

Variables in Bottle Cap Torque Testing

by

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I. Abstract

Today's manufacturing operations are very concerned with loose or stripped caps which will clearly affect product freshness, product stability, shelf life and possibly leakage. Stability is of particular concern, since moisture sensitive or pressurized products require that the integrity of the container closure and seal be maintained. Loose/stripped caps can lead to both package and product issues due to the loss of nitrogen in non-carbonated drinks or carbon dioxide in sodas or addition of moisture to a dry product can cause contamination, discoloration, significant changes in potency/taste, and thereby, affect the quality of the product. To maintain/improve process control, it is very important to monitor the closure integrity continuously. For this purpose there are various torque testing devices available on the market, however it is rarely mentioned, that closure integrity test results are influenced by a number of variables. In this white paper, we will focus on the various factors that influence the readout of torque analyzers and recommend methods to eliminate the effect of parasitic torque errors.

II. Introduction

In the past, cap torque testing was as simple as grabbing a container from the production line and manually checking how tight the cap felt. Due to the subjective feeling of cap tightness, over time the industry shifted toward using more objective measurement devices, spring based benchtop and handheld torque testers.



It did not take long before Quality Assurance personnel realized the limitations of the spring based devices. Additionally, entering the 1990's there were so much more to consider: changes in materials, marketing themes, package aesthetics, transportation methods, packaging processes such as induction sealing and hot filling. Product liability, versatility, compatibility and ergonomic issues made capping and torque testing much more than just placing a cap on a bottle and turning it by hand. As a result, automated torque testers emerged. While most of these automated testers provide a great way to reduce operator variation, it is still crucial to understand all of the process variables that may influence the torque test results.

III. Variables in Torque Testing

1. Closure gripping pressure:

Different cap finishes can be secured in a torque tester using different gripping methods. Especially with newer, light weight closure designs, manual gripping can distort the cap and introduce an operator dependent torque error between the container and closure threads.



In order to overcome the variation introduced by manual gripping, custom molded, 3d printed or machined “serrated” chucks can be used for securing the caps during the torque test.



While these type of chucks are great for eliminating the torque error introduced by gripping pressure variation, there are also some disadvantages of using them. Due to the large variety of serration types and cap diameters, a quality department is challenged with the high cost of change parts and the management of the various serrated chucks. Other disadvantages include the difficulty of aligning the chuck with the clamped bottle/cap and the inability to work with smooth closures, pump dispenser caps and other unique closure designs.

Alternatively, mechanically actuated chucks are available on the market and with careful package analysis and pressure configuration

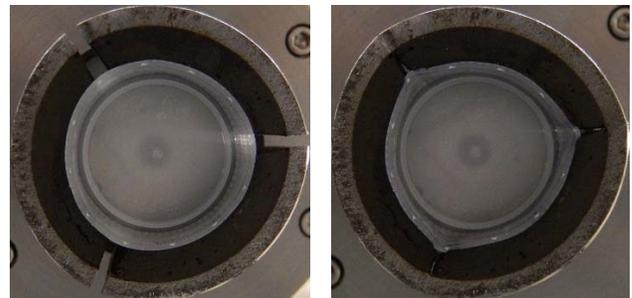
they can address all of short-comings of the serrated chuck design.



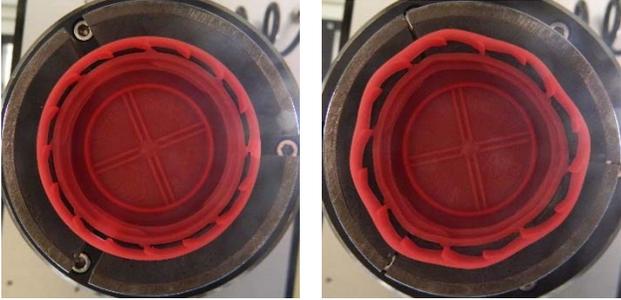
For example, one air actuated chuck size works well for multiple serration types for the same cap diameter and by optimizing the gripping pressure, the removal torque results are comparable to those measured with serrated chucks.

While many packages are not sensitive to chuck pressure variation because of the harder material (phenolic) or more robust structural design of the cap (child resistant caps), others can be extremely sensitive to the gripping pressure (“light weight” caps and closures made of flexible materials).

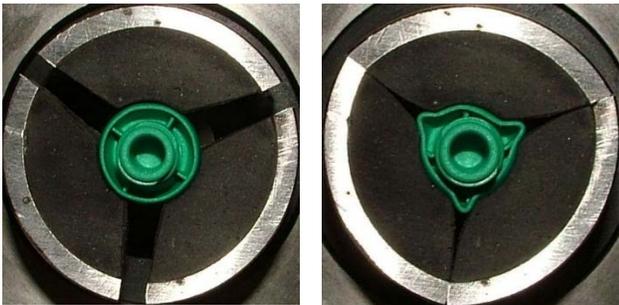
Examples of the deformation caused by chuck pressure variation are shown on the pictures below.



