

# Observed Temperature Effects on Load Cells

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## ABSTRACT

Researchers at Oak Ridge National Laboratory subjected load cells to a range of temperatures beyond their compensated range to characterize the temperature effect on the minimum dead load output over their entire operating temperature range. In modern front-end nuclear fuel cycle facilities, load cells are often used in UF<sub>6</sub> feed and withdrawal stations to monitor the material being fed to or withdrawn from the cylinders. Load cells exhibit some temperature dependence; however, manufacturers try to minimize temperature effects by compensating load cells over a range of temperatures (typically from -10 °C to +40 °C (+14 °F to +104 °F)). Load cells in modern UF<sub>6</sub> feed and withdrawal stations tend to operate beyond this range: down to -25 °C and up to 80 °C (-13 °F to 176 °F). While load cell data sheets often include specifications for the temperature effect on the minimum dead load output and the sensitivity over the compensated range, they do not include specifications for expected effects outside of this range. In this paper, we discuss our test setup and preliminary results of testing load cells representative of those that may be used in UF<sub>6</sub> feed and withdrawal stations.

## INTRODUCTION

Modern feed and withdrawal stations are typically instrumented with analog load cells which the operator uses for process monitoring and control. Feed stations in modern commercial gas centrifuge enrichment plants (GCEPs) typically heat 48Y cylinders to approximately 80 °C to sublime the solid UF<sub>6</sub> and allow gaseous UF<sub>6</sub> to flow to the process. Withdrawal stations are typically refrigerated to -25 °C to desublime either enriched UF<sub>6</sub> product into 30B cylinders or depleted UF<sub>6</sub> into 48Y cylinders.

Load cells can exhibit a temperature-dependent effect on the minimum dead load output (MDLO) and sensitivity. Manufacturers compensate for these expected temperature effects but commonly only publish data about the temperature effects over a compensated range, that is usually from -10 °C to 40 °C. This range does not include the full range that load cells in feed and withdrawal stations encounter during normal operation. This paper will examine the temperature effects to the MDLO of a representative set of load cells for the range of temperatures expected in feed and withdrawal stations by monitoring load cells inside an environmental chamber and stepping through the range of -25 °C to 80 °C with no load applied.

## EXPERIMENTAL SETUP

The testing subjected one digital shear beam load cell and 10 load cells representative of those that could be used in modern UF<sub>6</sub> feed and withdrawal stations to air over a wide temperature range. Two of the load cells were dual bridge load cells, which have two weigh bridges (or outputs) in one

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device. Therefore, all data refers to each separate output as a weigh bridge rather than a load cell. All the weigh bridges tested are shown in Table 1.

A Russell's RD-125 environmental chamber was used to control the air temperature; the chamber's active volume can be heated to +160 °C and cooled to -60 °C. An excitation voltage of 10 V was provided by an external precision power supply to all weigh bridges. This voltage was chosen because it gives the weigh bridges a relatively large output while being within the recommended range of all the manufacturers. Data collection was accomplished with a National Instruments Compact Data Acquisition System (NI cDAQ). NI bridge analog input modules were used to collect weight data from the 12 different weigh bridges. A LabView program collected 2000 samples for each weigh bridge in one second once every minute of testing. The program then averaged the samples and output them to a csv file along with the date and time. The program also collected the temperature data from the eight thermocouples using the NI 9214 at a rate of one sample per minute. Type T style thermocouples were applied to eight load cells to measure the temperature data for this experiment. Temperature data from each of the thermocouples was averaged to provide the average temperature of the chamber per second. For the experiment the load cells were placed in the environmental chamber and subjected to a temperature cycle ranging from -30 °C to 80 °C, with 16 holding temperatures held for 1.5 hours each. Between holding temperatures, the ramp rate was set to 10 °C per hour. To reduce systematic biases the set of temperatures alternated above and below our starting temperature of 20 °C. The temperature set points are shown in Table 2.

## RESULTS AND DISCUSSION

The raw test results are shown in Figures 1–3. In each plot the temperature data is shown with a dotted red line. Testing was suspended from 8/27/2016 to 8/29/2016 to remove WB13, as continuing the temperature cycle would exceed the safe operating temperature of the device.

