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INTRODUCTION

Regular inspections can be very beneficial to industrial processes. However, choosing the right inspection method and the right inspection percentage/frequency can be a challenging task. When choosing an inspection method, there are several things that must be considered, such as:

- the cost of inspection vs. the risk of not performing inspections,
- the value of the inspection, (i.e., will it provide the information needed to make effective decisions regarding run/repair/replace status of the equipment?),
- which types of inspections will yield the best results for the application and type of damage expected,
- when inspections should be performed, and
- what the acceptance criteria for the inspections should be.

Figure 1. Visual Inspection Using a Straight Edge

With new advancements in technology emerging rapidly, tools for customizing an inspection to address special requirements are becoming more available, feasible, and powerful. Each damage mechanism is unique and sometimes customized tools are necessary to achieve the desired result. One such tool and technique is utilizing Total Focusing Method/Full Matrix Capture (TFM/FMC) to inspect in-service flange faces for corrosion. Specifically addressed in this article is the detection and quantification of Hydrofluoric (HF) acid corrosion of flange faces.

Because the risk of bodily injury to personnel or the environment is so high in the case of a HF acid leak, it is necessary to regularly inspect all of the flanges in HF acid services (even trace HF acid services) to prevent leaks from happening. The most common method used to inspect flange faces is to schedule regular shutdowns of the pressure equipment followed by opening, cleaning, and visual inspection of each flange pair, often performed on a rotation. The corrosion damage is oftentimes not visible without the use of a straight edge ruler and a flashlight (see **Figure 1**) because of its slight, smooth tapering corrosion appearance in lieu of the rough, carbuncle looking corrosion seen with other damage mechanisms.

CURRENT FLANGE FACE CORROSION DETECTION METHODS

Visual inspection is an effective way to detect HF acid corrosion, but it is time consuming and costly (both in labor to open, clean, and inspect as well as to replace gaskets) and must be performed while the equipment is out of service. This results in lost revenue and high labor costs due to the extended shifts that are typical of shutdowns. Since HF acid corrosion is typically found only in a small percentage of flanges in HF acid service, it would seem that many flanges don't need to be opened at all because there is no active corrosion present. The problem is that without opening and inspecting, it is not known which flanges have active corrosion and which do not. A lot of time, money, and possibly injury could be avoided if there was a more effective and efficient method to identify or screen which flanges need to be opened and evaluated instead of opening and evaluating all of them during each outage.

Historically, attempts to detect and quantify HF acid corrosion while flanges are still in service have seen limited success. HF alky corrosion is unique in the way that it progresses because it is very subtle and can be quite difficult to detect. HF acid begins the corrosion process by smoothing out the striations on the raised face of the flange beginning at the inside diameter of the raised face, and then slowly working its way out toward the outside diameter of the raised face, creating a smooth taper that can progress under the sealing surface of the gasket. As the corrosion progresses, a deeper, more visible area of corrosion will occur which lags the smooth taper. This smooth, shallow corrosion morphology can cause a flange seal to fail while being nearly undetectable by conventional methods as there are few if any geometric features to reflect the UT signal.

Conventional zero-degree ultrasonic testing is typically not sensitive enough to detect the striations on the raised face of the flange and is therefore not an effective method for detecting and sizing the leading edge of HF acid corrosion. Conventional phased array testing (PAUT) has the capability to cover the entire raised face of the flange while at the same time using a simultaneous range of many different angles which may detect the deeper, late stage corrosion; however, the angle of approach is not ideal and therefore the probability of detection remains low. PAUT is not effective at detecting the early stage, smooth tapering which is where the real danger of a flange leaking lies. UT is currently the most effective way to reach the raised face portion of a flange without removing the flange from service and physically inspecting the area of concern visually, which highlights the need for a new approach to solve this problem.

