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REVISION HISTORY

REV	ECO	DESCRIPTION	DATE	APPROVED
A	4177	Initial Release	3/24/06	Gershon S.

1. Introduction

1.1 Overview

The EX1629 Calibration Procedure is accomplished under control of the calibration function in the instrument's firmware. The calibration function communicates with the operator through the facilities of the network interface. This document details the operations that take place during calibration.

1.2 Audience

This document is intended for technical staff who need to understand the process by which the EX1629 is calibrated.

2. Terminology

2.1 *Factory Calibration*

Factory calibration refers to the full calibration process that is conducted prior to unit shipment and, is performed on an annual basis thereafter. Within this process, all of the unit's operating characteristics are calculated and stored in nonvolatile memory.

2.2 *Self-calibration*

A subset of the factory calibration process. It does not require any external equipment, nor does it require external sensors to be removed from the input connectors. Most of the instrument's accuracy-determining characteristics are updated by self-calibration. The instrument specifications require a self-calibration at least every 30 days.

2.3 *Bridge Channel or Main Channel*

One of the 48 strain gage input channels. Connection is made through an RJ-45 connector on the front panel of the EX1629.

2.4 *Confidence Channel*

Each main channel is supported by an auxiliary analog multiplexer whose output is routed to the 'Confidence Channel ADC'. The purpose of the confidence channels is to provide assurance that the external sensor connections are 'healthy'. In addition, excitation voltage measurement is provided through the confidence system. There are seven voltage inputs and two current sense inputs to the confidence ADC multiplexer.

The voltage inputs to the confidence channel multiplexer are:

+BUFFERED_IN	*Absolute voltage on the +Sense input*
V_CMD	*Bridge common mode voltage*
-BUFFERED_IN	*Absolute voltage on the –Sense input*
+EXCITEOUT	*Positive excitation source (local sense)*
-EXCITEOUT	*Negative excitation source (local sense)*
-V_SENSE	*Negative excitation source (remote sense)*
+V_SENSE	*Positive excitation source (remote sense)*

The current sense inputs to the confidence channel multiplexer are:

+EXCITE_CURR	*Positive excitation source current*
-EXCITE_CURR	*Negative excitation source current*

2.5 *TEDS* or *TEDS Memory*

A TEDS (Transducer Electronic Datasheet) memory device is embedded in the blue and red calibration blocks which stores the exact value of the block's resistors. These values are read during the calibration process.

3. Overview of Calibration Operations

3.1 The factory calibration of the EX1629 requires four pieces of equipment: a precision voltmeter, a LAN/GPIB Gateway unit, red calibration blocks, and blue calibration blocks.

3.2 The voltmeter is used to measure the EX1629's internal voltage reference. The red block is a calibrated 20 Ω resistance whose value is stored within a TEDS memory embedded in the block. The red block is employed in excitation current calibration. The blue block is a calibrated 350 Ω resistance whose value is stored within a TEDS memory embedded in the block. The blue block is employed in completion resistor and shunt resistor calibration.

3.3 The order of operations within factory calibration are:

Nothing connected to front panel connectors
Internal Reference Calibration
Bridge Channel Gain Calibration
Bridge Channel Offset Calibration
Confidence Voltage Channel Gain Calibration
Confidence Voltage Channel Offset Calibration
Excitation Voltage Source Calibration
Wagner Ratio Calibration
Excitation Current Common Mode Resistance Calibration
Red calibration block connected to front panel connectors
Excitation Current Gain/Offset Calibration
Blue calibration block connected to front panel connectors
Completion Resistor Calibration
Shunt Resistor Calibration

In summary, the functionality of the factory calibration process is the following:

Calibration begins with the measurement of the internal voltage reference with the externally connected voltmeter.

This internal reference is then used to calibrate the gain and offset characteristics of the main bridge and confidence voltage input paths.

The calibrated confidence voltage input path is then used to calibrate the positive and negative excitation voltage supplies.

