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Field Calibration and Accuracy of Torque Wrenches

Warren Brown
Integrity Engineering Solutions
Dunsborough, Western Australia
wbrown@integrityes.com

Scott Hamilton, An Nguyen
Alltite
Wichita, KS, USA
scott@alltite.net

Tom Smith
MobileCal
Wichita, KS, USA

ABSTRACT

In most cases, it is assumed that a manual or hydraulic torque wrench will deliver the requested torque value if set correctly. However, torque wrenches have moving parts that will be subject to wear. They are also subject to harsh operating conditions in the field, which elevates the risk of damage. It is common sense that calibration of wrenches on a periodic basis would be advisable. This activity is regulated and required in some industries, such as automotive and wind-power generation. However, in the Petrochemical and Oil & Gas industries there are relatively few companies that practice regular calibration. In part, this may be because there is not data available to justify the cost of such a calibration program. It is not until the calibration program is underway that the value can truly be determined. In this paper, the results of field calibration of several hundred torque wrenches is presented and an analysis of the data reveals exactly why calibration of torque wrenches should be an important part of any leak-free bolted joint program.

INTRODUCTION

The goal of this paper is to look at some general trends for a sample of torque wrenches that received calibration, in order to compare the overall accuracy of the wrenches prior to calibration versus post-calibration. The study was conducted on data obtained during the calibration of wrenches from industrial settings in various locations. The data available did not include the operational history or maintenance history of the wrench. It is not, therefore, possible to use the data to demonstrate the rate of degradation of torque wrench calibration in the field. However, it may be considered a reasonable snap-shot of the inaccuracy of torque wrenches that may be expected in the field if recent calibration has not been performed.

For manual torque wrenches, data was recorded during the wrench calibration process both before and after calibration adjustment. This enables a snap-shot of the condition of the wrench prior to calibration and also enables an assessment of how effective the calibration process is in re-establishing the accuracy of the wrench. For the hydraulic torque wrenches, no adjustment of the wrench is possible (other than rectifying any obvious mechanical issues) and the calibration is performed by providing a new pump pressure versus obtained torque chart that is specific for that wrench.

The intent of the paper is to provide a general overview as to the level of accuracy that may be expected in the field for the actual torque wrench. The achieved accuracy of a torque procedure for assembling pressure boundary bolted joints is a function of several different factors, including:

1. Accuracy of the wrench
2. Accuracy of the applied nut factor
3. Effectiveness of the bolting procedure

It should be noted that this paper details only one source of inaccuracy in pressure boundary bolted joint assembly. However, the overall level of inaccuracy will be cumulative and it will always be preferable to eliminate inaccuracy wherever possible.

A further use for the calibration procedure is to identify, for repair or replacement, wrenches that are no longer able to meet the required accuracy. In the case of manual wrenches, this is achieved by identifying wrenches for which one or more test points fall outside of the required limits after attempted calibration adjustment. For hydraulic wrenches there is not an easy method, but an indication may be obtained by the difficulty in achieving calibration of the wrench using a linear relationship between pressure and torque. At present, there is no industry standard for calibration of hydraulic wrenches. Development of industry guidelines should be assisted by studies, such as this one, which demonstrate the effectiveness of calibration in improving assembly activities and reveal some of the characteristics of the test results.

METHOD EXPLANATION

For information, the basic approaches of calibrating both kinds of torque wrenches are explained below:

Manual Wrenches are calibrated in accordance with ASME B107.14-2004 [1], ISO 6789:2003 [2] or similar standard. The process used for the wrenches studied in this paper was in accordance with the above ASME standard (ref. Fig. 1):

1) Set torque wrench to its lowest setting and leave for 20 minutes.
2) Set wrench to 100% of the torque range and apply that torque three times to precondition the wrench.
3) Set wrench to 20% of full range setting
4) Install wrench into calibration bench fixture, with the handle captured in arm A.
5) Rotate wrench handle by turning (manually or automatically) the drive handle B, which rotates arm A.
6) The torque is reacted and measured with a certified load cell located at C.
7) The torque is applied and measured three times, with the obtained torque measured on the third application.
8) The above procedure (from step 3) is repeated for torque settings of 60% and 100%.
9) If the wrench is found not to be within the calibration specification required, then the wrench settings are adjusted and the above procedure repeated.