Lightweight Beverage cap at 30 and 70PSI gripping pressures



Lightweight Beverage Cap at 40 and 70PSI gripping pressures



Rubber Luer Lock Cap at 30 and 70PSI gripping pressures

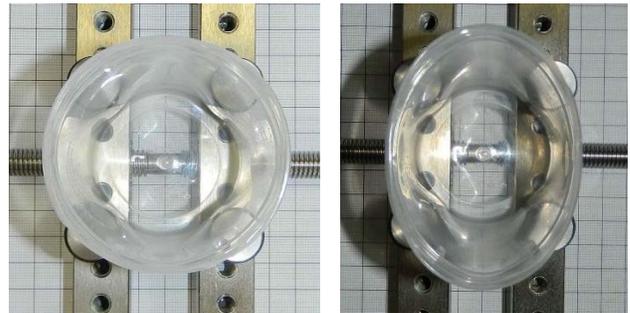
In most cases the visible deformation can reduce the measurement sensitivity or results in higher release torque values. Decreased measurement sensitivity can cause torque testers to fail

detecting the drop in the torque after the thread break.

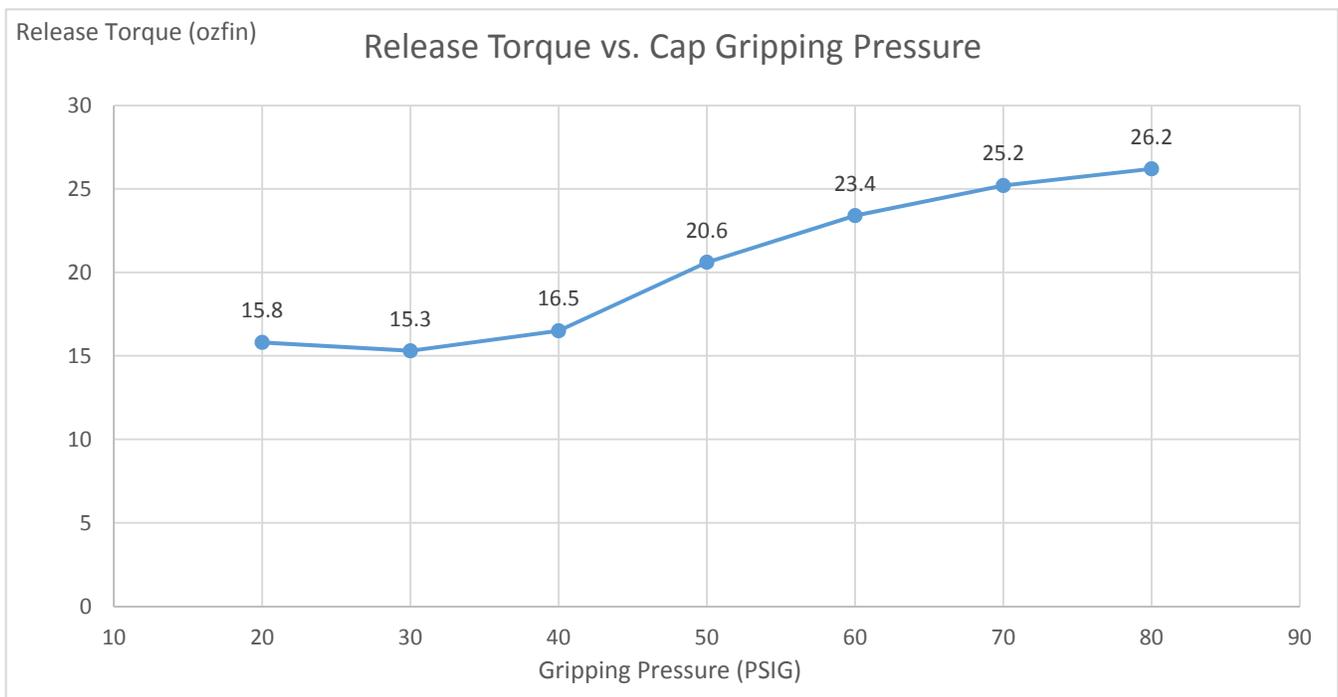
The graph at the bottom of the page shows an example of increasing thread break torque in the function of increasing cap gripping pressure. Each data point on the graph represents the average of 10 release torque measurements at the given pressure.

2. Bottle gripping pressure:

It is not as common to see the torque readout influenced by the bottle clamping pressure, nevertheless it can also “de-sensitize” the automated release torque measurement and contribute to variations in the result:



Distortion caused by excessive bottle clamping pressure in a manual clamping table





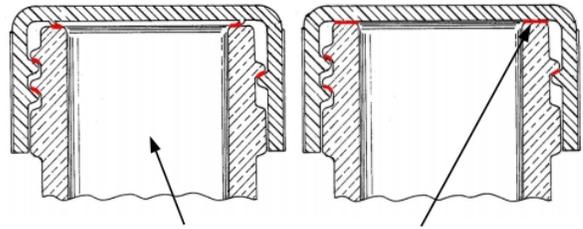
Distortion caused by excessive bottle clamping pressure in an automatic clamping system

The distortion of the bottle opening is most often visible as seen on the images above. The torque error introduced by the excessive clamping can be easily evaluated by rotating a loose cap on the bottle threads. A clamping pressure sensitive bottle will produce noticeably higher torque (blue line) compared to the torque on a bottle that is clamped with optimized pressure (orange line). When there is noticeable “drag” between the bottle and cap threads, the operator should reduce the clamping pressure to the optimal level at which point the bottle is not slipping but the cap rotates with minimal torque. The clamping pressure must be verified at the low and the high process limits to ensure the bottle clamping

configuration will work for the normal measurement range.