TOTAL FOCUSING METHOD/FULL MATRIX CAPTURE

TFM/FMC is able to largely solve these traditional drawbacks with ultrasonic methods not being sensitive enough to detect the leading taper corrosion caused by HF acid. There are multiple techniques utilized to introduce sound waves into the raised face area (e.g., from the flange neck or in between the bolts), but the most sensitive angle of approach is straight through the flange itself from the outside radius of the flange. Without going too deep into the theory behind how TFM/FMC works, suffice it to say that conventional PAUT probes are used for the inspection, but in a new way. In comparison to PAUT, which uses timed pulses of individual elements to create constructive interference of overlapping beam fronts to create a desired focal angle, TFM/FMC fires individual elements in turn and collects all possible sound beam returns at all of the elements in the array. The transmit and receive process results in greater imaging resolution through individual grid point focusing algorithms based on all possible sound returns. All of this data is compiled into software and processed rapidly to render a true image of the geometry of what is being inspected (flange face).

The entire process requires a great deal of processing power and complex mathematics. It also requires a smooth, consistent surface across the entire footprint of the probe (flange outside diameter) as well as an accurate understanding of the dimensions of the test piece. Otherwise, the math becomes less precise and the sensitivity drops dramatically—leading to an inaccurate evaluation. The greatest sensitivity is achieved by maximizing both the number of elements in a probe as well as the footprint of the probe (i.e., more elements and a larger footprint equals higher sensitivity). With the right probe it is possible to resolve the striations on the raised face of the flange when sound is introduced from the outside diameter of the flange. In fact, in some rare cases, when the conditions are optimal, it is even possible to see the location of the gasket seating surface itself and identify gaskets that are off-center. Flanges with no corrosion are easily identified and eliminated from the outage work scope. Flanges with a loss of signal are identified as suspect and should be added to the outage work scope to be opened up for visual inspection.

The reason flanges with a loss of signal should be inspected further is because, as with any method, TFM/FMC has weaknesses as well as strengths and corrosion is not the only thing which can cause a loss of signal. In many cases corroded flanges have definite reflectors indicating damage. In other cases there is merely a loss of raised face signal which could indicate early stage corrosion but could also be caused by other factors.

Many factors can affect the quality of the data and create signal loss because a consistent contact with the probe face is lost:

Figure 2. Rough Flange Surface

Figure 3. Rounded (Not Flat) Surface

- a rough outer diameter flange surface (**Figure 2**),
- flange ODs with rounded edges (**Figure 3**), or
- coatings with rough or uneven thicknesses.

At first glance, the inability to definitively quantify a loss of signal on the raised face may seem like too big of a drawback for this method to have value. However, experience indicates a good record of properly identifying flanges with no damage. A pilot project was conducted by the author at three separate facilities with a work scope of around 1,000 flange faces. The results of that inspection showed that over 80% of all flanges inspected were shown to have no signal loss and could definitively be quantified as good with no need to open them. Of the remaining flanges that had signal loss, it was possible to measure how far into the raised face the signal loss was occurring and, since the dimensions of the flanges and gaskets are known, it could be determined that the number of flanges with signal loss near the gasket seating surface was in the single digits.