The calibrated confidence voltage input path is then used to calculate the Wagner ratio, the voltage divider ratio of the back-half completion resistors.

The common mode resistance of the excitation current input path is then calibrated.

The calibrated confidence voltage input path and attached red calibration block are then used to calibrate the gain and offset characteristics of the positive and negative excitation current input paths.

The calibrated confidence voltage input path and attached blue calibration block are then used to calculate the value of the completion resistors.

The calibrated main bridge input path, calibrated confidence voltage input path, and attached blue calibration block are then used to calculate the value of the internal shunt resistor.

4. Internal Reference Calibration

4.1 In order to support calibration, the EX1629 is equipped with an internal 6.95 V precision voltage reference. This reference and its associated circuitry provides stimulus voltages of a known magnitude which are used to determine the gain and offset characteristics of both the main bridge and confidence voltage channel input paths.

4.2 Support circuitry surrounding the reference provides gains of 1.0, 1.667, and 2.0, yielding nominal levels of 6.95 V, 11.58 V, and 13.9 V, respectively. For simplicity, these are referred to as the 7 V, 11 V, and 14 V references.

4.3 Other support circuits both divide and invert the reference signal. In this way, the 7 V, 11 V, and 14 V references can be divided by ±1, ±10, and ±100. The following table lists the nominal reference voltage levels and their tolerances. Note that the 0 V and 7 V levels have absolute limits, while the rest are relative.

V_{ref} Level	Nominal Value	Nominal Ratio	Tolerance
-14.00 V	-13.9 V	-2.000	±0.20% relative
-11.00 V	-11.58 V	-1.667	±0.20% relative
-7.00 V	-6.95 V	-1.000	±0.10% relative
-1.40 V	-1.39 V	-0.200	±0.30% relative
-1.10 V	-1.158 V	-0.1667	±0.30% relative
-0.70 V	-0.695 V	-0.100	±0.20% relative
-0.14 V	-0.139 V	-0.020	±0.40% relative
-0.11V	-0.1158 V	-0.01667	±0.40% relative
-0.07 V	-0.0695 V	-0.010	±0.35% relative
0.00 V	0.0 V	N/A	±100 µV absolute
0.07 V	0.0695 V	0.010	±0.25% relative
0.11V	0.1158 V	0.01667	±0.30% relative
0.14 V	0.139 V	0.020	±0.30% relative
0.70 V	0.695 V	0.100	±0.10% relative
1.10 V	1.158 V	0.1667	±0.20% relative
1.40 V	1.39 V	0.200	±0.20% relative
7.00 V	6.95 V	1.000	±2.16% absolute
11.00 V	11.58 V	1.667	±0.10% relative
14.00 V	13.9 V	2.000	±0.10% relative

4.4 For the 0 V reference level, the upper and lower limits are absolute. That is, the reading may not be lower than -100 µV or greater than +100 µV.

NOTE This 0 V reference level is not used for offset calibration. Instead, a pure grounded input is used.

4.5 For the +7 V reference level, the upper and lower limits are absolute. The expected value is 6.95 V. The tolerance is ±2.16%. So, the reading may not be less than 6.79988 V or greater than 7.10012 V.

4.6 For the reference levels with relative limits, the error is calculated as 'percent of expected value'. To determine the expected value, multiply the reading at +7 V by the *nominal ratio* for the reference level of interest. For example, assume the +7 V reading is +6.92V. The expected value for the -11 V level would be (V_{ref} * *nominal ratio*) = (6.92 * -1.667) = -11.536 V. To determine the error limits, multiply the expected value by the tolerance. For positive reference levels, subtract the product of the expected value and the tolerance from the expected value to obtain the lower limit and add the product of the expected value and the tolerance to the expected value to obtain the upper limit. For negative reference levels, add the product of the expected value and the tolerance to the expected value to obtain the lower limit and subtract the product of the expected value and the tolerance to the expected value to obtain the upper limit. Thus, the lower limit for the -11 V reference level would be
-11.536 + (-11.536 * 0.002) = -11.559 V
and the upper limit would be
-11.536 – (-11.536 * 0.002) = -11.513 V

4.7 This first step in the factory calibration process measures and validates each of the reference voltage levels using an external voltmeter. The actual reading at each reference level is stored in nonvolatile memory for use in the calibration process. If the voltmeter reading at any level fails to meet the specified tolerance, the calibration fails and the operator is alerted.

