Analyzing the Effects of Reducing the Ending Zero Vs. Ignoring the Trailing Zero on Measuring Instruments Used for Force Calibration

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Differing opinions are found within the ASTM E28 sub-committee regarding the proper treatment of the trailing zero following the removal of an applied force. The ASTM E28 committee is responsible for the ASTM E74 standard, which is the generally accepted standard for calibration of force-measuring instrumentation in the United States. Prior to the existence of ASTM E74, there was a split-out sub-set from E4 that hardly resembled what is currently found in ASTM E74. The ASTM E74 standard was published in 1974, and the current revision is ASTM E74-13a.

The current standard allows for two different methods—Method A and Method B—for the treatment of the ending zero. Method A defines the deflection calculation as the difference between the deflection at an applied force and the initial reading at zero force. Method B defines deflection as the difference between the deflection at an applied force and a zero value derived from either an average zero (if the loading sequence is zero, load, zero) or an interpolated zero (if a series of forces are applied before return to zero force). Morehouse Instrument Company conducted an analysis consisting of 46 various measuring instruments and analyzed the effect on the Lower Limit Factor, which is the standard deviation of the differences from the predicted response, multiplied by a coverage factor of 2.4.

1.0 Data Collection

Morehouse Instrument Company used data gathered from previous and current calibrations that were performed in accordance with ASTM E74–06. Several load cells from various manufacturers were selected in a random order for this analysis. The actual number of load cells sampled was 46.

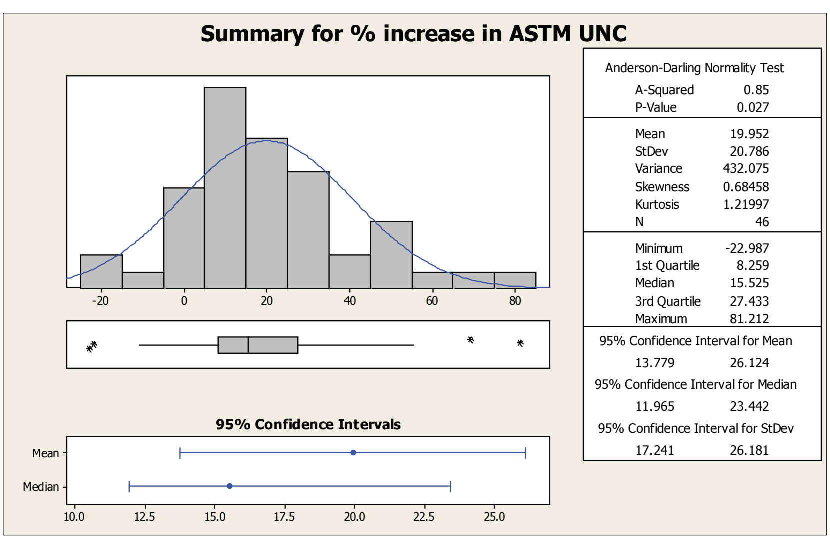


Figure 1. Using 46 ASTM E74 calibrations and not removing the ending zero resulted in an average increase in the ASTM E74 uncertainty of 19.952%.

2.0 Data Analysis

The calibration data gathered from 46 different calibrations was curve fit in accordance with ASTM E74-06 which requires that the trailing or ending zero be considered as part of the calibration per section 8.1 of ASTM E74-06:

> **8. Calculation and Analysis of Data**
>
> 8.1 *Deflection*—Calculate the deflection values for the force-measuring instrument as the differences between the readings of the instrument under applied force and the averages of the zero-force readings taken before and after each application of force. If a series of incremental force readings has been taken without return to zero, a series of interpolated zero-force readings may be used for the calculations. In calculating the average zero-force readings and deflections, express the values to the nearest unit in the same number of places as estimated in reading the instrument scale. Follow the instructions for the rounding method given in Practice E 29.

This data was referred to as ASTM E74 Unc with Trailing Zero or this data was calculated in accordance with ASTM E74-06, which is referred to as Method B in ASTM E74-13a.

The raw data was curve fit a second time ignoring any change in 0 during calibration. For the purpose of this test the beginning zero was used as the ending zero. If an instrument had a beginning zero of 0.00040 then an ending zero of 0.00040 was used. If the Instrument had a beginning zero of 0.00040 and an ending zero of 0.00075 then 0.00040 was used.

This data was referred to as ASTM E74 Unc Ignoring Trailing Zero.

The following equation (ASTM E74 Unc Ignoring Trailing Zero - ASTM E74 Unc with Trailing Zero)/ ASTM E74 Unc Ignoring Trailing Zero))*100 was used to determine the percentage change in ASTM Uncertainty or ASTM Lower Limit Factor (LLF).