As shown in Figure 1, the output from weigh bridge 1 (plotted in black) was negatively correlated with temperature toward the end of the experiment, whereas previous measurements showed a positive correlation. It also exhibited instances where the output abruptly jumped down before reaching the maximum temperature in the second half of the experiment. Weigh Bridge 1 through 5 are the same make and model, but weigh bridge 5 exhibited roughly three times the temperature effect on MDLO. Previous experience with this load cell suggested a temperature dependence, and this data supports this premise.

Weigh bridge 8 (in Figure 2) exhibited an output that increased with positive and negative changes in temperature. Observing the other weigh bridges indicated either a positive or negative correlation but not both.

Weigh bridges 10 – 12 are shown in Figure 3. The errors for WB 10 and 11 are much greater than those of WB's 11 and 12. Weigh bridges 10 and 11 also exhibited an upper and lower limit to the error starting at about 50 °C.

Observed errors are compared to the manufacturer's specifications for temperature effect on MDLO in Figures 4–7. These figures have the observed data points plotted against the temperature effect envelope, which is shown by the two blue lines. Weigh bridges in Figure 4 and Figure 5 have the same specification but were separated due to the magnitude of the error. It is clearly seen in Figure 5 that weigh bridge 5's errors are much greater than those of the other load cells; note that the scale is from -5% to 5% where as the scale in Figure 4 is from -0.25% to 0.25%. Weigh bridges from this

manufacturer for the most part did not meet the manufacturer’s specifications with the exception of weigh bridges 3 and 7. Weigh bridge 8, shown in Figure 6, had an interesting effect. Inside the compensated range the weigh bridge performed close to the specification. Outside of the compensated range, there was a significant effect that caused the data to appear more parabolic in nature.

Weigh bridges 9 and 10 in Figure 7 are part of a dual bridge load cell that include a welded-on enclosure. It appears the welding process may have affected the accuracy of weigh bridges 9 and 10 since weigh bridges 11 and 12 have the same specifications but have much smaller observed errors. Weigh bridge 9 appears to have an upper limit of 0.2% for the output starting at 50 °C or a  $\Delta T$  of 30 °C.

Table 1: Weigh bridge information

Weigh Bridge #	OIML Rating	NIST Rating	Capacity	Rated Output (mV/V)	Temperature Effect on Minimum Dead Load	Notes
1	C6	III M	5000 kg	1.954	0.0012%RC/°C (0.06 kg/°C)	New
2	C6	III M	5000 kg	1.955		New
3	C6	III M	5000 kg	1.962		New
4	C6	III M	5000 kg	1.955		New
5	C6	III M	5000kg	1.954	0.0012%RC/°C (0.06 kg/°C) Field data shows a strong correlation with temperature ~ 1 lb/1 °F (0.82 kg/ °C)	Removed from a working scale because demonstrated a strong temperature correlated drift
6	C6	III M	2000 kg	2 <sup>1</sup>	0.0012% RC/°C (0.024 kg/°C)	Authenticated with welded enclosure
7	C6	III M	2000 kg	2	0.0012% RC/°C (0.024 kg/°C)	Representative of ORNL Scale
8	C3	III M	4700 kg	2.85	0.0007% RC/°C (0.033 kg/°C)	Representative of UF <sub>6</sub> Industry
9			10K lbf (4536 kg)	4.395	0.00144% RC/°C (0.065 kg/°C)	Dual bridge: Bridge for traditional analog and bridge for welded enclosure
10			10K lbf(45	4.677		
11			10K lbf (4536 kg)	3.999	0.00144% RC/°C (0.065 kg/°C)	Dual bridge
12			10K lbf (4536 kg)	4.003		
13	C3		20 kg		0.0016%RC/°C (0.00032 kg/°C)	Small Digital

Table 2: Temperature set points

Set Point Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Temperature (°C)	20	30	0	10	40	20	-10	50	20	60	-20	70	10	80	-30	20