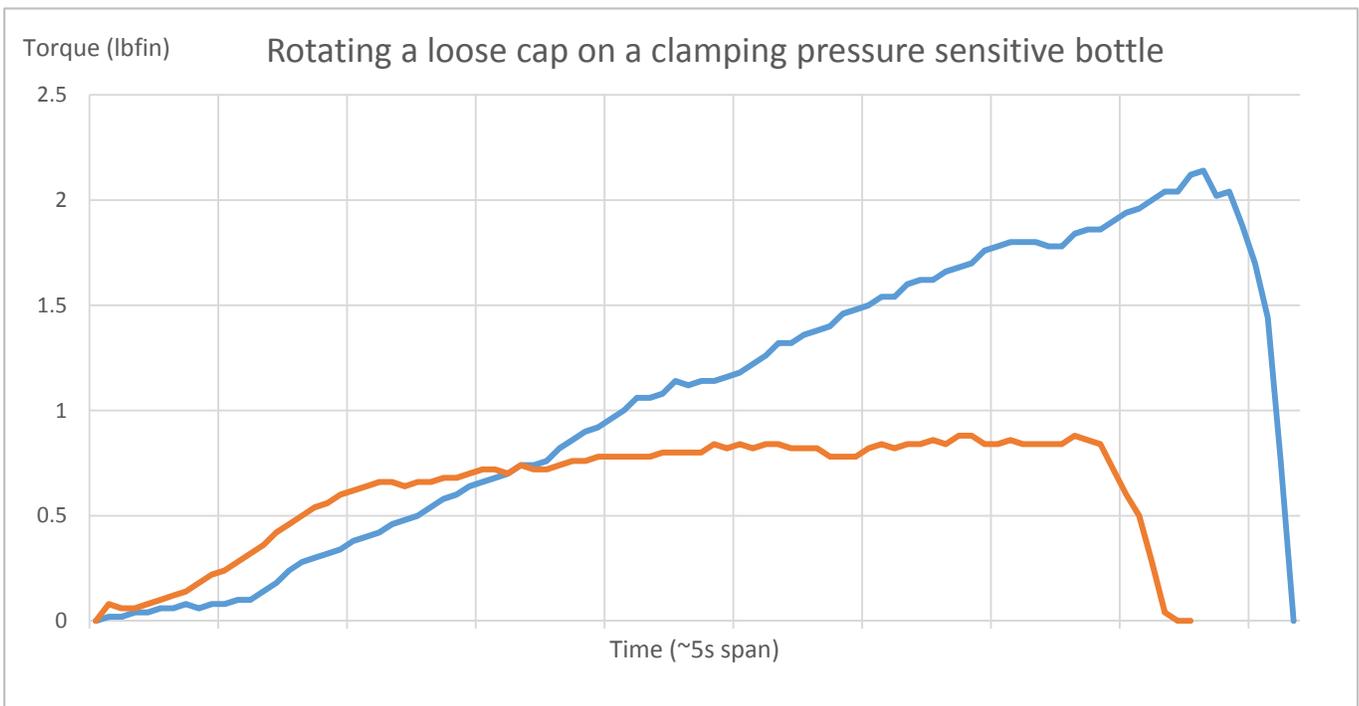
3. Top load

While many pharmaceutical and chemical applications require some kind of top load control for the successful release torque testing of a CR closure, excessive and varying top load can also contribute to torque errors.



Increased pressure on liner and larger contact areas may result in higher release torque readouts

Similar to the cap and bottle gripping sensitivity, the top load sensitivity of the release torque measurement largely depends on the specific package design (cap/bottle/liner materials, dimensions). The optimal top load should be



evaluated and optimized for each product individually.