5. Bridge Channel Gain Calibration

5.1 Each of the 48 bridge channels provides an 'X1', 'X10', and an 'X100' signal path. The next step in the calibration process is to determine the gain factor for each of the three signal paths.

5.2 The calibrated internal reference is routed to the calibration input of the bridge channel input multiplexer. The calibration function in the firmware steps the reference through the appropriate levels for each of the signal paths. Using the X100 path as an example, the applied reference levels are -0.14 V, -0.11 V, -0.07 V, 0 V, +0.07 V, +0.11 V, and +0.14 V.

5.3 At each reference level, multiple samples are acquired and averaged. Using a ‘least squares’ curve fitting technique, the calibration function in the firmware determines the gain factor for each input channel and signal path combination.

5.4 The gain factors are limit checked against the following values:

	Nominal Value	Tolerance
Main_ADC_X1_gain	0.9892	±0.01
Main_ADC_X10_gain	0.9892	±0.01
Main_ADC_X100_gain	0.9892	±0.01

If a gain factor fails to meet tolerance, the operator is alerted and the calibration process is terminated. Otherwise, the gain factors are stored.

6. Bridge Channel Offset Calibration

6.1 The next step in the calibration process is to determine the offset factor for each of the signal paths for each channel.

6.2 In this step, the ground input to the bridge channel input multiplexer is selected. For each signal path, multiple samples are acquired and averaged.

6.3 Using the previously determined gain factor, the offset factor is calculated.

6.4 The offset factor is limit checked against the following values:

	Nominal Value	Tolerance
Main_ADC_X1_offset	0.0 V	±0.012
Main_ADC_X10_offset	0.0 V	±0.001
Main_ADC_X100_offset	0.0 V	±0.0002

If an offset factor fails to meet tolerance, the operator is alerted and the calibration process is terminated. Otherwise, the offset factors are stored.

7. Confidence Voltage Channel Gain Calibration

7.1 The next step in the calibration process is to determine the gain factor for each of the voltage inputs of the confidence system.

7.2 The calibrated internal reference is routed to the calibration input of the confidence ADC multiplexer. Using the same technique as in the main channel ADC calibration, the calibration function in the firmware determines the gain factor for each confidence ADC voltage path.

7.3 The gain factors are limit checked against the following values:

	Nominal Value	Tolerance
Conf_ADC_gain	1.0	±0.004

If a gain factor fails to meet tolerance, the operator is alerted and the calibration process is terminated. Otherwise, the gain factors are stored.

8. Confidence Voltage Channel Offset Calibration

8.1 The next step in the calibration process is to determine the offset factor for each of the confidence voltage paths. In this step, the ground input to the confidence ADC multiplexer is selected. Using the same technique as in the main channel ADC calibration, the calibration function in the firmware determines the offset factor for each confidence ADC voltage path.

8.2 The offset factor is limit checked against the following values:

	Nominal Value	Tolerance
Conf_ADC_offset	0.0 V	±0.06

If an offset factor fails to meet tolerance, the operator is alerted and the calibration process is terminated. Otherwise, the offset factors are stored.

9. Excitation Voltage Source Calibration

9.1 The next step in the calibration process is to determine the gain and offset factors for each channel's excitation source. The excitation voltage is sequenced in 1 V steps from 0 V to +8 V for the positive supply and from 0 V to -8 V for the negative supply. At each step, the actual value of the excitation source is measured by the calibrated confidence paths, specifically the +EXCITEOUT and –EXCITEOUT inputs.