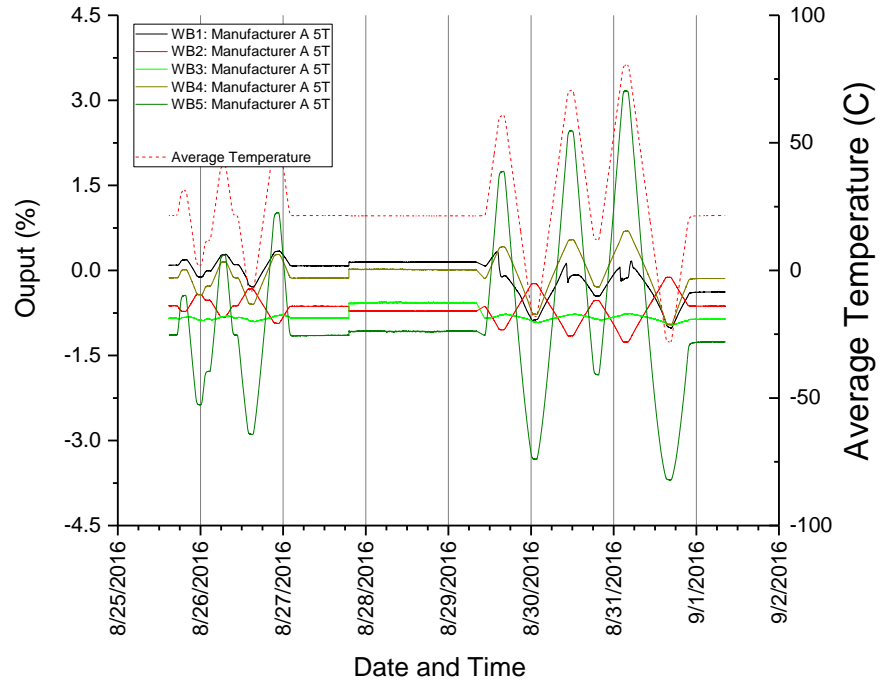


Figure 1: All data for weigh bridges 1-5

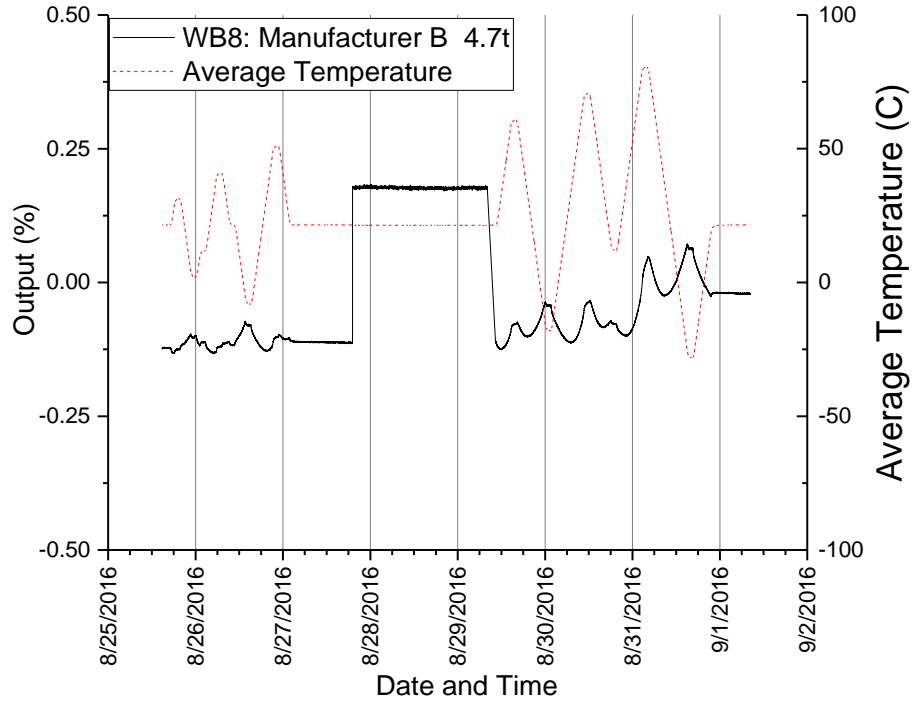


Figure 2: All data for weigh bridge 8

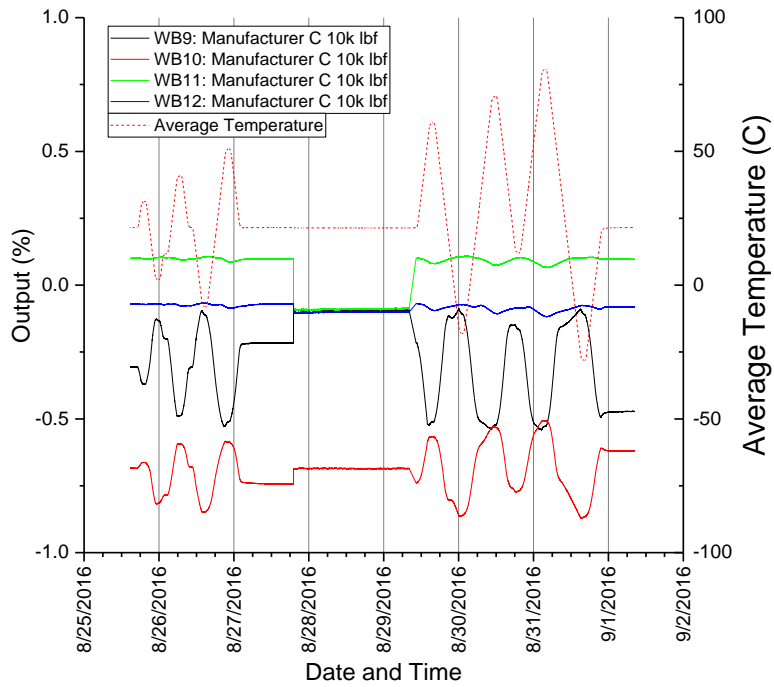