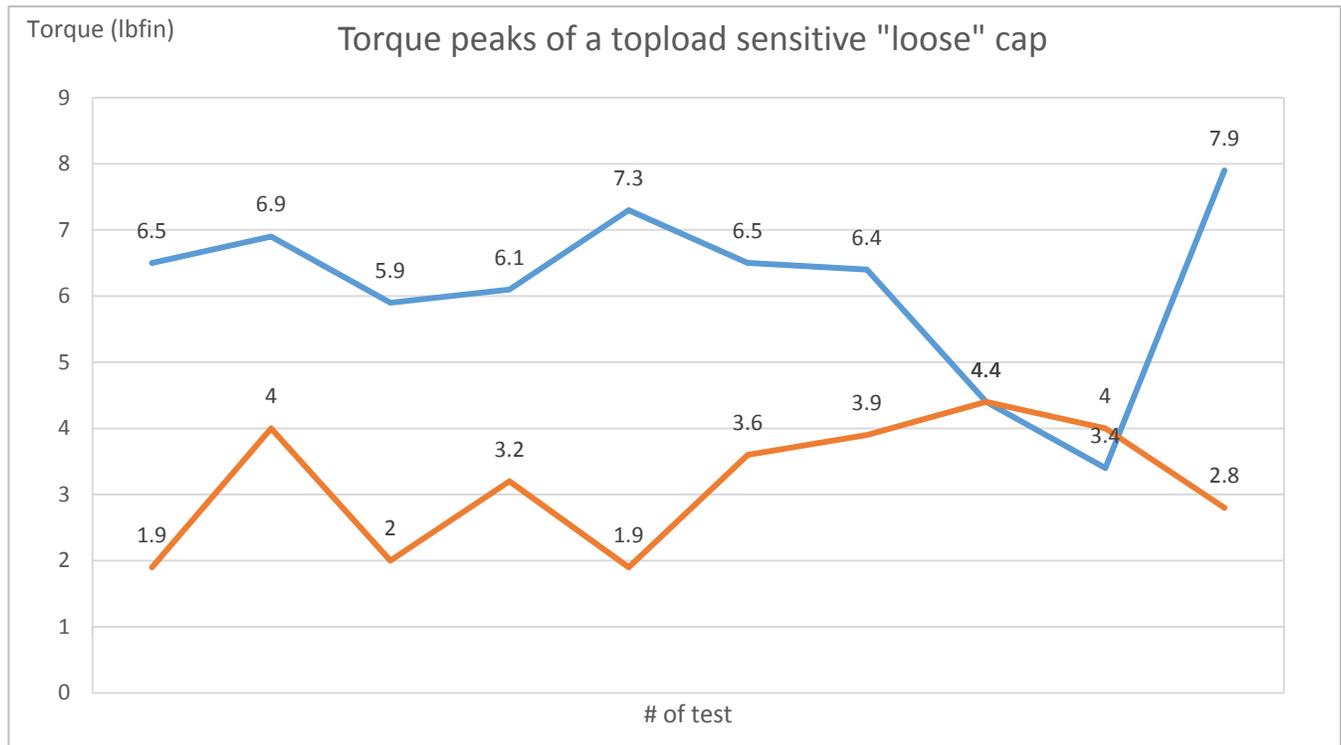
Certain applications require minimized top load during the rotation of the cap, for example, when testing the thread break, seal break and bridge break torque of a closure with a tamper evident band.

Minimized top load is also beneficial when measuring the snap torque of the tamper evident band during a cap tightening cycle or when measuring torque on a loose cap. A good representation of a top load sensitive package is shown on the graph below. The blue data points represent the torque measured between the threads of a loose cap in the presence of excessive top load, while the orange data points show substantially lower torque values due to the reduced vertical force.

While some child-resistant closures only require an initial top load to engage the outer shell with the inner cap, it is best to optimize and maintain the vertical force during the measurement, and this is especially true for CR closures featuring a tamper evident band.

One of the bigger challenges in automated torque testing is also related to top load sensitivity. In many applications there is a requirement to detect a loose child-resistant cap, however when appropriate top load is applied on the CR closure, due to the top load introduced torque between the cap and bottle threads or between the opening of the bottle and the liner, the loose caps will produce torque values that meet or exceed the acceptable low process limit.

While it is preferable to carefully specify the cap, liner and bottle materials and designs to avoid these kind of quality assurance problems during production, alternative process limits may be re-established and/or customized release torque validation methods can be developed to differentiate between top load sensitive loose and tight CR closures.



4. Angular speed of rotation vs. sampling rate of the Analog to Digital converter

When the caps are rotated on the bottle neck, another variable to consider is the speed of the rotation. The angular speed can influence the torque readout in a number of different ways. On a manually operated, analog/spring based torque tester for example, as the needle is accelerating the peak indicator, depending on the speed and the mass of the indicator, it may travel well beyond the actual peak torque due to its momentum.

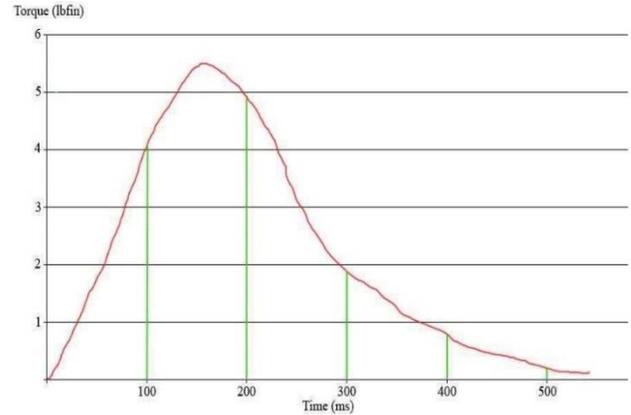


For this reason, it is very important to control the torque ramp/angular acceleration of the cap in order to avoid torque readout errors. On digital torque testers however another critical parameter must be considered: the sampling time of the Analog to Digital converter.