Hydraulic Wrenches lack a standard calibration procedure, but the process is similar to that of the manual wrench (ref. Fig. 2):

1) Install wrench into the calibration bench fixture, with the wrench drive captured in the appropriate adapter at location A.
2) Wrench reaction arm pushes against the reaction point B. Wrench and reaction point are adjusted such that the clearance is minimal.
3) The torque is reacted and measured with a certified load cell located at C.
4) Hydraulic pressure is applied to the wrench using a hand pump and measured with a calibrated pressure gauge.
5) Once the wrench is installed in the calibration bench correctly, the hand pump is operated in 10% of full load steps from 10% to 100% of full load. In the case of most wrenches, this means taking the hydraulic pressure from 1000 psi to 10,000 psi in 1000 psi increments.
6) At each increment the obtained torque is recorded.
7) If needed, once the test is finished, an adjusted pressure/torque chart can be produced that provides effective calibration of the tool by relating the applied pressure to the obtained torque.

ANALYSIS OF WRENCH CALIBRATION DATA

Manual Wrenches

The calibration test data for manual wrenches contains three test points per wrench. Typically, in a wrench that is out of calibration the data exhibits an offset from the expected 1:1 ratio of applied torque to measured torque, as shown in the example tests plotted in Fig. 3. If such an offset exists, the wrench can typically be adjusted and re-measured until it is within calibration. By graphing the measured torque as a percentage of the expected torque (normalize against the torque target), it is possible to examine all of the test points as a single population irrespective of the wrench size or the target torque. The distribution of the population before any calibration (adjustment of the wrench) can be compared to the distribution after calibration, as shown in Fig. 4 through Fig. 6. The graph x-axis lists the mid-point of the value of the column above it, so the 100% column represents all test points that fall within the range of 97% to 104%. Similarly the 94% column represents values within the range of 92% to 97% and the 108% column represents all values falling within 104% and 112% of the target value. A higher value indicates that the measured torque was above the target value and a lower value indicates a measured torque below the target value.

It can be seen that prior to adjustment, only 35% to 45% of the results fall within the middle 97% to 104% range. In addition, it can be seen that the results tend to be worse for the higher capacity wrenches and that the torque value achieved tends to be below the target value. Some of the worst-case test results are in the order of 50% inaccurate, which is significant. However, once the wrenches have been adjusted, then almost all of them are within the desired middle range. This indicates that there is significant improvement in torque accuracy obtained from wrench calibration. Prior to calibration, just under one quarter of the results had an inaccuracy greater than 10% of the target torque. This level of inaccuracy is of the same order of magnitude as typical errors involved in not establishing the correct nut factor. Such a percentage is significant, and will play a factor in determining whether a pressure boundary bolted joint will leak or not.

Hydraulic Wrenches

Examples of the hydraulic wrench test data, expressed as percentage of the target torque, so that different size wrenches can be compared, is shown in Fig. 7. These are examples of the worst test results that were obtained and it can be seen that the results appear non-linear and have significant variation between them. The presence of the non-linearity is due to an offset in torque value. In other words the wrench consistently applied a torque that was a certain amount under or over the target torque value. This can be seen more clearly if the results are normalized on pressure as well as target torque (Fig. 8). It can be seen that there is both variation in slope and variation in offset from the ideal case, where the output torque is equal to the target torque value.

The presence of both a variation in slope and an offset in torque value are important concepts when understanding the calibration of hydraulic torque wrenches. With a hydraulic torque wrench, adjustment to account for the variation from manufacturer's recommended pressure versus torque relationship is made by providing an updated table of values determined from the torque wrench calibration test. The relationship provided by the manufacturer is based on the size of the hydraulic cylinder in the tool and the offset of the cylinder reaction point versus the center of the bolt and contains an in-built offset to account for frictional forces. Since the pressure area and tool geometry (moment arm) are assumed to be constant, then this relationship is assumed to be linear, with the obtained torque proportional to the applied pressure.