Figure 3: All data for weigh bridges 9-12

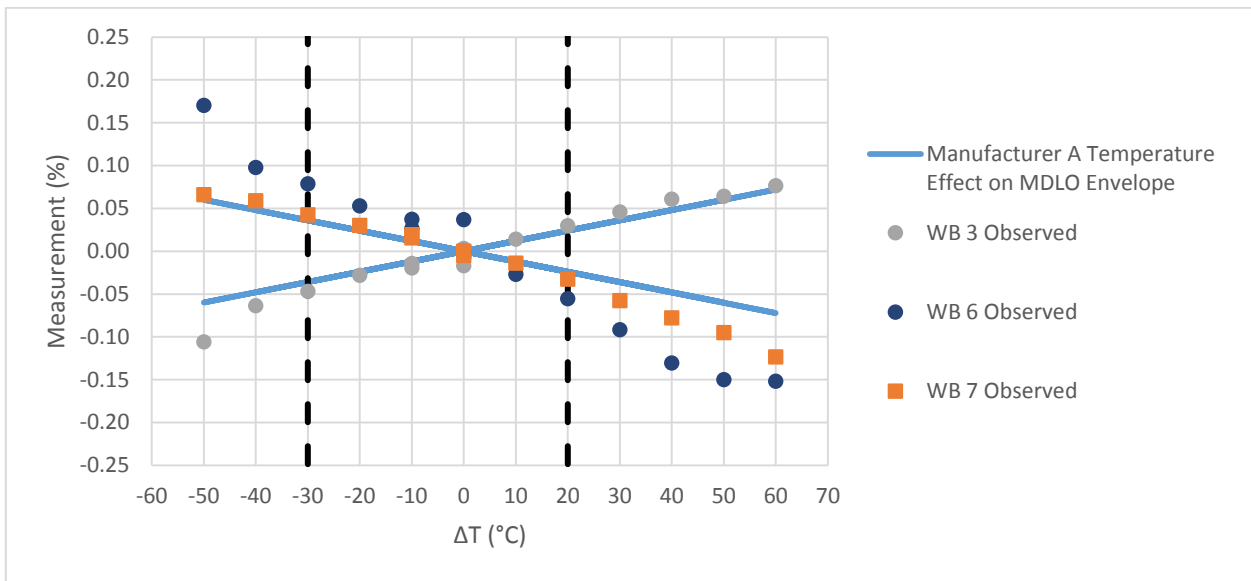


Figure 4: Plot of observed weigh bridge outputs for weigh bridges 3, 6, and 7 compared to the manufacturer's error envelope

