Calibration Test of the HDice CAENels CT-Box

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To calibrate the CAENels current transducer box (CT-Box) to be used for the HDice experiment, current measurements across the entire range of the CT-Box are used for calibration. A DC source and a transconductance amplifier, acting as a single instrument, are used to generate the current measured by the CT-Box.

For the HDice experiment, precise current measurement is required for nuclear magnetic resonace (NMR) measurements. A CAENels CT-Box, Fig. 1, with a precision of <0.005%, was bought for these measurements. A test procedure was developed to calibrate the CT-Box to ensure it at least meets the HDice requirement of 0.01% accuracy. A precision DC source generates the voltage that is amplified and converted to a current by a transconductance amplifier. A diagram of the test setup is shown in Fig. 2.

FIG. 1. CAENels CT-Box. The USB cable on the right connects to a PC that runs the CT-Box drivers. The serial cable that allows communication from the CT-150 current transducer to the CT-Box connects to the back.

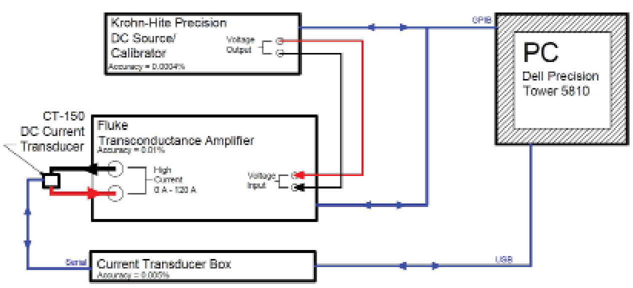

FIG. 2. Drawing of the CT-Box test instrumentation and connections.

A Krohn-Hite Model 523 Precision DC Source/Calibrator is used for the precision source. The Krohn-Hite (Fig. 3) provides either a voltage or a current, and can be positive or negative. The Krohn-Hite's voltage output mode is used for the CT-Box test. This mode is more precise than the Krohn-Hite's current output mode and the Krohn-Hite's maximum current (I_{max} = ±110 mA) is too low to cover the complete range of the transconductance amplifier. Further specifications are in Appendix A.

The transconductance amplifier used is a Fluke 52120A. The Fluke (Fig. 4) multiplies the input voltage from the Krohn-Hite by a transconductance value of 1, 10, or 100 A/V, corresponding to one of the three current output ranges of 0–2 A, 0–20 A, or 0–120 A, respectively, to produce the required output current. Appendix B lists specifications in Table BI and shows example transconductance calculations for voltage input in Table BII.

FIG. 3. Krohn-Hite Model 523 Precision DC Source/Calibrator. The cables on the right are the output leads that connect to the Fluke 52120A.

FIG. 4. Fluke 52120A Transconductance Amplifier. The thin, right cables are the input leads from the Krohn-Hite. The thick, left cables carry the amplified high current output.

The Krohn-Hite and Fluke act together as a single instrument to produce a current to be read from the CT-Box. The accuracy of the final amplified current is 0.0104%.

If $0\ A \leq I_{output} \leq 20\ A$, then either low or high current output leads can be used with the Fluke. High current output leads must be used if $20\ A < I_{output} \leq 120\ A$.

For the CT-Box calibration test, the high current output leads of the Fluke are used. The leads are connected to each other, passing through a CAENels CT-150 DC current transducer (Fig. 5) to form a current loop. The CT-150 measures the current flowing in the cable passing through it and communicates the information to the CT-Box via a serial cable. The CT-Box displays the data from the CT-150 to an accuracy of <0.005%. During the CT-Box calibration test, the CT-Box also logs the data on a PC for later analysis.

FIG. 5. CAENels CT-150 current transducer. The thick, red cable passing through the current transducer is the high current output lead from the Fluke that forms the current loop.

Drivers that were used in the calibration program software were written in LabVIEW 2015 for the CT-Box, Krohn-Hite, and Fluke. All drivers use Virtual Instrument Software Architecture (VISA) components. The drivers for the Krohn-Hite and Fluke communicate to the respective instruments through General Purpose Interface Bus (GPIB), while the CT-Box drivers communicate through USB.