However, as the tool wears, then factors such as friction within the components and variation in the cylinder reaction point may become significant. As can be seen from the test results, the wrenches have variation that is both proportional to pressure (change in slope of the results), but also variation that is independent of pressure (change in offset). If the test results are not used directly to create a calibration chart, then the original manufacturer approach should be followed, and both variation in slope and offset accounted for in order that the calibration may be as accurate as possible. This concept is illustrated in Fig. 9, where adjustment is made to the slope of the line only, by comparison with Fig. 10, where adjustment is made to both the slope and the offset. It can be seen that the second calibration method provides substantially better results, with most test points falling very close to target. It is possible to use the calibration data directly to establish the pressure-torque relationship, however this then allows the use of a non-linear relationship that may mask issues with the wrench. By assuming that the linear relationship must apply, then it is possible to use the % variation from the calibrated line as a measure of when the tool must be overhauled or replaced.

As such, the worst-case results presented in Fig. 10 are also a good illustration of the second purpose of the calibration activity; to determine when a wrench has reached the end of life. There are a couple of wrenches that have significant non-linearity over the range of applied pressures (MXT3, 3XLT and 5K 1" drive, for example). One possible result of this calibration activity is that those wrenches could be selected for complete overhaul and, if calibration is still not successful after that, then replacement of the wrench would be appropriate.

If the full calibration method is applied to the test results, then it can be seen that across all 132 wrenches tested, it was possible to increase the number in the 97% to 104% range from 37% to 90% (Fig. 11). Similarly to the manual wrenches, around one quarter of the test results where more than 10% inaccurate prior to calibration. The results can be improved if the lower end of the tool pressure range is removed from the data set (i.e.: by including only the 3000 psig and 10,000 psig results). Since the lower pressure end of the wrench operation tends to be more inaccurate, then the pre-calibration results improve, and it can be seen that only around 20% of test points are now worse than 10% inaccurate. In addition, it can be seen that the post-calibration tests result in 97% of the data being within the middle range of 97% to 104% of the target. These results indicate that in order to increase the accuracy of the obtained torque, hydraulic torque wrenches should not be used at pressure settings below 20% of the full load pressure.

To examine whether there was any difference in accuracy or calibration characteristics, the low-profile torque wrench data points were separated from the population. The result graphs, for both the full pressure range and the 3000 psig to 10,000 psig pressure range are shown in Fig. 12 and Fig. 13, respectively. It can be seen that the results are very similar to the overall results, with perhaps a slight improvement in both accuracy and ability to calibrate. However, the level of improvement is very marginal and may be caused by other factors that were not assessed, such as the amount of use of the low-profile wrenches being less than the average. The difference found is not significant enough to warrant any different treatment of the low-profile wrenches.

However, one difference of the low-profile wrenches is that the drive unit containing the hydraulic cylinder is detachable from the link unit that contains the wrench hex head. This is so a single drive unit can be used for multiple bolt sizes. Of the test results studied, there were six low-profile wrench drive units that were tested with two or more different size link units. By comparison of those test results, it is possible to see if calibration of the drive unit is independent of the link unit, or not. Two example results are shown in Fig. 14 and Fig. 15. It can be seen that there is a significant effect on the obtained torque value accuracy depending on the link unit being used. If the test results are compared by performing only one calibration per drive unit (per drive), versus calibrating each drive and link unit combination (per link), then it can be seen (Fig. 16), that the per link method is significantly more accurate than calibrating the drive unit with only one link. It is, therefore, evident that it is necessary to assign serial numbers to both the link and the drive units and to calibrate and use them in pairs, in order to obtain the best overall accuracy.

The final aspect that was examined was the effect of the amount of time between calibrations on the pre-calibration accuracy of the hydraulic wrench results. The accuracy of the results for a calibration frequency of 12 months, 24 months and 36 months is shown in Fig. 17. It can be seen that there is little difference between the 12 month and 24 month results, whereas the 36 month results appear to be less accurate. This may be taken as an indication that a 12 month to 24 month calibration frequency appears appropriate and that a 36 month frequency would be too long. However, this is not a comprehensive study of the effect of time on tool calibration, since there was no measure of the amount of use the tool received during the time period and nor were there any records available of how often the tool was subjected to maintenance during the period between calibration. Obviously these two factors would have a significant effect on the outcome of any comprehensive study on frequency of calibration. It should also be noted that ISO 6789 [2] has a specified calibration frequency of 12 months for manual wrenches.