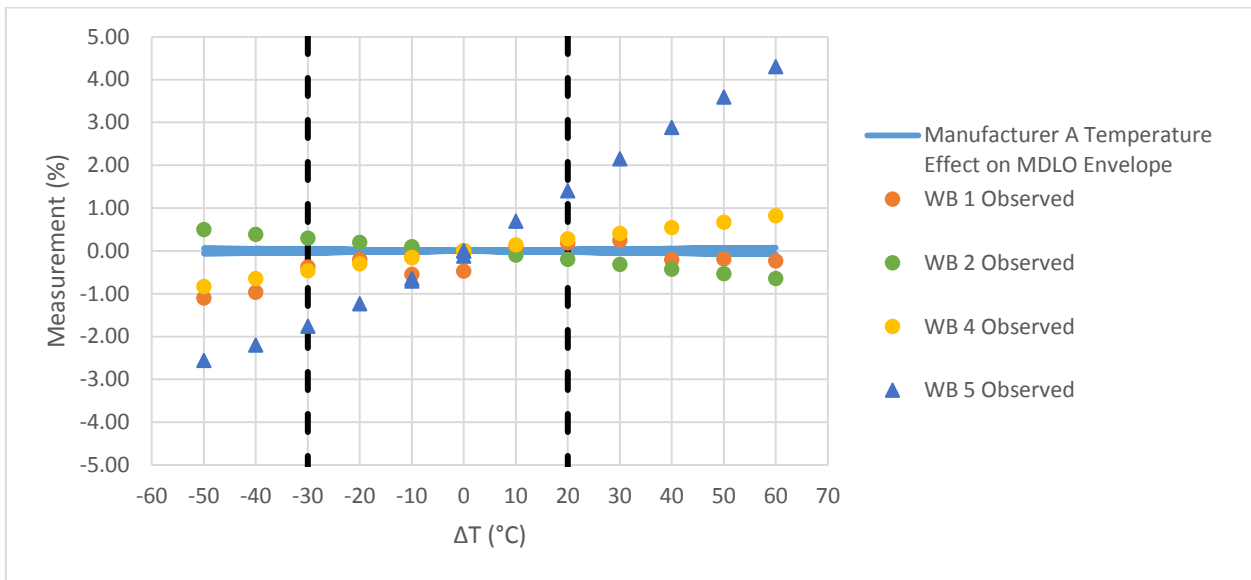


Figure 5: Plot of observed weigh bridge outputs for weigh bridges 1, 2, 4, and 5 compared to the manufacturer's error envelope