The drivers communicate to their respective instrument to allow parameters to be set and/or read back from the instrument. All drivers open a VISA interface to the specified instrument, send instrument-specific text commands to set or read back a parameter, write to or read from the instrument through GPIB or USB, before finally closing the VISA interface.

A LabVIEW program was written to generate a current to be measured by the CT-Box and record the measured value. The program steps through a user-defined range at a user-defined step-size in order to create a calibration curve for that range. The program generates a current using Krohn-Hite and Fluke drivers and then uses the CT-Box drivers to measure the current. The current generated and the actual measured current from the CT-Box is recorded in a text file for analysis. The program increases the generated current by the user-defined step size and repeats the recording process until the entire defined range has been completed. From the text file generated, a calibration curve is created.

In a preliminary test, only the transconductance value for the 0–120 A output range was used. Measurements were taken with the current increasing from 0 A to 25 A with a step-size of 0.05 A. The data were plotted in Mathematica (Appendix C, Fig. C1) and fit with the linear regression curve $I_{meas} = 0.00268 + (0.99997)I_{set}$.

In the final test, the CT-Box was used to take 1000 measurements at each 1 A step, from 0–25 A, a total of 26,000 measurements. Appendix D contains the mean measured current and standard deviation for each set of 1000 measurements. The data were plotted in Mathematica (Appendix C, Fig. C2) and fit with the linear regression curve $I_{meas} = 0.00222+(0.99996)I_{set}$. The linear regression curve was used to extrapolate the measured current I_{meas} for the entire range of the CT-Box of 0–100 A.

I_{meas} was used to calculate the error of the current measurements I_{meas}*error* using the formula

$$I_{meas}error = \frac{|I_{set} - I_{meas}|}{I_{set}}$$

The I_{set} and I_{meas}*error* were plotted in Mathematica (Appendix C, Fig. C3). It was noted that for a large I_{set}, $I_{meas} \rightarrow 0.003\%$.

Combined with the input accuracy of the Fluke (0.01%), this result means that current can be measured to an accuracy of 0.0104% with the CT-Box. While this is not the CAEN specified accuracy of <0.005%, it is the accuracy that HDice has requested for the NMR measurements. A second CT-Box will be purchased.

APPENDIX A: KROHN-HITE SPECIFICATIONS

Output mode	Precision [ppm]	Precision [%]	Lower bound*	Upper bound
Voltage	4	0.0004	0.01 μV	110.11119 V
Current	8	0.0008	1 nA	110 mA

*Can be set to 0.00, but not to a value between 0.00 and the lower bound.

APPENDIX B: FLUKE

Range [A]	Permitted current output leads	Current gain	Transconductance [A/V]	Maximum current output [A]	Maximum current input [mA]	Maximum voltage input [V]	Accuracy [% of output]
0–2	low, high	10	1	2	200	2.0	0.01
0–20	low, high	100	10	20	200	2.0	0.01
0–120	high	1000	100	120	120	1.2	0.01

TABLE BI: Properties of the output ranges of the Fluke.

Krohn-Hite output/ Fluke input voltage [V]	Fluke output [A]		
	Range 0–2 A transconductance = 1 A/V	Range 0–20 A transconductance = 10 A/V	Range 0–120 A transconductance = 100 A/V
0.0	0.0	0	0
0.1	0.1	1	10
0.2	0.2	2	20
0.3	0.3	3	30
0.4	0.4	4	40
0.5	0.5	5	50
0.6	0.6	6	60
0.7	0.7	7	70
0.8	0.8	8	80
0.9	0.9	9	90
1.0	1.0	10	100
1.1	1.1	11	110
1.2	1.2	12	120
1.3	1.3	13	—
1.4	1.4	14	—
1.5	1.5	15	—
1.6	1.6	16	—
1.7	1.7	17	—
1.8	1.8	18	—
1.9	1.9	19	—
2.0	2.0	20	—

TABLE BII. Example calculations for the output current generated when the Fluke is in voltage input mode. For output range of 0–120 A, the maximum current output provided will be 120 A.

