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ASSET INTEGRITY INTELLIGENCE

THE PIPING INTEGRITY MANAGEMENT CHALLENGE

LAZA KRSTIN, *Principal Consultant at ABB*
FERNANDO VICENTE, *Asset Integrity & Reliability Management Consultant at ABB*

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BY: LAZA KRSTIN, *Principal Consultant at ABB*
FERNANDO VICENTE, *Asset Integrity & Reliability Management Consultant at ABB*

INTRODUCTION

The mechanical integrity of process piping is critical to effectively manage process safety, environmental hazards, and business risks in the oil & gas, chemical, petrochemical and power industries. Operating companies seek to achieve cost-effective risk management and stay in compliance with state and federal regulations. So, how does one determine the optimum levels of inspection and maintenance for piping? The scale and complexity of the facility (thousands of feet of process piping in a typical refinery), significant costs related to inspection (insulation removal, provision of access,) variety of inspection techniques, and other factors present significant challenges in establishing a mechanical integrity strategy for piping.

These challenges are compounded by piping and process complexities, misunderstandings and underestimating the importance of piping. The reality is that many asset integrity management programs focus on pressure vessels, heat exchangers, and fired heaters without considering the piping systems as an important asset.

A process piping system failure or leakage could have a significant impact on the business due to interruptions in production, or a catastrophic effect if an explosion or fire occurs or a hazardous fluid is released.

This article highlights some of the myths, the challenges, and the good practices related to piping integrity management activities in order to help inspection and maintenance managers make the right decisions to develop cost-effective piping inspection plans without compromising the asset's reliability or performance.

PART 1 – THE CHALLENGE

The following statements from site management illustrate the nature of the "piping integrity management challenge":

Management: "We meet all our legal obligations"

Reality:

- The primary purpose of legislation is to protect workers, the public and the environment. Legislation does not cover the risks to the business from an incident.
- In most countries, legislation does not adequately cover piping (if at all).

Management: "Inspection is done by the official third party inspector; we get a certificate for continued operation from him"

Reality:

- How much piping is actually inspected?
- Does the inspector know the key hazards and vulnerabilities/deterioration mechanisms for piping, and understand the risks to the business?

Management: "We have a Risk-Based Inspection system"

Reality: In the authors' experience with clients around the world, Risk-Based Inspection (RBI) approaches often do not adequately identify the specific vulnerabilities of piping, or translate these into effective inspection plans.

Management: "Our inspection regime complies with API 570"

Reality: This mention of API 570 (American Petroleum Institute) usually means the site has a statistical approach based on Thickness Measurement Locations (TML), in the belief that corrosion is uniform, so its condition can be determined by thickness measurements at defined locations.

Let's look more closely at some typical myths.

Myth No.1: Pressure vessels are more important for plant safety than piping.

Reality: Contrary to what many plant personnel might think, piping is more likely to fail than a pressure vessel. Incident data from a variety of sources shows that approximately 40% of major plant losses are due to piping—the largest single cause. For example, the UK's Health and Safety Executive Report RR672 "Offshore Hydrocarbon Release 2001-2008" revealed that piping is the most common equipment type to experience releases, together with associated equipment such as flanges and valves.

The myth may arise from the situation in most countries where legislation focuses on pressure vessels rather than piping.

Myth No.2: The requirements for managing piping are specified in legislation. So compliance with regulations is sufficient to assure the integrity of piping.

Reality: Legislation in many countries does not cover piping, or only covers certain categories of piping. For example, the European Pressure Equipment Directive applies only to the design and construction of new piping and does not apply to piping equal to or less than NPS 1 (Nominal Pipe Size in inches). In some other regions, "larger bore" piping has more focus than "small bore" piping (based on stored energy considerations). This can lead to an impression that small-bore piping is not important. However, most mechanical engineers know that many leaks involve small-bore piping because of the range of loads to which it can be subjected, its inherent vulnerability to failure (corrosion, vibration/fatigue, mechanical damage, etc.), and the sheer amount of small-bore piping in a typical facility. It is worth noting that for most process plants (even large-scale refineries) the average pipe size (based overall length) is between NPS 2 to NPS 4. There are many thousands of feet of piping in a typical process plant, and much of it is not readily accessible for inspection.

Failures of small bore piping may be regarded as "minor incidents," but these can be early warnings of major weaknesses in management systems and plant practices. And each incident represents a potential disruption to production and places plant personnel under increased risk.

Myth No.3: Piping integrity is the responsibility of the "Inspection Team."

Reality: Piping integrity is everyone's responsibility. Many piping incidents are caused by operational excursions outside of the design limits or ineffective management of change, not simply "deterioration" or "ineffective maintenance." Implementing an effective operational integrity program (e.g., Integrity Operating Windows) helps focus the inspection plan (scheme of examination) on the key vulnerabilities and locations where potential problems may occur.

Myth No.4: Piping supports are not included in the inspection plan; they are not part of the pressure envelope.

Reality: The integrity of a piping system is not only dependent on the soundness of the "pressure envelope" but also on the pipe supports. A proper support system is required to take the weight of the pipe (including its contents, fittings, valves, etc.), to control movement of the piping, and protect sensitive equipment, through all its operational modes.

If supports are not properly designed, installed and maintained, excessive stress can be created in the piping system, and excessive loads can be transmitted to support structures and connected equipment. This may exhibit as pipe deformation, leaking joints, damage to connected equipment, and failure at welds and other "high stress" points. If the excessive stress coincides with deterioration mechanisms (e.g., internal and external corrosion and stress corrosion cracking), premature pipe failure may occur.