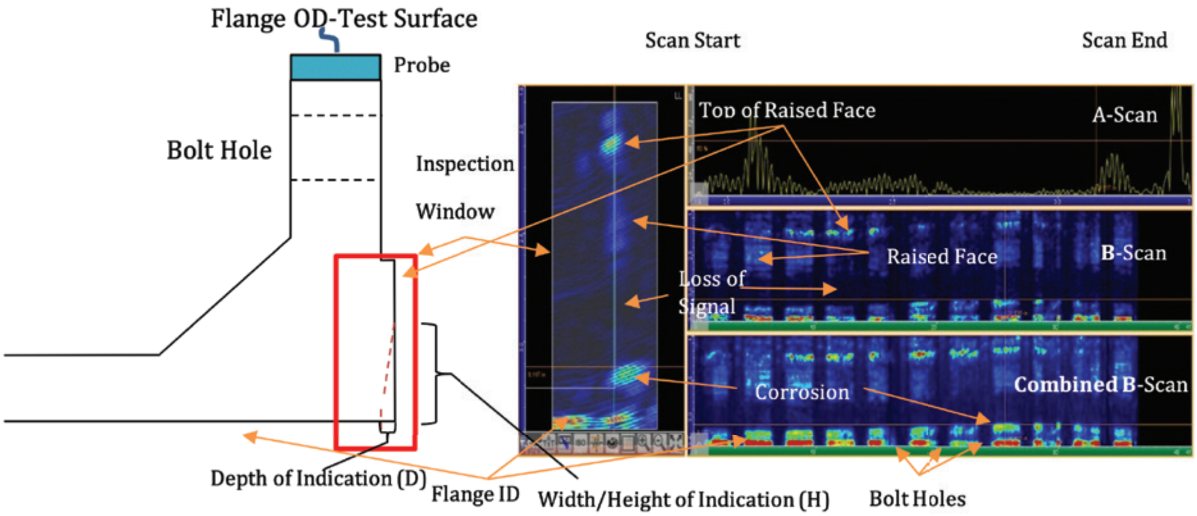

Figure 4. Flange Cross Section as Compared to the Inspection Screen

Also notable is the statistic that roughly 20% of the flanges could not be inspected because of either:

- rough surface conditions,
- the operating temperature of the flange being above the limitations of the probe (125°F / 52°C for this project).

Even so, the large percentage of corrosion-free flanges allowed for a significant reduction in time and cost of intrusive inspection methods.

During this project it was found that the addition of a wedge to the probe resulted in an unsatisfactory loss of test sensitivity, but this is likely a limitation of the software not adequately compensating for the wedge in its calculations. It is hoped that later software releases will include advancements in that regard which will enable the inspection of flanges at higher temperatures, further advancing the number of flanges which can be tested while they are still in operation. In addition to software algorithm optimizations, other potential improvements to this technology include improved probe design and scan plans, developing procedures for different flange sizes and pressure ratings, and high temperature considerations such as coupling, probe designs, filtering, and operator environment.

One last limitation of inspecting from the outside diameter of the flange is that there are blind spots where the bolts are located. For this 1,000 flange pilot project, that didn't prove to be a hindrance since HF acid corrosion, when it occurs, typically happens fairly uniformly around the entire circumference of the flange. This means that even though there are gaps, a representative sample is collected. When looking for localized corrosion damage mechanisms, an alternate technique is recommended.

ACCEPTANCE CRITERIA

As important as it is to be able to detect corrosion in flanges, it is also important to have well defined acceptance criteria. Unfortunately, TFM/FMC is still relatively new and almost all of the acceptance criteria is based around a visual inspection and assumes the flanges will be taken apart, cleaned, and re-torqued with a new gasket. With this approach, flanges that experienced active corrosion can sometimes be put back in service without repair provided the corrosion was shallow and smooth enough for a new gasket to seal.

Visual acceptance criteria doesn't translate well to ultrasonic testing for two main reasons:

- First, because taper corrosion doesn't create a true reflector to accurately measure the depth of the corrosion, it simply creates a loss of the raised face signal.
- Second, and more important, any active corrosion in the gasket seating area, no matter how shallow, constitutes a break in the integrity of the seal and is a risk for continued corrosion and eventual failure.

For this reason, it is recommended that any corrosion signals or loss of signals that would infringe upon the gasket seating surface, as defined by known flange and gasket specified dimensions, should be opened and evaluated visually for fitness before being returned to service.

CONCLUSION

The use of TFM/FMC can be an effective method to screen for potential problem flanges before a planned shut down and can be a very useful tool in planning which flanges require further evaluation. Having this knowledge in advance of the shutdown, when executed properly, can be a significant time, money and safety saving asset in terms of time, labor costs, and preparing materials that need to be ordered in advance instead of risking potential delays waiting on supplies or manpower for unexpected findings, as well as reducing the exposure that a craftsmen could come into contact with HF acid. ■

For more information on this subject or the author, please email us at inquiries@inspectioneering.com.

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Mark Schramm has more than 13 years of experience in Advanced NDE with an emphasis in electromagnetic and ultrasonic testing techniques in the oil and gas, petrochemical and utilities industries. His prior experience includes both technical roles as a principle and ASNT Level III responsible for the creation and oversight of QA/QC programs, as well as management roles, including the oversight of multiple inspection divisions and personnel. Mark holds ASNT level III certifications for ET, MT, PT, and UT, as well as API QUTE and QUPA certifications.

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