APPENDIX C: MATHEMATICA PLOTS

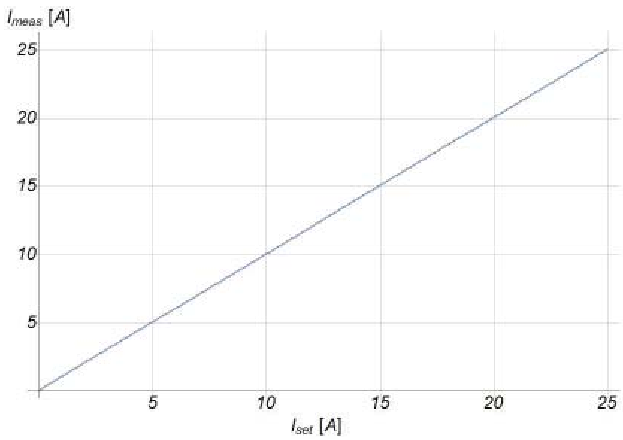

FIG. C1. Plot of set current vs. measured current for the preliminary calibration test. The data are fit with a linear regression line of I_{meas} =0.00268 + (0.99997)I_{set}.

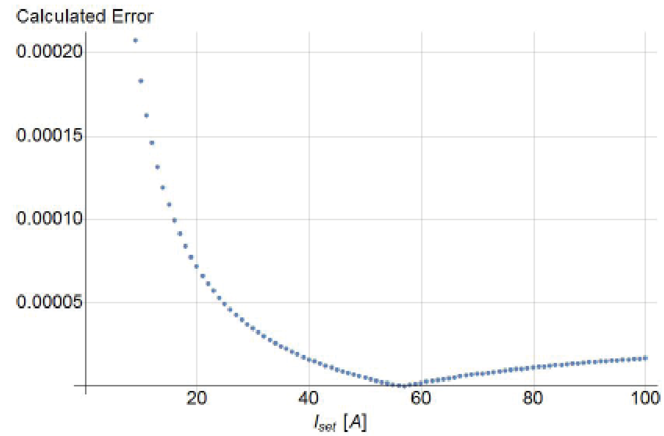

FIG. C3. Plot of set current vs. measured current error for the final calibration test.

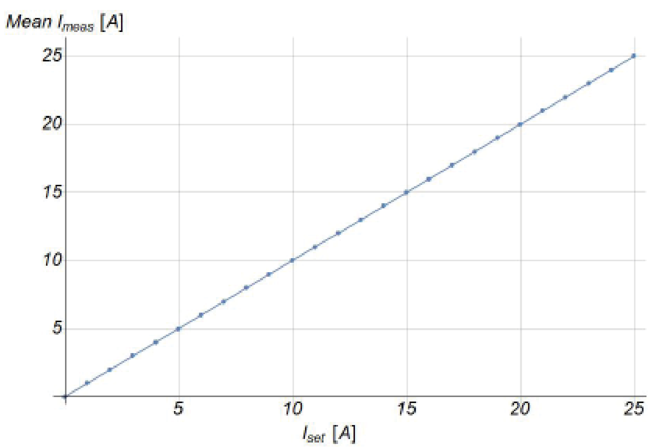

FIG. C2. Plot of set current vs. mean measured current for the final calibration test. The data are fit with a linear regression line of I_{meas}= 0.00222 + (0.99996)I_{se}

APPENDIX D: CALCULATED MEAN AND STANDARD DEVIATION OF THE MEASURED CURRENTS FROM FINAL CALIBRATION TEST

Set current [A]	Mean measured current [A]	Standard deviation
0	0.002323321	0.000321995
1	1.0022565	0.000312699
2	2.002073409	0.000337284
3	3.002011658	0.000315499
4	4.001906267	0.000318183
5	5.001844364	0.000309754
6	6.001940113	0.000339971
7	7.002048954	0.000329092
8	8.002057634	0.000342922
9	9.002005167	0.000317464
10	10.00194094	0.000336618
11	11.00166552	0.000331834
12	12.00176778	0.000338485
13	13.00178676	0.00034052
14	14.00168603	0.000347209
15	15.00158706	0.000350069
16	16.00147898	0.000349172
17	17.00155416	0.000321995
18	18.00147779	0.000322989
19	19.00158313	0.000338079
20	20.00150036	0.000342021
21	21.00144625	0.000350592
22	22.00141428	0.000333952
23	23.00132306	0.00032525
24	24.00116699	0.000329179
25	25.00117336	0.000324092