Figure 1 shows that use of method (A) ignoring the trailing or ending zero results in an increase of the ASTM E74 Lower Limit Factor (LLF) for the majority of instruments calibrated.

The P-Value of 0.027 for the Anderson-Darling Normality Test indicates this data sample does not follow the normal distribution. Therefore the following discussion will focus on the median and IQR (Interquartile Range).

The sample median (15.525), range (-22.987 – 81.212), 1st Quartile (which represents 25% of the sample population = 8.259) and 3rd Quartile (which represents 75% of the sample population = 27.433) indicates the middle 50% of the data (data between the 1st and 3rd Quartiles ranges from 8.259 to 27.433). The population median can be expected to vary between 11.965 to 23.442 at the 95% confidence level. This 95% confidence interval roughly predicts that in 95 out of 100 future samples, the median can be expected to fall between 11.965 to 23.442. (Note: The majority of the instruments calibrated will fall in this range, which will result in an increase in ASTM Lower Limit Factor.)

The graph below (Figure 2) shows the individual value for each sample.

This data was also broken down by the manufacturers of these specific load cells (Figure 3). We excluded cells and any force measuring instruments sold or manufactured by Morehouse, since we have several varieties of force measuring instruments that exhibit different characteristics. For example, some multi column load cells should have a better zero return than a single column load cell. We also prefer and recommend Method B for any force-measuring instrumentation manufactured by Morehouse.

In some instances, removing the trailing zero actually improved the Lower Limit Factor; in others, the removal of the trailing zero increased the Lower Limit Factor above 0.025% of full scale. An analysis of the variance, popularly known as ANOVA, was used since there are more than two groups of manufacturers. ANOVA analysis by manufacturer, on the following page (Figure 4), shows that there is no difference in the means of the % increase in ASTM LLF. The standard deviations were also found to be statistically equal. The dataset was slightly reduced for this analysis by removing manufacturers with only one instrument in the sample. Ideally, more samples per manufacturer would have been preferred, but the sample size was sufficient for the ANOVA and tests for equal standard deviations.

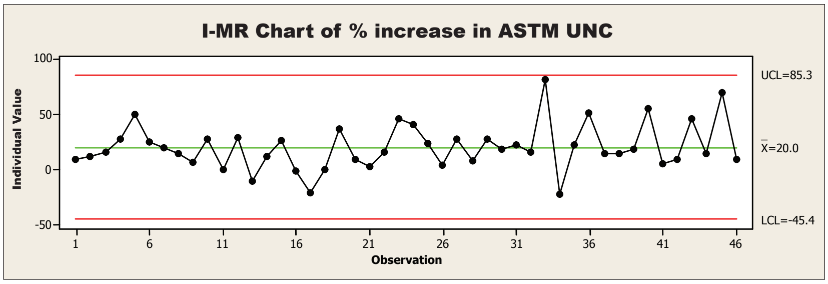


Figure 2.

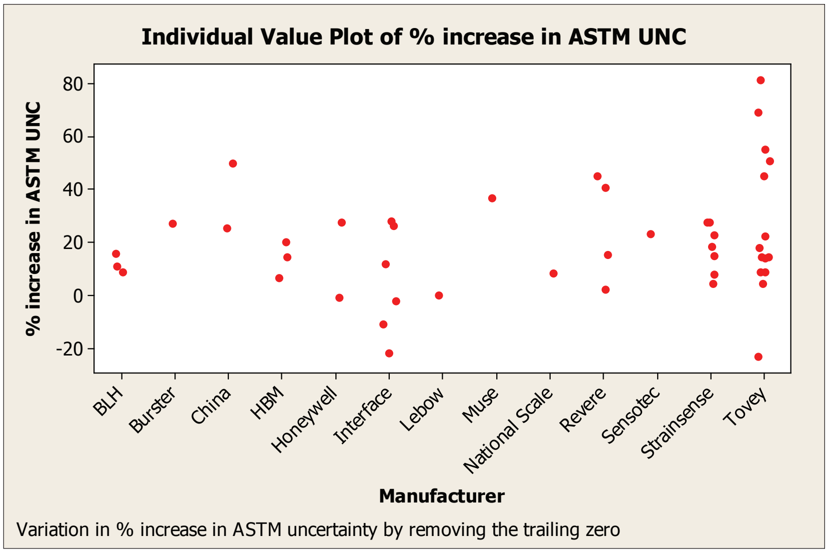


Figure 3.