When the angular speed of the cap is fast compared to the conversion time of the analog to digital converter, the removal torque readout may be considerably lower than the real peak value. The error originating from the slow sampling speed should not be confused with the quantization error.

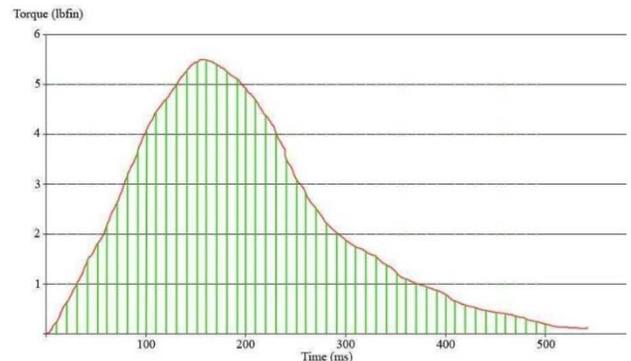
The error originating from the insufficient sampling time can be best represented using the following graphs.

On the first graph, the analog torque signal (red) sampled using a 12 bit, 100ms sampling time AD converter. The green lines represent the times at which the analog signal is “sampled” by the



analog-digital converter. The peak readout in this example is ~4.9lbf·in at 200ms.

On the second graph, the same signal is sampled using a 12 bit, 10ms sampling time AD converter. Clearly, the real peak torque is captured more accurately at 160msec, at a value of ~5.5lbf·in.



For more information, about digitization errors, please refer to the Nyquist-Shannon sampling theorem and the quantization noise.

Fortunately, there are various dynamic torque references available on the market allowing operators to analyze and verify the analog sampling speed and transient behavior of manual and automatic torque testers. These devices typically use magnets to create repeatable attracting and repelling peaks, simulating the thread break torque of a closure.

5. Process variables

Torque variation are often introduced by variations in the packaging process. A couple of examples are included in the section below.

Induction sealing

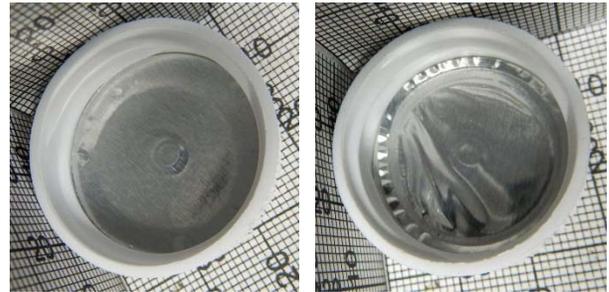
As a result of the induction heating of the metal foil inside the cap, the bottle and cap may deform, expand then shrink. Because the cap and the bottle are typically made of different plastics, the timing and the rates of expansion/shrinking is different, as a result the torque between the threads can change considerably before and after the induction sealing process.

A typical induction sealing related torque degradation trend is shown on the graph below. After tightening 20 caps to 15lbfin torque, we measured the removal torque on 10 bottles before (blue line) and 10 bottles after (orange line) a typical induction sealing process

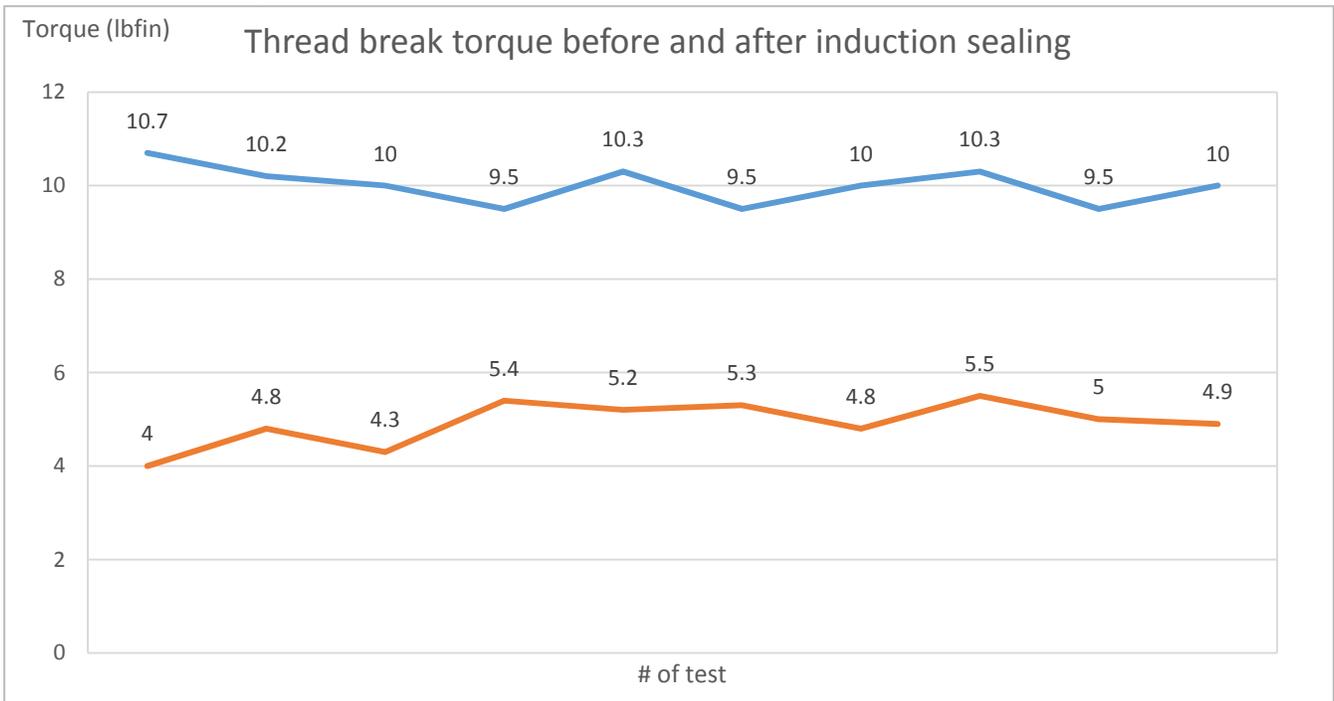
The noticeable difference between the release torque values before (blue) and after (orange) the induction sealing process can be influenced