9.2 Using a 'least squares fit', gain and offset calibration factors are determined for the excitation voltage source DACs. The gain and offset factors are limit checked against the following values:

	Nominal Value	Tolerance
Excite_src_pos_gain	1.0	±0.009
Excite_src_neg_gain	1.009	±0.009
Excite_src_pos_offset	0.0 V	±0.04
Excite_src_neg_offset	0.0 V	±0.04

If a factor fails the limit check, the operator is notified and the calibration process is terminated. Otherwise, the factors are stored.

10. Wagner Ratio Calibration

10.1 The next step in the calibration process is to calculate the voltage divider represented by the back-half completion resistors, termed the Wagner ratio. This ratio is ideally 0.5 (exactly equal resistors), limited by actual resistor tolerances.

10.2 The excitation voltage source is configured for ±2.5 V to impress a voltage across the back-half completion network. The positive and negative source values are measured by their confidence inputs so that their exact values are known. The midpoint of the completion network is then routed to the +Sense input by setting the EU conversion to quarter-bridge and measured by the +BUFFERED_IN confidence input. Combining the measured quantities yields the Wagner ratio value.

10.3 The Wagner ratio is limit checked against the following value:

	Nominal Value	Tolerance
Wagner_ratio	0.5	±0.001

If a factor fails the limit check, the operator is notified and the calibration process is terminated. Otherwise, the factors are stored.

11. Excitation Current Common Mode Resistance Calibration

11.1 This is the first step in the process for calibrating the excitation current sense confidence inputs. Like the other measurement paths, the excitation current sense function uses gain and offset calibration factors. However, due to the fact that the excitation current measurement is slightly modulated by the excitation voltage level, it requires a secondary correction factor. This secondary correction factor is modeled as a common mode resistance.

NOTE The calibration process for the positive common mode resistance will be described. The negative common mode resistance is calibrated in an analogous manner.

11.2 In this step, excitation current measurements are taken on the +EXCITE_CURR confidence input at two different excitation voltage source points, specifically 0 V and 4 V. Since no external load exists on the source, the only actual delta current that flows as a result of the voltage change is due to the back half completion network. After adjusting for this, the measured delta current should ideally be zero. However, the measured delta current will be nonzero because the current sense circuit has non-infinite common mode rejection. The common mode resistance is then calculated as the (delta voltage/delta current).

11.3 The common mode resistances are limit checked against the following values:

	Nominal Value	Minimum Value
Pos_cmr	100000 Ω	18000
Neg_cmr	100000 Ω	18000

If a factor fails the limit check, the operator is alerted and the calibration process is aborted. Otherwise, the factors are stored.

NOTE	At this step in the calibration process, the red blocks are inserted into the front panel connectors. The EX1629 reads the actual value of each resistor from the embedded TEDS memory within the block.

12. Excitation Current Gain/Offset Calibration

12.1 The next step in the calibration process is to determine the gain and offset factors for the excitation current confidence inputs.

NOTE	The calibration process for the positive excitation current gain/offset factors will be described. The negative excitation current gain/offset factors are calibrated in an analogous manner.

12.1.1 The positive excitation supply is commanded to 0 V and enabled.

12.1.2 The main input is configured for full bridge, voltage input and the X10 signal path is selected.

12.1.3 The negative excitation source is sequenced from 0.0 V to -0.8 V in -0.1 V steps.

12.1.3.1 At each step, an average value is computed for the +EXCITE_CURR confidence input.

12.1.3.2 At each step, an average value is also computed for the main input. This is the voltage across the precision resistor in the calibration block. This voltage is used to calculate the actual excitation current flow, which is the measured voltage divided by the actual resistance value seen by the voltage. This actual resistance is the parallel combination of the resistance value read from the TEDS device and 20 kΩ (represented from the back-half completion network).