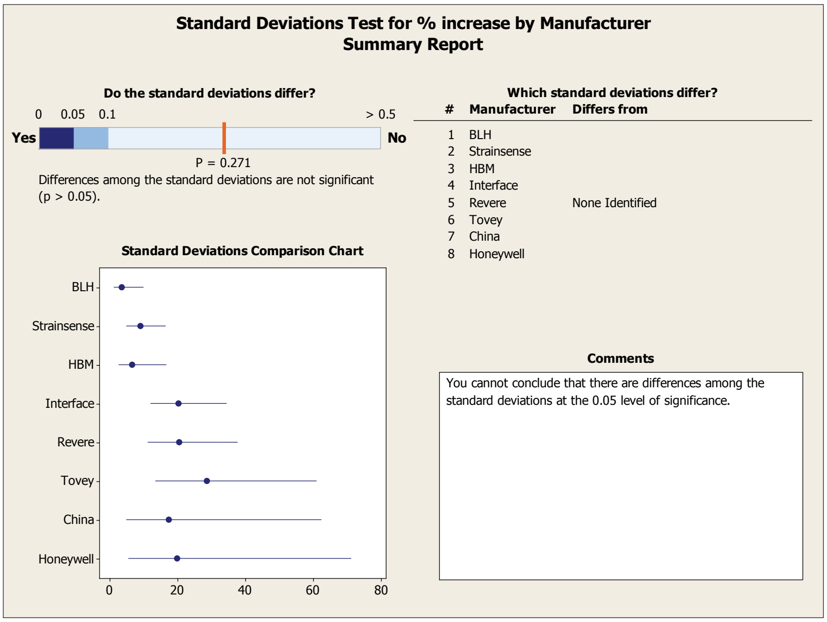


Figure 4.

3.0 Data Analysis – Change in Full Scale Output

The raw data gathered from 46 different calibrations was curve fit in accordance with ASTM E74-06. The full scale output was recorded with and without the ending zero being removed from the full scale output.

The raw data was curve fit a second time, ignoring any change in 0 during calibration. For the purpose of this test, the beginning zero was used as the ending zero. If an instrument had a beginning zero of 0.00040 then an ending zero of 0.00040 was used. If the instrument had a beginning zero of 0.00040 and an ending zero of 0.00075 then 0.00040 was used.

The data with the trailing zero reduced from the full scale output is referred to as Net Output @ Capacity with 0. The data without the trailing zero reduced is referred to as Output @ Capacity no Trailing 0.

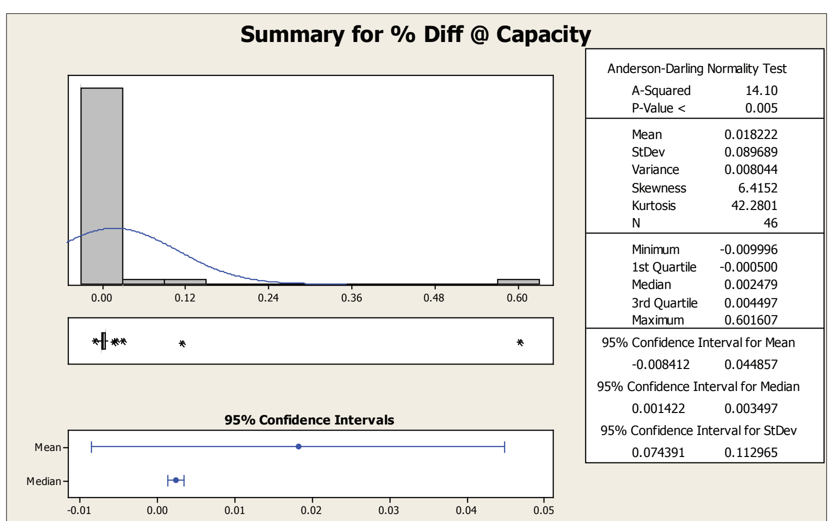
To calculate the percentage change the following formula was used ABS((‘Net Output @ Capacity with 0’-’Output @ Capacity no Trailing 0’)/’Net Output @ Capacity with 0’*100) to determine the % change in capacity between the current treatment of zero versus the proposed.

The graph below (Figure 5) shows method (A) ignoring the trailing or ending zero results in a difference of full scale output for the majority of instruments calibrated.

This increase can be summarized by analyzing the median (0.002479), which shows that in 95 out of every 100 calibrations in future samples, the full scale output difference between method B and method A (Ignoring the trailing zero) would be expected to vary between 0.0014% to 0.0034% by not removing the trailing or ending zero. The median is used for this sample given the sample does not follow the normal distribution.

This data was also broken down by the manufacturers of these specific load cells (Figure 6 on the following page).