CONCLUSIONS

The analysis of torque wrench calibration performed for this paper has demonstrated that, on average, approximately one quarter of the wrenches will be out of calibration by up to 10% at their first calibration check. This is a significant factor when compared to other variables which will combine to determine whether a pressure boundary bolted joint will leak. The benefit of regular calibration has, therefore, been demonstrated for both manual and hydraulic wrenches. For hydraulic torque wrenches, it has been demonstrated that the calibration procedure (adjustment of the pressure versus torque relationship) must include both a variation in offset and variation in slope in order to accurately describe the wrench behavior.

The analysis of data performed for this paper has also demonstrated the usefulness of the calibration procedure in detecting wrenches that should be repaired or replaced. For both the manual and hydraulic wrenches studied, there were several that had test results after calibration in excess of 10% above or below the target torque. Prior to calibration, some of the wrenches tested were inaccurate by 50% of the target torque, which means that if the wrench is set to 250 ft.lb, the delivered torque will be either only 125 ft.lb or will be significantly higher at 375 ft.lb. This level of variation is likely to be the root cause of leakage. Since the results improved significantly after calibration, then it is likely that the simple maintenance steps performed during calibration significantly improved the wrench accuracy with relatively very little effort or cost.

In addition, it has be shown that the effect of different link units on a low-profile torque wrench is significant and, wherever possible, the wrench drive unit and link units should be calibrated and used as a paired item, rather than considering that the drive units are inter-changeable between link units with no impact on accuracy.

Finally, although a cursory study of the effect of calibration frequency was made, it is worth re-stating that the purpose of the calibration process is twofold; to adjust the wrench back into calibration and also, secondly, to determine when a wrench requires replacement or overhaul. If inaccuracy of the wrench was caused simply by gradual wear of the components, then it might reasonably be expected that a lower frequency of calibration would be sufficient, with the sole purpose of bringing the wrench back into calibration. However, since wrench failure may not always be gradual, the lower frequency approach increases the probability that a wrench that is out of calibration will be used for a significant period of time, thus increasing the likelihood of leakage. A suitable calibration period should, therefore, be based not only on the amount of use the wrench will see during the period, but also the risk that an out of calibration wrench will cause leakage prior to recalibration. This risk can also be minimized by recording which wrench is used to tighten each joint. In that way, any leakage can potentially then be traced back to a problematic wrench.

REFERENCES

[1] ASME B107.14 Hand Torque Tools (Mechanical)

[2] ISO 6789:2003 "Assembly tools for screws and nuts -- Hand torque tools -- Requirements and test methods for design conformance testing, quality conformance testing and recalibration procedure"