by the energy/proximity of the electromagnetic field, the speed of the conveyor (dwell time within the induction field), the application torque, metal foil type, etc.

In order to ensure proper sealing and product integrity, it is important to apply enough torque on the cap so the foil is compressed firmly on to the opening of the bottle. One mistake often made is the overtorquing of the cap.



By overtorquing it is possible to achieve good removal torque values after the induction sealing process, but high application torque increases the chance of the threads stripping during the tightening cycle and the excessive torque may break the cap or create wrinkles on



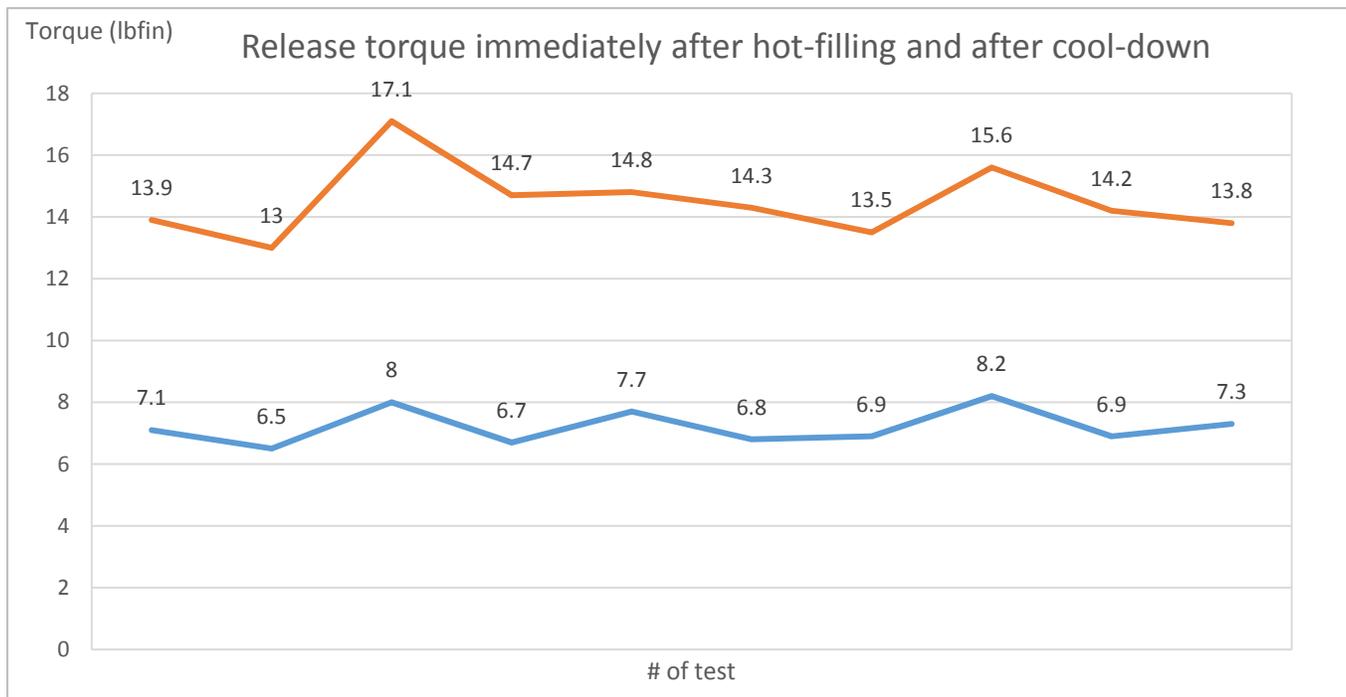
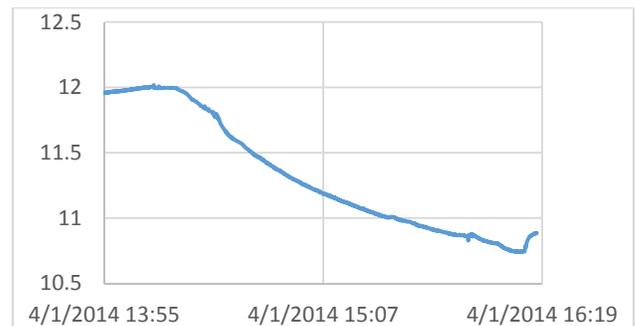
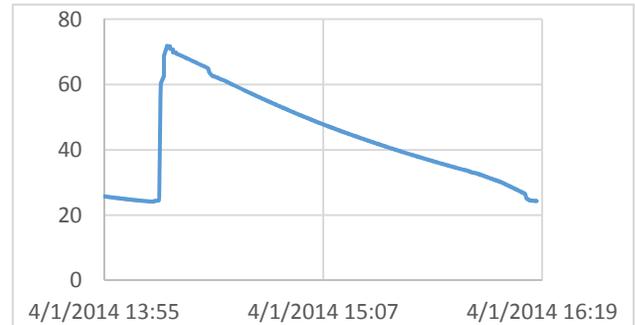
the metal foil. As a result, the wrinkled foil is not sealed properly and the product shelf life is reduced significantly.