Out of 46 samples, 1 load cell exhibited a very significant change in full scale output. We would consider this load cell an outlier. Further evidence would suggest that this load cell was not fit for calibration as the zero balance was quite high, indicating a possibility of mechanical damage. This is typically the result of a load cell being overloaded. When a load cell is overloaded, residual stresses and strains are introduced into the structure. The past mechanical history of the flexure, gauge alloy, backing and adhesive is altered. As a result, the load cell symmetry is modified, and the compression and/or tension output deviates from what it was prior to overload. Strain Gauge characteristics are modified,



The change in % difference at capacity current method versus proposed

Figure 5. Shows method (A) ignoring the trailing or ending zero results in a difference of full scale output for the majority of instruments calibrated.

such as Resistance and Gauge factor, which will modify the temperature coefficients. This is important to note, since anyone using a load cell that has been overloaded may have very large unaccounted error sources, and all force measurements made with this device are suspect. Several methods and devices can be used to test a load cell to determine if it has been overloaded. These devices range from handheld meters, load cell testers which are made specifically for this purpose, to high end meters.

4.0 Closing Comments

This analysis shows that following ASTM E74-13a Method (A), which ignores changes in zero during calibration, will increase the LLF (Lower Limit Factor) median value between 11.9% to 23.4% assuming 95% confidence interval.

The end user of any measuring system should evaluate how the instrument is being used and notify the laboratory performing the calibration of the appropriate method for the normalization of data. These tests can be applied to almost any non-mechanical force measuring instrumentation, and any laboratory performing calibrations on force measuring instruments should report to the end user the zero reduction method used, along with the values of the trailing zero recorded during calibration.

Timing between recording force values and trailing zeroes was between 25 and 30 seconds after the application or removal of force. Differences in timing may also contribute to an additional uncertainty component that should be considered.

Mechanical Instruments were not considered for this test as it has been widely accepted that a change in zero must be accounted for.

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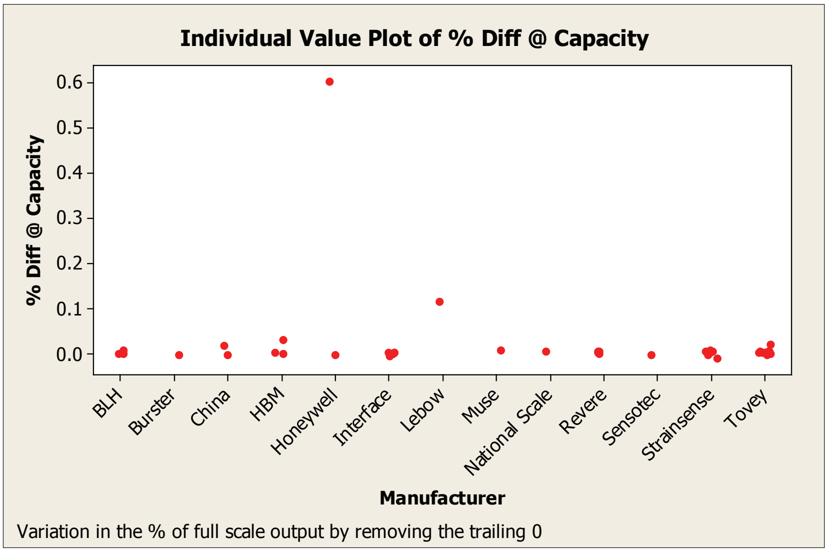

Figure 6.

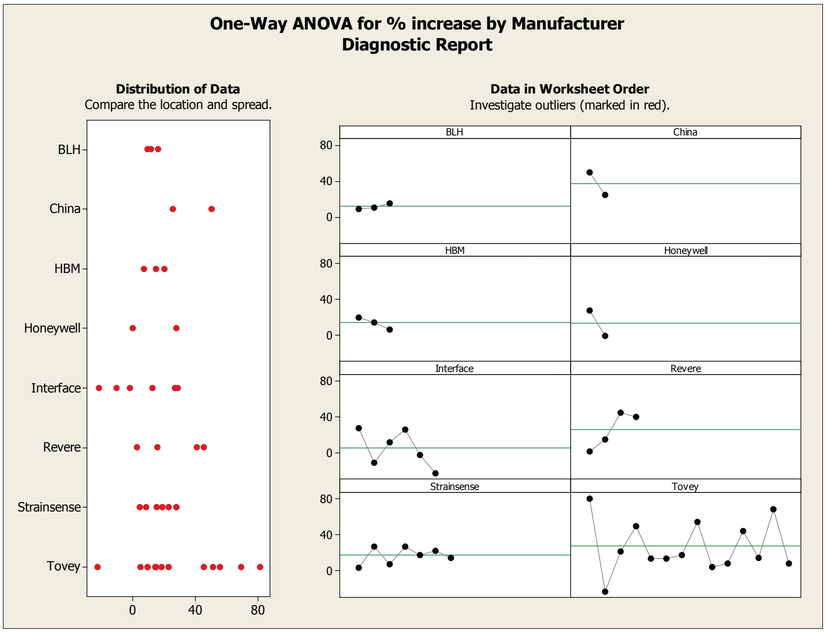

Figure 7. Percentage increase in ASTM LLF (Lower Limit Factor) by manufacturer.