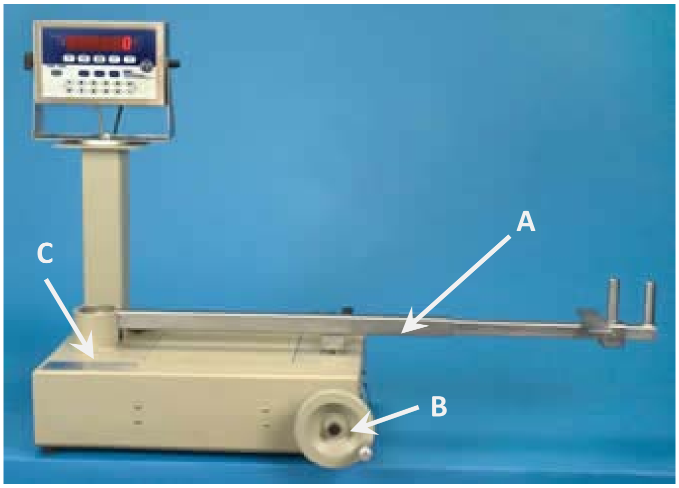


Figure 1 – Manual Torque Wrench Calibration Bench

Figure 2 – Hydraulic Torque Wrench Calibration Bench

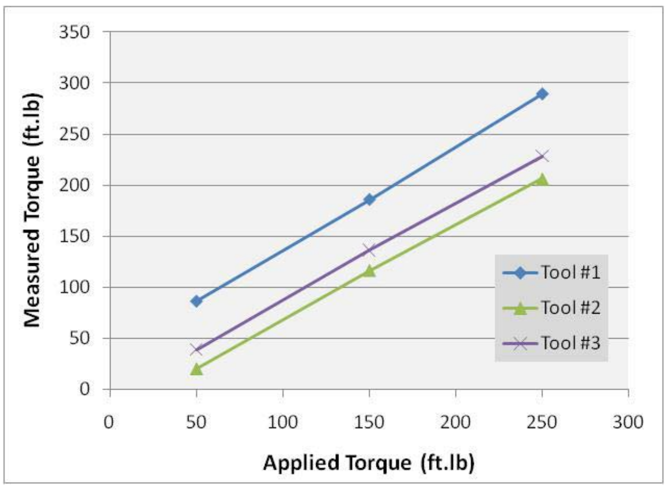


Figure 3 – Example Manual Wrench Test Results

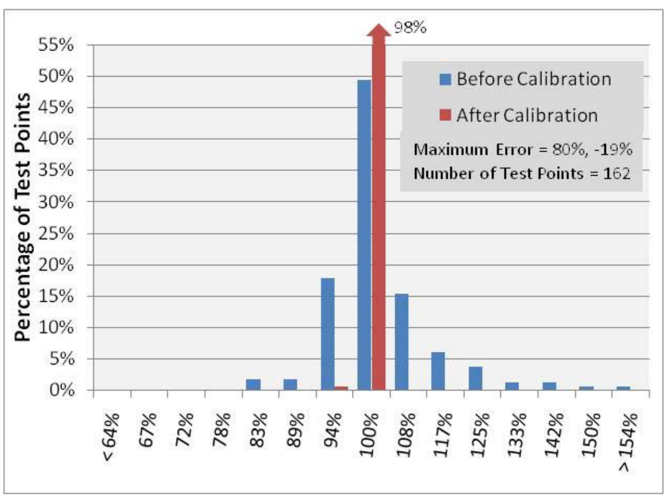


Figure 4 – 100 ft.lb Manual Wrench Results

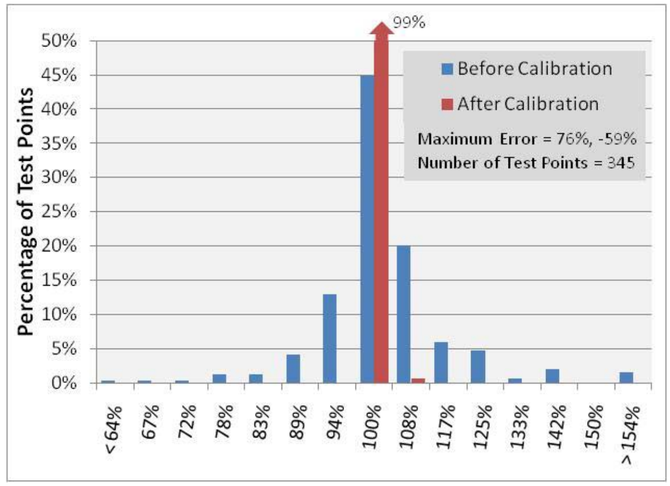


Figure 5 – 250 ft.lb Manual Wrench Results

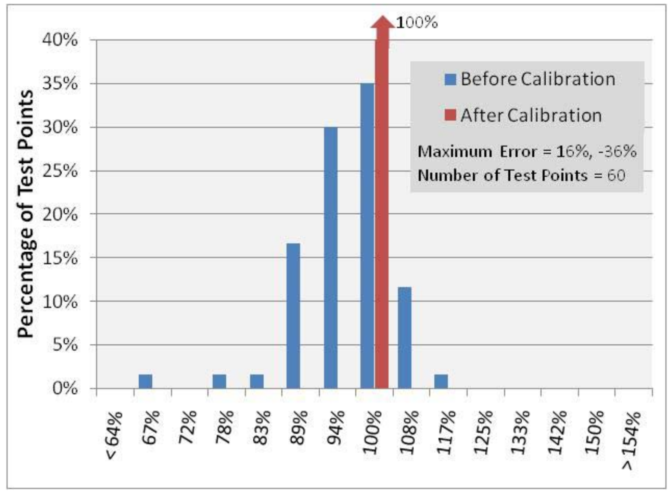
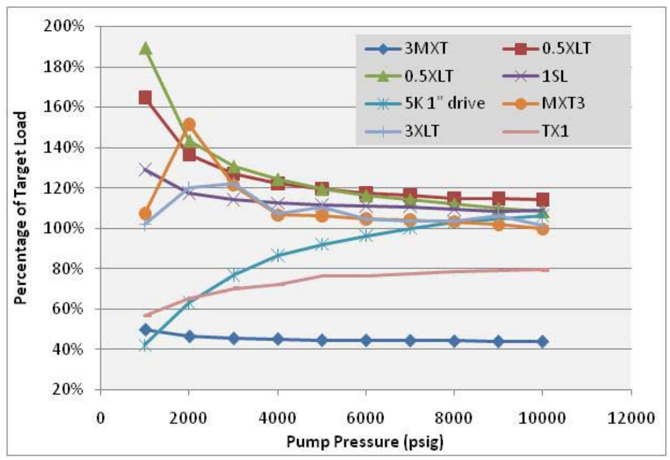