A good approach to packaging induction sealed products is to tighten the closures to a torque range that is optimal for seating the seal on the bottle then after the induction sealing, the cap can be secured on the bottle threads by utilizing a shrink wrapper and/or re-torquer.

Hot-filling

Another good example of torque variation introduced by a packaging process variable is presented by hot fill bottling and steam cap applications. During the hot-fill process, the 80-90°C product transfers heat directly to the bottle/cap. Fill temperature variation, the different thermal expansion contraction rates of different cap, liner and bottle materials, varying dwell times between cap tightening and release torque measurements can all result in different release torque values. When the torque is applied right after hot-filling, the cap is soft and as the cap is cooling and shrinking the removal torque increases. The relationship between product temperature and release torque is

shown on the graph at the bottom of the page. Caps were tightened to 18lbfin, then removal torque measurements were taken immediately after hot-filling (blue line) and after cool-down to room temperature (orange line).



Typically products are sampled for fill volume/weight and cap removal torque values shortly after the hot-fill process. In order to ensure correct opening performance after the cool-down period, it is important to understand the effect of dwell time and thermal contraction on the removal torque value of the closure.

It is the subject of a future white paper to evaluate the effect of internal pressure and headspace volume variations to the thread break torque of the closure as well as comparing the degradation caused by dwell time to the torque increase caused by the thermal contraction of the cap.

Spills

Certain products and materials are more sensitive to spills than others. During filling, it is possible that the product spills on the threads or the liner/seal. While the spilled product can act as a lubricant during the capping process, after storage/drying it can leave a residue with thread-locking properties. A good example is displayed on the picture below.



Due to the thread locking properties of such product residue, the release torque readouts can be considerably higher and the product appearance/quality is also adversely affected.

F. Dwell time and the repeated opening/closing of a closure

The dwell is defined as the time interval between the cap tightening and the release torque measurements. In various experiments,

it has been established that release torque levels are highest immediately after application and then gradually decrease to a stable level over a period of time (hours to days). The rate of the release torque decay is greatest in the first couple of hours then it gradually decreases before reaching its stable level. Transportation (vibration), thermal stress (varying storage temperatures) and production processes such as induction sealing, hot filling or the use of heat activated/sterilized package designs can amplify or offset the torque decaying effect of the dwell time.

6. Product variations

Changes that are not noticeable to the naked eye, such as minor variations in the material composition, the dimension of the cap, bottle, liner, can also influence the repeatability of release torque values and the reliability of the automated release torque measurement. A good example is a Child Resistant closure with a top load sensitive liner. The closure system required 20+ lbf top load to consistently engage the outer shell with the inner cap when the closure was tightened to the high specification limit. Due to material or process changes the coefficient of friction between the opening of the bottle and the liner changed considerably from one batch to another, desensitizing the release torque detection to the point where the system was unable to differentiate between loose cap and properly torqued caps.

Another example is shown on the picture at the top of the next page. While the cap on the left side is rigid, impossible to collapse by manual gripping, the cap on the right side is from a different batch and it is quite flexible, easily distorted by minimal gripping pressure.

While it is possible to address these issues by developing customized release torque



validation methods and gripping pressure, top load optimization, it is a better practice to test the bottle, cap and liner for compatibility during the initial package evaluation process.

7. Release torque validation method

In the automatic detection of the thread break torque, there are two commonly used modes: fallback/sensitivity and rotation based release torque validation.

Fallback/sensitivity based release torque validation

This is the fastest and most cost effective way to measure the thread break torque of a closure. However, for the testing of CR closures, special attention must be made to the fine tuning of the sensitivity of the measurement system.

