ohm to 1000 ohms and 0.2 ppm at the 0.1 ohm and 10,000 ohm level.

Introduction

For many years now, the measurement of resistance ratios has depended on either of two techniques:

1: passing a current through two or more resistors in series and measuring the ratio of voltages developed across the resistors, or

2: passing ratios of current through each pair of resistors until the voltage developed across each

The classical Wheatstone bridge and the Kelvin double bridge are examples of the first technique whereas the direct current comparator is an example of the second technique.

The Direct Current Comparator (fig 1.1) is a multiple winding toroidal transfer device in which the primary and secondary windings carry direct currents and in which a separate detection winding is used for the detection of DC flux in the core. When the primary and secondary ampereturns are equal and opposite then the voltage developed across each resistor is the same, Ex = Es and the ratio = Nx/Ns.

THE AUTOMATED DIRECT CURRENT COMPARATOR

Using a binary wound comparator, with effective linearity of better than 1 part in 10^8, has made the principle of automation much more attractive as the number of turns switching relays is greatly reduced. All the advantages of the conventional decimal wound current comparator are maintained as the new bridge is not sensitive to lead resistance, current stability is unimportant and when scaling resistors the greater power is dissipated in the smaller resistor.

Transient current reversals have been greatly reduced by eliminating the voltage feedback winding and tracking feedforward compensation circuit and switching the current off at the time of reversal. Elimination of the feedback winding was achieved by always operating the bridge at final balance and the feedforward compensation circuit of the tracking by continually sampling the tracking output. Improvements to the peak detector circuitry and core design have effectively reduced the modulation component of the magnetic modulator to zero.

The two resistors been compared are supplied form different current sources and the ratio of the two currents is measured when the voltage drop across the resistors is equal.

1: Es = Ex and/or 2: IsRS = IxRx

The current comparator is used to obtain an ampere-turn-balance between the primary and secondary windings by adjusting the primary windings (Nx) and slave current supply (Is) until zero flux exists in the core. The relationship between the two currents and the windings follows the expression.

3: IsNs = IxNx and 4: From 1 and 2: Rx = Nx/Ns * Rs.

In the practical form of the technology, the requirement for two simultaneous balances has been a manual operation requiring fairly skilled personnel.

In the practical form of the automated bridge only the primary current Ix and Reversal Rate need to be set by the user and the simultaneous balances of Nx and Is are performed automatically. To establish this balance the bridge must first determine a rough ratio of the voltages across Rs and Rx. First passing the primary current Ix through Rs and then Rx and measuring the voltage drop across the two resistors perform this procedure. The ratio of the two voltage drops Vx/Vs is used to set the primary turns of the comparator and the secondary current via a tracking DAC in order to maintain an ampere-turns-balance to better than 1.5 PAT. The remaining ampere-turn-balance residual is compensated for by the ampere-turn-detector as sensed by the detector windings and peak detector.

The master current (Ix) is then reversed and the comparator output and voltage difference across the resistors are remeasured. The positive and negative voltages are summed, weighted and added to the respective rough settings and the primary-turns and sale current are readjusted to with-in a few ppm of their final value. High resolutions A/D's are used to measure the detector output and to measure the voltage difference across the resistors under test.

The voltage difference measured at the potential terminals of the resistors is more finely measured by using a guarded electronic nanovolt amplifier. The nanovolt circuitry uses a separate double-shielded toroidal amplifier. The nanovolt circuitry uses a separate double-shielded toroidal power supply for isolation from the comparator circuit. The voltage noise of the amplifier is approximately 7 to 8 nanovolts. This noise level is equivalent to 0.7 ppm at the 10 mV level. At the 1 ohm level with 50 mA applied this voltage noise is equivalent to approximately 0.1 ppm. Further reduction of the uncertainty can be achieved by taking multiple readings.

Reversal of the current eliminates thermals in the measuring circuit and all DC balances, that of the tracking A/D and measuring A/D's are made to the DC offset of their associated circuitry. This eliminates the need for any offset trims on the amplifiers used.

<u>COMPARATOR TURNS CALIBRATION</u>

Calibration of the comparator turns is performed in an open loop condition. Open loop condition is where the slave or Rs side is open circuited and the peak detector and subsequent A/D used as the measuring device. The gain of the peak detector has been established to give a 100 mV output for a 100 PAT offset in the comparator. A 0.1 mV dc shift at this point is equivalent to one part in 10 8 of full scale. The turns consist of 11, 264 real turns and 16,384 partial turns. The 16,384 partial turns has the same weight as one real turn. As fractional turns cannot be wound on the toroid, they are created by dividing the primary current.