Figure 6 – 600 ft.lb Manual Wrench Results



Note the labels (3MXT, etc…) are manufacturer tool model designations.

Figure 7 – Example Hydraulic Tests (Before Cal.)

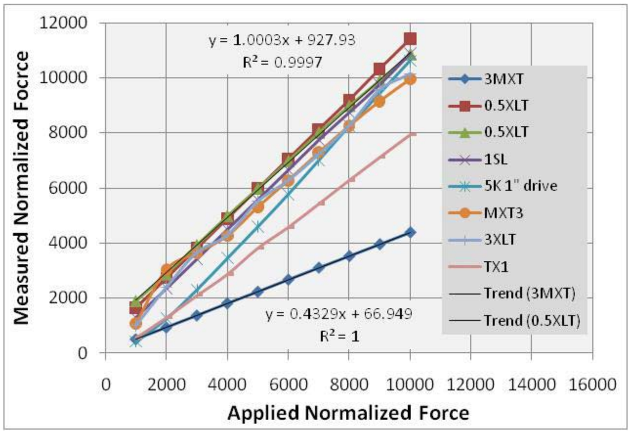


Figure 8 – Example Hydraulic Tests

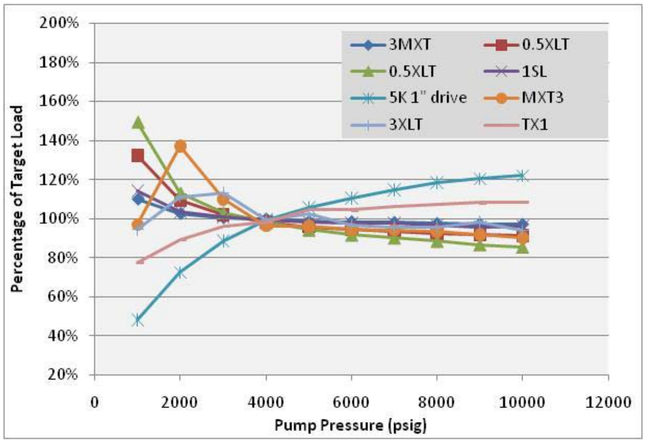


Figure 9 – Example Hydraulic Tests (After Fact. Cal.)

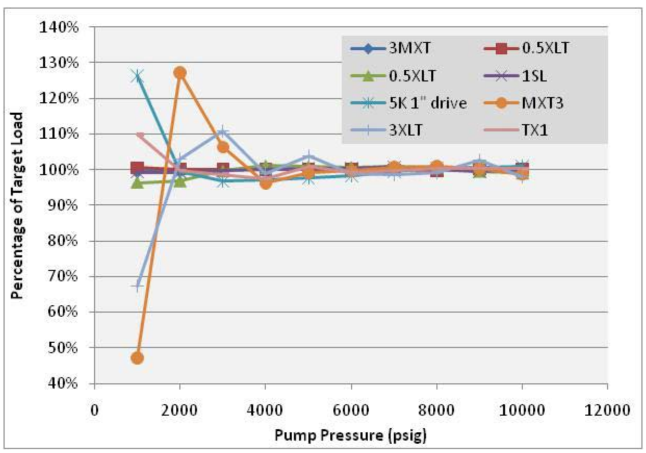


Figure 10 – Example Hydraulic Tests (After Full Cal.)