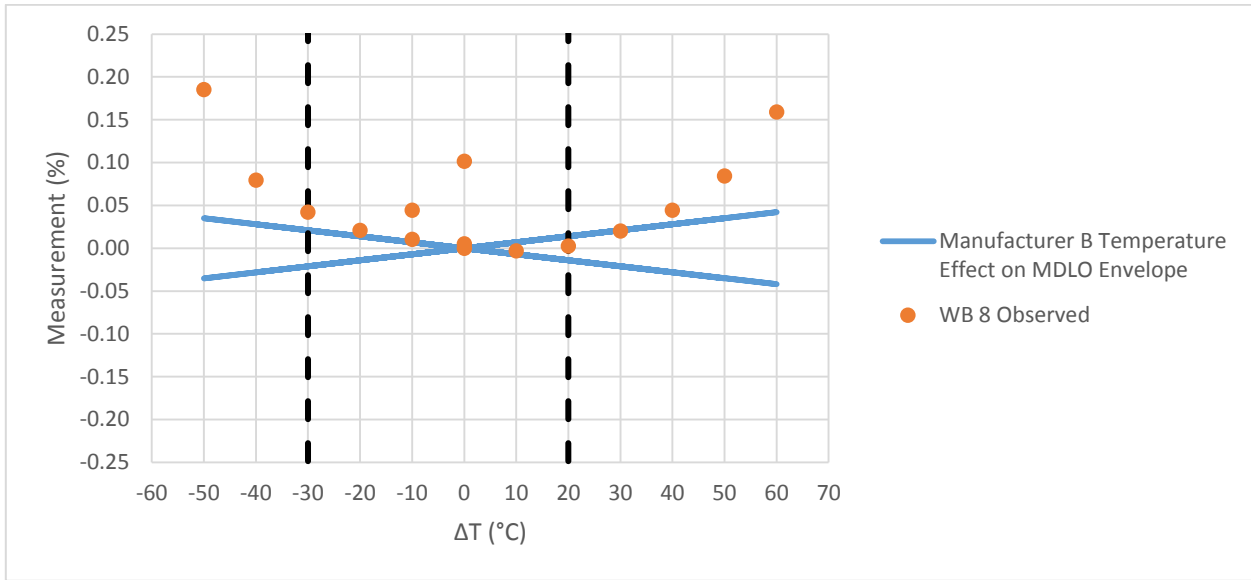


Figure 6: Plot of observed weigh bridge outputs for weigh bridge 8 compared to the manufacturer's error envelope

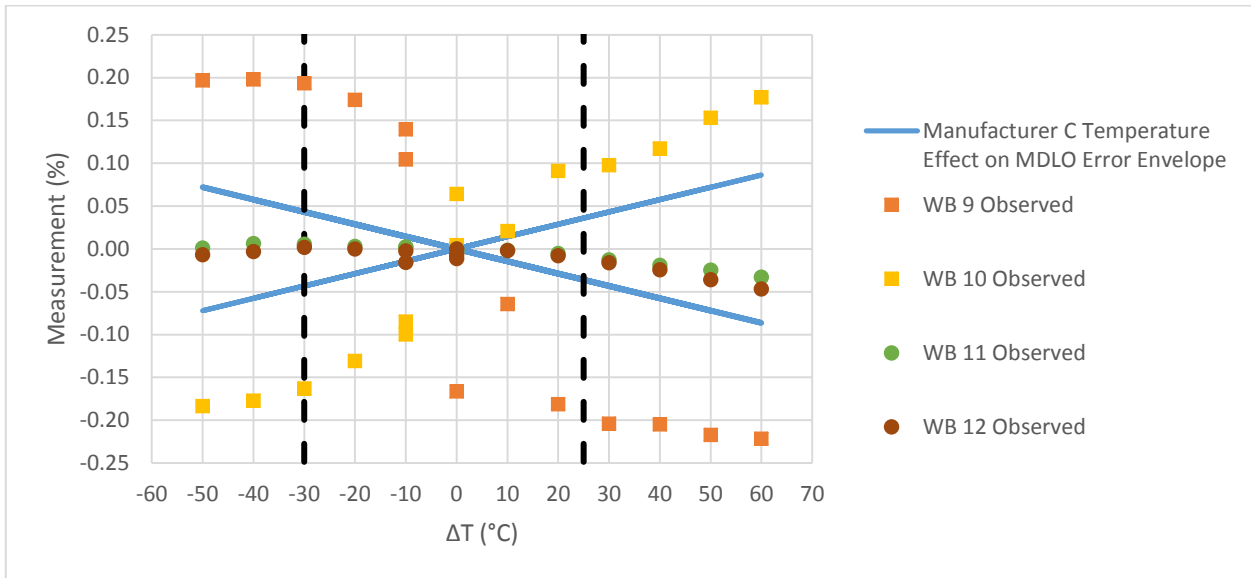


Figure 7: Plot of observed weigh bridge outputs for weigh bridges 9–12 compared to the manufacturer's error envelope

Figure 8 considers the output of each weigh bridge during period 1 to be the baseline or zero of the output. Any deviation from this zero indicates a drift. In Figure 8 the outputs have not drifted much by Period 6, however they have drifted significantly by Period 9a, which is the stay period before the suspected power flicker. This suggests that beyond the effect on minimum dead load, there may be a lasting offset caused by temperature changes.