The turns on the comparator are wound binary, 1 2 4 8 etc., with an additional one turn added which is used for calibration purposed only. To begin the process of calibration the output of the peak detector is measured with zero turns and 10 mA of current applied. The results are recorded and this becomes the basis for all other measurements.

The 16,384 partial turns are compared directly against one real turn. Provision has been made to reverse the turns. The result is subtracted from the zero turns balance and this represents the linearity error of the fractional turns to the real turn. Subsequent measurements of the individual real turns and fractional turns are performed and the differences recorded. Typical errors range from 2 parts in 10 9 or less. Table 1.1 illustrates the following calibration results.

The fractional turn windings were achieved by splitting the primary current with a high precision, low drift resistor and adjustment. The most critical element of the drift of this adjustment is the power and temperature coefficient of the copper used for the fractional turn windings. To avoid this problem the wire gauge for the fractional turns was increased with the resulting change in resistance from both temperature and power coefficients of the copper used for the fractional turn windings. To avoid this problem the wire gauge for the fractional turns was increased with the resulting change in resistance from both temperature and power coefficients negligible compared to the adjustment range of the series resistor.

PERFORMANCE

Two methods were used to check the operation of the bridge. Preliminary testing of the automated resistance bridge was performed using a Guideline Instruments Model 9975 Resistance Bridge and secondly a comparison of the ratio of absolute values from a set of standard-working resistors at the National research Council. Uncertainties in the range from 1.0 ohm to 1000 ohms for 10 readings were less than 0.05 ppm with 10:1 ratio's being less than 0.03 ppm. At the 10,000 ohm level the uncertainty was less than 0.2 ppm for 10 readings. A reversal rate of 4 seconds was used from 1 ohm to 100 ohms increasing to 8 seconds and 12 seconds for 1000 ohms and 10,000 ohm measurements respectively. Table 1.2 illustrates the following results.

DIRECT READING CAPABILITIES

Direct reading capabilities for both resistance and temperature can easily be performed using a DOS based computer with an IOTECH IEEE-488 interface card and MIL supplied software. The external software for the bridge is menu driven and allows the user to perform direct reading measurements for both resistance and temperature with a real-time-uncertainty analysis. The uncertainty of the measurement is derived using the root-sum-square method for determining uncertainties. The software allows the user to enter in the number of measurements to be made and the number of measurements to be used for statistical analysis. It was found that in order to achieve an uncertainty of (0.03) ppm it was only necessary to perform 15 measurements and use the last 10 for statistical analysis over the range of 1 ohm to 1000 ohms. Refer to Table 1.3 for a typical measurement.

The main menu of the software is used to select any of the subsequent menus for performing a calibration or measurement. The main menu includes

1) Resistor ID Menu for entering in the resister ID, normal value and associated laboratory conditions at the time of measurements.

2) Program ID Menu for generating programs when doing automatic measurements.

3) Calibration Menu for performing a turns calibration and recording the data.

4) Measurements Menu for performing automatic measurements using the programs generated.

SUMMARY

The development of an automatic direct current comparator and its application as a resistance bridge constitute a major advance in completing the process of laboratory automation. With the addition of a 20-channel matrix scanner up to 20 resistors can be calibrated in a single run. Various combinations of resistors have been measured and the results confirm the anticipated sensitivity required and convenience of measurements.

ACKNOWLEDGMENTS

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REFERENCES

1) Andrew F. Dunn, Measurement of Resistance ratios in the Range to 100 Megohms, IEEE Transactions of Instrumentation and Measurement and Vol. 40, No2, April 191.