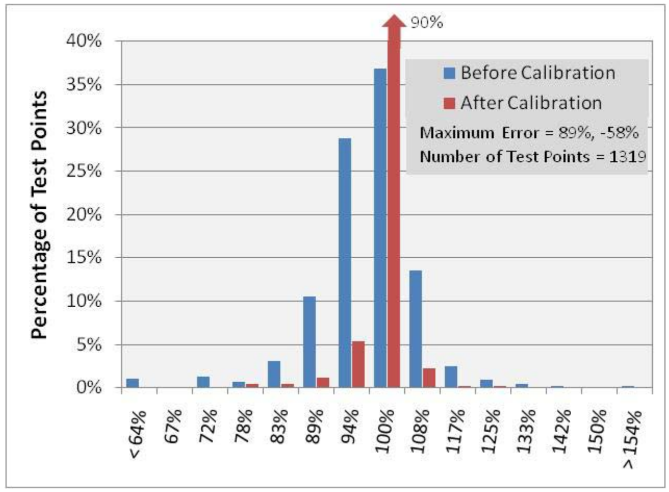


Figure 11 – Hydraulic Wrench Results (1 to 10 ksi)

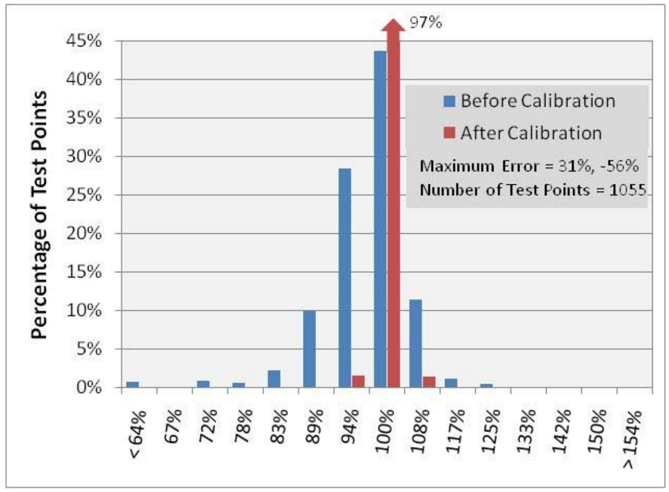


Figure 12 – Hydraulic Wrench Results (3 to 10 ksi)

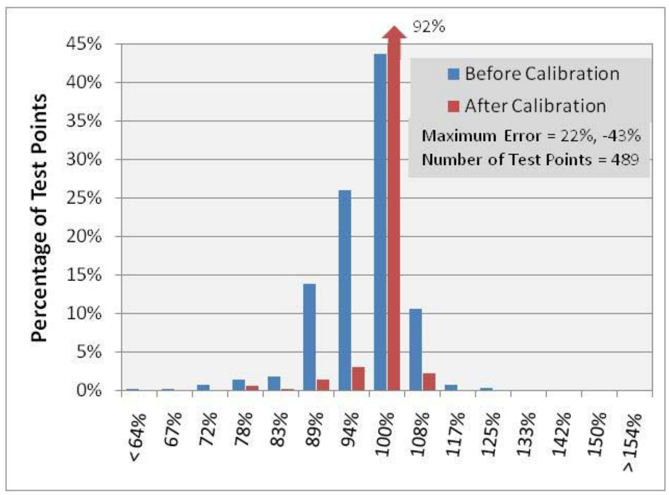


Figure 13 – Low-Profile Wrench Results (1 to 10 ksi)

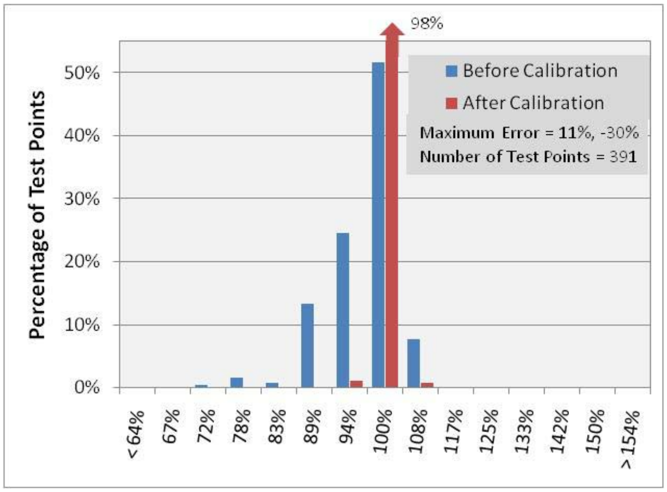


Figure 13 – Low-Profile Wrench Results (3 to 10 ksi)