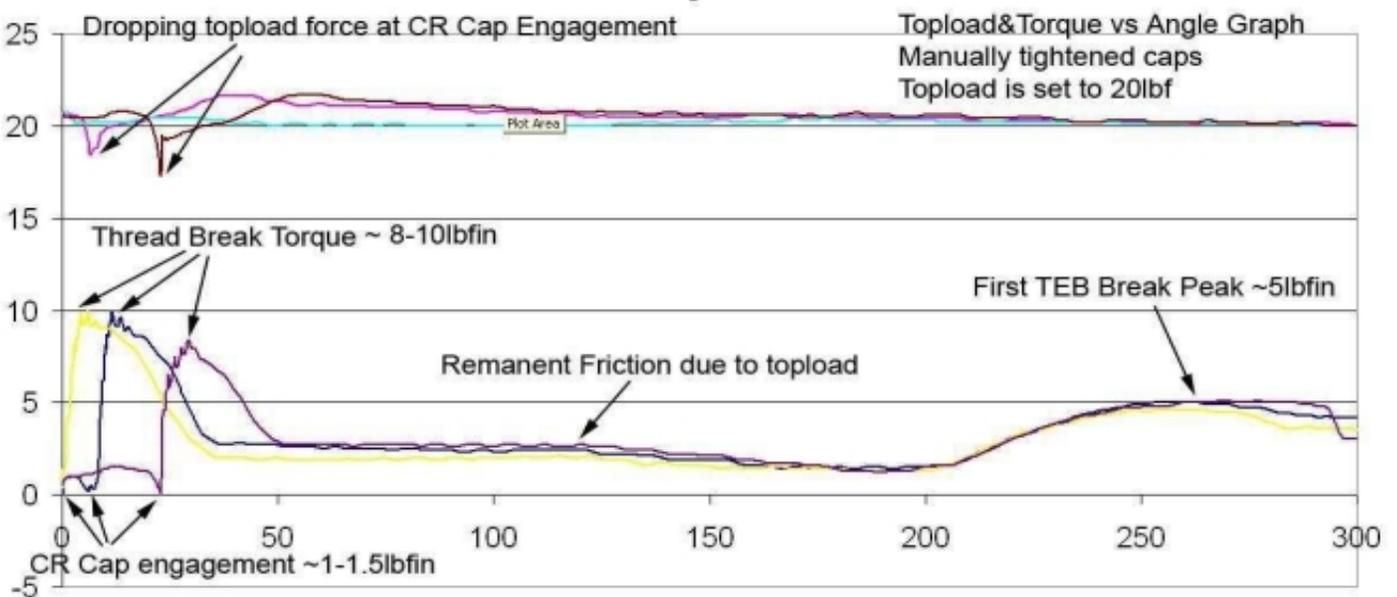
In order to differentiate between the torque peaks at the engagement of the outer shell with the inner cap, the ratcheting of the outer shell and the actual thread break, the operator must evaluate and adjust the fallback/sensitivity of the measurement.

Rotation based release torque validation

Assuming that appropriate top load is applied and the cap/bottle is not slipping during the tests, the angle of rotation can be also used to validate torque transients. For CR closures, the rotation limit must be set according to the worst case scenario of the shell engagement, therefore the required rotation may go as high as 60 degrees.

To understand the differences between the different methods please look at the graph at the bottom of the page.

If fallback based validation is used during the measurement and the fallback is set at <1.5lbf, the tester will validate the first peak in <25 degrees and display the peak torque immediately after the outer shell engaged with the inner cap. Obviously this is a false release torque readout, therefore the fallback value must be increased well above the 1.5lbf engagement peak in order to detect the real



thread break. Similarly, a rotation based validation configured to 10 degrees of rotation will not display the correct thread break torque consistently.

After the careful analysis of the potential torque transients, an operator can use either the fallback based (>1.5lbf·in) or the rotation based (>40 degrees) validations.

8. Application torque

Variations are often introduced by inline and chuck capping equipment as well. Changes in magnetic/electrical or pneumatic settings on chuck capper heads and the speed/pressure applied by the inline spindle/belt type capping stations can influence the application and removal torque. In a production environment the application torque is typically unknown but the capper chucks or spindle system is adjusted according to the release torque results.

Generally, the higher the application torque, the higher the thread break torque. This is true up to the strip torque when the threads break/deform irreversibly during the cap tightening cycle. If the manufacturer of the cap/bottle does not provide recommended torque specifications, it is best to start with an application torque setting that equals the cap diameter in mm divided by 2 (in lbf·in).

The release torque/applied torque quotient depends on the specific cap/bottle/liner design and the control of the previously listed variables. It is usually in the range of 0.6-0.9, higher for glass and lower for plastic bottles. It is not uncommon to see values out of this range, but extremely high quotients typically indicate the presence of torque errors introduced in the torque measurement.

IV. Conclusion

As demand is continuously placed on all products to have extended shelf life, improved

ergonomics, lower cost and improved appearance, application issues continue to emerge. In order to achieve maximum shelf life, the closure must create the best possible seal and the only way to ensure this is through continuous release torque monitoring at the production line.

As previously shown, a number of different variables can create a parasitic torque between the threads, changing the torque results or desensitizing the automated release torque measurement of threaded closures. To overcome these issues it is essential to understand all the variables affecting the torque between threaded closures, optimize change parts and the configuration of the torque testing equipment accordingly.