2) Dr. E. So, A Microprocessor-Controlled Current Comparator-Based DC Voltage Calibrator IEEE Transactions on Instrumentation and Measurement, Vol. 36, No 2, June 1987

Starting Calibration

Calibration of 6010A System, S/N 911202 1992-07-03 12:01:28

BALANCE AT ZERO TURNS:

0.0053 +/- 0.0012 (volts)

1 REAL TURN VERSUS 16384 PARTIAL TURNS:

ERROR: 0.0024 +/- 0.0026 (PPM) -0.0011 +/- 0.0012

128 PARTIAL TURNS VERSUS 128 PARTIAL TURNS:

ERROR 0.0079 +/- 0.0017 (PPM) -0.0014 +/- 0.0011

REAL TURN COMPARISON:

Real Turns	Error		(ppm)	Change		(ppm)
1 versus 1	0.0016	+/-	0.0012	0.0024	+/-	0.0041
2 versus 2	0.0010	+/-	0.0009	0.0014	+/-	0.0040
4 versus 4	0.0013	+/-	0.0013	0.0002	+/-	0.0031
8 versus 8	0.0021	+-/	0.0017	0.0028	+/-	0.0034
16 versus 16	0.0016	+/-	0.0005	0.0025	+/-	0.0038
32 versus 32	0.0034	+/-	0.0012	0.0004	+/-	0.0040
64 versus 64	0.0034	+/-	0.0023	0.0005	+/-	0.0023
128 versus 128	0.0028	+/-	0.0014	0.0021	+/-	0.0031
256 versus 256	0.0019	+/-	0.0008	0.0013	+/-	0.0020
512 versus 512	0.0022	+/-	0.0018	0.0028	+/-	0.0031
1024 versus 1024	0.0045	+/-	0.0012	0.0031	+/-	0.0038
2048 versus 2048	0.0016	+/-	0.0012	0.0014	+/-	0.0037
4096 versus 4096	0.0036	+/-	0.0009	0.0033	+/-	0.0015
1024 versus 1024	0.0065	+/-	0.0015	0.0062	+/-	0.0029
2048 versus 2048	0.0072	+/-	0.0015	0.0054	+/-	0.0032

PARTIAL TURN COMPARISON

Partial Turns	Error		(ppm)	Change		(ppm)
1 versus 1	0.0066	+/-	0.0017	0.0024	+/-	0.0024
2 versus 2	0.0057	+/-	0.0023	0.0038	+/-	0.0038
4 versus 4	0.0057	+/-	0.0023	0.0041	+/-	0.0041
8 versus 8	0.0076	+/-	0.0012	0.0032	+/-	0.0032
16 versus 16	0.0060	+/-	0.0012	0.0029	+/-	0.0029
32 versus 32	0.0060	+/-	0.0012	0.0026	+/-	0.0026
64 versus 64	0.0080	+/-	0.0015	0.0049	+/-	0.0049
128 versus 128	0.0059	+/-	0.0017	0.0038	+/-	0.0038
256 versus 256	0.0060	+/-	0.0020	0.0046	+/-	0.0046
512 versus 512	0.0066	+/-	0.0017	0.0038	+/-	0.0038
1024 versus 1024	0.0085	+/-	0.0020	0.0058	+/-	0.0058
2048 versus 2048	0.0083	+/-	0.0020	0.0040	+/-	0.0040
4096 versus 4096	0.0076	+/-	0.0012	0.0023	+/-	0.0023
8192 versus 1024	0.0085	+/-	0.0012	0.0032	+/-	0.0032

Calibration Completed Calibration End Time 12:20:32

Table 1.1

Model 6010A Intercomparison Chart

#	Resistor Type	Valı ppı	6010A Ratio & Interchange
R1	1 ohm Thomas Type sn 1029331	+ 20	1.00000570 X .9999941
R2	1 ohm GLD 9330 sn 32,262	+26	
R1	1 ohm Thomas Type sn 1029331	+20	10.0002058
R3	10 ohm GLD 9330 sn 38,556	+40	
R3	10 ohm GLD 9330 sn 38,556	+40	1.00003280 X .9999673
R4	10 ohm GLD 9330 sn 42,953	+8.	
R4	10 ohm GLD 9330 sn 42,953	+8.	10.0001171
R5	100 ohm GLD 9330 sn 9330 32,96	+19	
R5	100 ohm GLD 9330 sn 32,962	+19	1.00001440 X .9999855
R6	100 ohm GLD 9330 sn 30,814	+5.	
R6	100 ohm GLD 9330 sn 30,814	+ 5.	10.0000774
R7	100 Kohm GLD 9330 sn 36,963	+13	
R7	1 Kohm GLD 9330 sn 36,9631	+13	1.00000340 X .9999965
R8	1 Kohm GLD 9330 sn 33,671	+9.	
R8	1 Kohm GLD 9330 sn 33,671	+9.	9.9999850
R9	10 Kohm GLD 9330 sn 34,150	+8.	

Tests were conducted using Front Panel Display

Stand Alone Bridge S/N 911202

Table 1.2