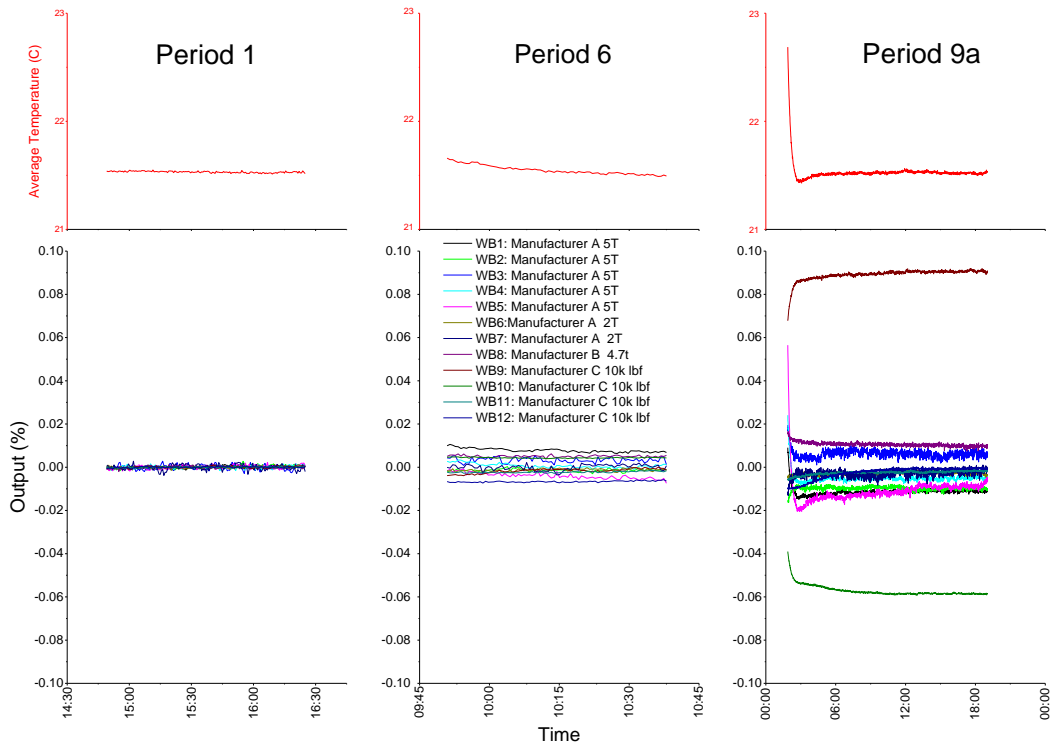


Figure 8: Output of weigh bridges at 20 °C holding periods before the power loss

In the time span from 8/27/2016 to 8/29/2016, it is speculated that a power flicker in the lab space on 8/27/2016 caused the excitation voltage power supply to reset. The power supply was found to be set to 0 V and was manually reset to 10 V when testing resumed on 8/29/2016.

## CONCLUSIONS

The ability of load cells to meet advertised specifications for temperature effect on MDLO appears to vary among brands. Additionally, there seems to be a significant variation even among load cells of the same make and model. Weigh bridge 5, one of the five Manufacturer A 5,000 kg weigh bridges tested, was suspected to have a large correlation with temperature. This test demonstrated a very large effect. At 79.88 °C the load cell had an observed measurement that deviated 214 kg from zero, a 4.28% error. Weigh bridges 9 and 10 had much greater errors than weigh bridges 11 and 12. Perhaps these weigh bridges had manufacturing defects from the addition of the welded-on enclosure. Notably after the tests, the dead load outputs of the devices all exhibited some drift from the original zero measurement. These results suggest that the combined error does not give the full picture and that the temperature effects are significant in the compensated range and very significant outside of the compensated range. For the IAEA to use load cells to continuously monitor the weight of cylinders in the feed and withdrawal stations, the combined error and the temperature effects should be considered.

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