12.1.4 A 'least squares fit' is then computed for the calculated actual excitation currents versus the measured excitation current readings to determine the gain and offset factors.

12.2 The gain and offset factors are limit checked against the following values:

	Nominal Value	Tolerance
Excite_curr_pos_gain	1.0	±0.015
Excite_curr_neg_gain	1.0	±0.015
Excite_curr_pos_offset	0.0 A	±0.00075
Excite_curr_neg_offset	0.0 A	±0.00075

If a factor fails the limit check, the operator is alerted and the calibration process is aborted. Otherwise, the factors are stored.

NOTE	At this step in the calibration process, the blue blocks are inserted into the front panel connectors. The EX1629 reads the actual value of each resistor from the embedded TEDS memory within the block.

13. Completion Resistor Calibration

13.1 The next step in the calibration process is to calculate the actual values of the completion resistors. There are two standard completion resistor values: 120 Ω and 350 Ω. The third completion resistor is optional.

13.2 The operator is prompted to input the value of the optional completion resistor and the resistor's tolerance in percent.

13.3 The excitation voltage source is configured for ±2.5 V to impress a voltage across the series combination of the external resistor in the calibration block and the completion resistor being calibrated. The positive and negative source values are measured by their confidence inputs so that their exact values are known. The midpoint of two resistors is then routed to the -Sense input by setting the EU conversion to quarter-bridge and measured by the -BUFFERED_IN confidence input. Combining the measured quantities and the known value of the external resistor yields the actual value of the completion resistor. This process is conducted for each completion resistor.

13.4 The completion resistor values are limit checked against the following values:

	Nominal Value	Tolerance
Compres_350	350.65 Ω	±0.7
Compres_120	120.65 Ω	±0.7
Compres_user	As Provided	As Provided

If a factor fails the limit check, the operator is alerted and the calibration process is aborted. Otherwise, the factors are stored.

14. Shunt Resistor Calibration

14.1 The next step in the calibration process is to determine the internal shunt resistor.

14.2 The operator is prompted to input the value of the shunt resistor and the resistor's tolerance in percent.

14.3 In essence, the shunt resistor value is calculated by performing the traditional quarter-bridge shunt calibration process. With the blue calibration block installed, a quarter-bridge circuit is created with the 350 Ω completion resistor. The excitation voltage source is configured for ±2.5 V to impress a voltage across the bridge. The positive and negative source values are measured by their confidence inputs so that their exact values are known. The voltage of the main bridge path in X100 gain is then measured first with the shunt resistor disabled and then with it enabled. With the delta measured voltage of the main bridge combined with the measured excitation voltages, the effective change in the completion resistor is calculated. Then, since the static completion resistor is known from previous calibration, the shunt resistor value can be calculated.

14.4 The shunt resistor values are limit checked against the following values:

	Nominal Value	Tolerance
Shunt_res	As Provided	As Provided

If a factor fails the limit check, the operator is alerted and the calibration process is aborted. Otherwise, the factors are stored.

SELF-CALIBRATION

Self-calibration is a subset of the factory calibration process. It does not require any external equipment, nor does it require external sensors to be removed from the input connectors. Most of the instrument's accuracy-determining characteristics are updated by self-calibration. The instrument specifications require a self-calibration at least every 30 days.

Referencing the process outlined above, self-calibration performs the following steps:

Bridge Channel Gain Calibration
Bridge Channel Offset Calibration
Confidence Voltage Channel Gain Calibration
Confidence Voltage Channel Offset Calibration

Self-calibration does not overwrite or otherwise modify the factory calibration constants in any way. Instead, it generates an additional set of gain and offset factors (very close to 1 and 0, respectively). These factors are used in conjunction with the factory calibration factors in the calculation equations of the instrument. Self-calibration results are volatile by default, meaning that they are cleared by instrument power cycle or reboot. However, they can be commanded to be stored to nonvolatile memory. In that case, they will be retained and utilized through power cycle.