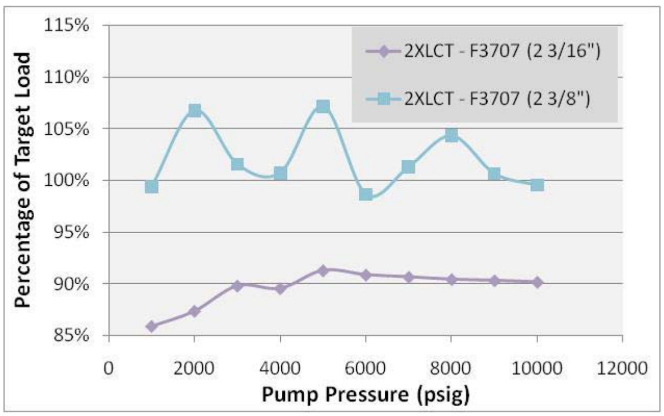


Figure 14 – Example Low-Profile Test Results, 2XLT

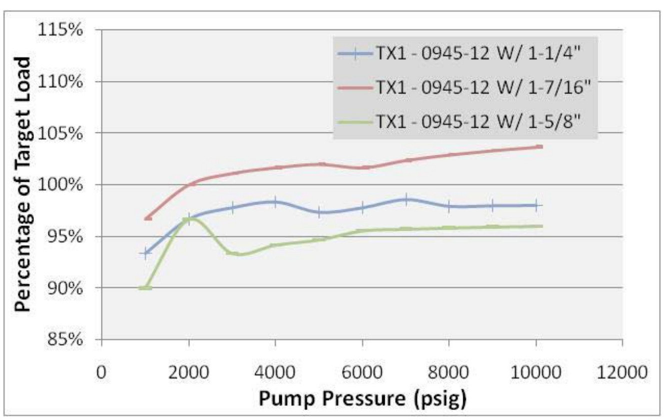


Figure 15 – Example Low-Profile Test Results, TX1

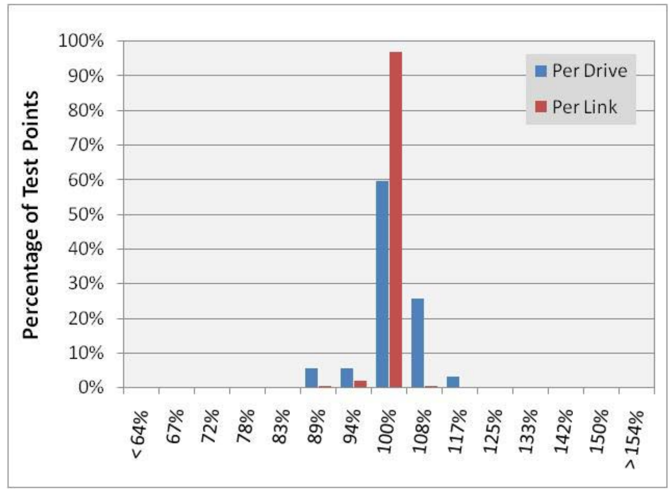


Figure 16 – Low-Profile Wrench Calibration Comparison

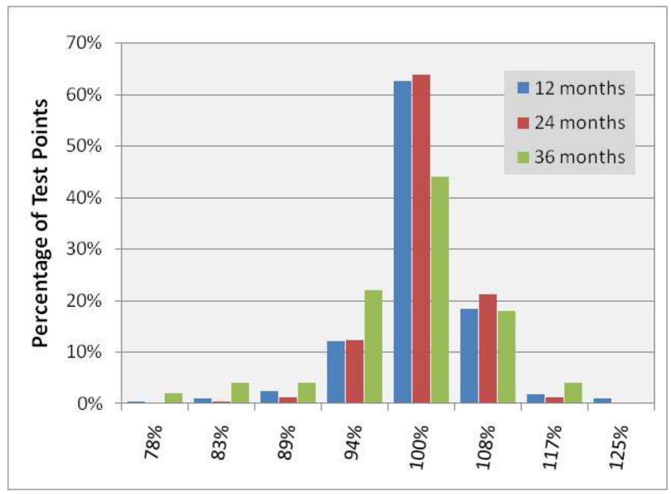


Figure 17 – Hydraulic Calibration vs. Time Results