Experience across the process industries indicates that corrosion under pipe supports is a major area of concern for plant maintenance engineers and inspectors. API RP 574 (supplements the API 570 piping inspection code), provides guidance how to inspect piping supports.

Myth No.5: Flanges are not an integrity issue - the maintenance team go round and tighten flanged joints with manual torque wrenches.

Reality: Incident reports indicate that flanged joints are involved in a large proportion of piping failures. In addition, a number of operating companies cite a significant number of leaks from flanged joints during start-up following shutdowns and overhauls. A Bolted Flange Joint Assembly is a complex mechanical device; therefore, a Joint Integrity Program (JIP) should be an integral part of every piping integrity management plan including quality of materials selected, well-trained competent technicians and effective management controls. The American Society of Mechanical Engineer's ASME PCC-1 "Guidelines for Pressure Boundary Bolted Flange Joint Assembly" gives guidance for the training and qualification of bolted joint assembly personnel, and may be used to develop joint assembly procedures for a broad range of sizes and services as well.

The Business Perspective

As organizations are coming under increasing pressure to deliver more for less, the challenge for the inspection and maintenance managers is to develop a cost-effective piping inspection plan. From the asset management point of view, "cost-effective" usually represents the lowest combined business impact of costs, risks and performance, or the maximization of net value, over the piping life cycle (design, construction and installation, commissioning, operation, maintenance and decommissioning).

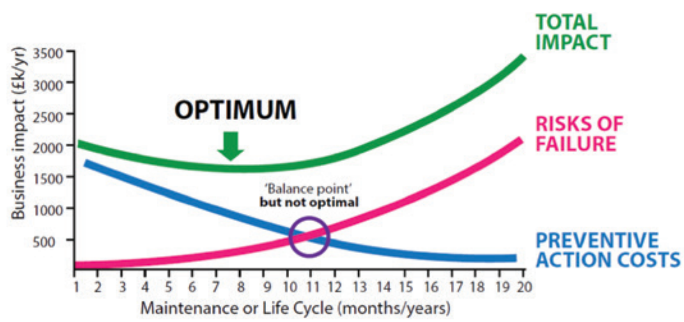

Figure 1. Optimum value achieved by optimizing total cost/risk/performance impact. Source "Asset Management – an anatomy" Institute of Asset Management.

The challenge for managers is to answer the following questions:

- Do you understand the complexities and vulnerabilities associated with your piping systems (corrosion, creep, stress corrosion cracking, fatigue, etc.) and how these will change over time?
- How much piping should you inspect and how often? All of it, or some of it? How do you decide what and how often to inspect?
- For corrosion under insulation, should you remove 100% of the piping insulation to fulfil the inspection plan?
- Can you demonstrate the business consequences on your piping systems when faced with management demands to reduce capital investment or maintenance budgets?
- Can you easily identify which inspection could be deferred when there is funding or cash flow constraints?
- Do you have the appropriate data and information to support your piping integrity management decision-making?

- Do you know if your people have the right competences and capabilities to manage your piping integrity management plan?

To answer these questions properly, organizations should develop and implement a sound piping integrity management plan.

PART 2 – IMPROVEMENT USING GOOD PRACTICES

In Part 1, we looked at the challenges faced by operating companies to cost-effectively manage the integrity of their piping systems. The scale and complexity of piping systems in a typical process plant presents technical, organizational, and practical challenges. Legislation in most countries does not provide much help:

- The primary purpose of legislation is to protect workers, the public, and the environment.
- It tends to ignore piping - this is interpreted to mean that piping is less of a concern (and requires less attention) than pressure vessels.
- Legislation does not address risks to the business in general—loss of inventory, loss of business, damage to reputation.

Consequently, operating companies should do more than the legislation requires—they should manage the wider business risks. The "better companies" do!

Applying industry practices is required throughout the entire life cycle of the piping. The life cycle will include the following stages:

1. Design, construction and installation (early failure stage)
2. Commissioning, operation and maintenance (in-service stage)
3. Decommissioning (wear-out stage)

Design, Construction and Installation

Piping systems need to be designed, manufactured, fabricated, installed, inspected, and tested in compliance with their specifications. However, experience shows that specific areas of weakness exist during this early stage. For example, it is not uncommon for the piping to be incorrectly installed (e.g., pipe is over-stressed during assembling process, wrong welding procedures, bad practices during the welding process, including fit-up and joint preparation, bad practices during support and insulation installation, etc.). This is generally due to lack of technical understanding of the installation requirements of equipment by the construction group, and of the consequences of such shortcomings—the potential to introduce or accelerate damage mechanisms.

Operation and Maintenance (useful life)

This stage of the life cycle is where operation and maintenance should be aligned in order to extend as much of the piping's useful life as possible.

Operation

In order to maintain the integrity and reliability of pressure equipment during operation of any process unit, a set of operating ranges and limits needs to be established for key process variables in order to achieve the desired results (i.e., product within specification, safe operation, reliability, etc.). These limits are generally called operating limits or operating envelopes. It is important that operating boundaries are established, and documented, including allowable excursions during start-up and shut-down of facilities. It is equally important that systems are in place to communicate when piping has been operated outside of the agreed limits, so that appropriate action can be taken.

A good practice for piping is the establishment, implementation, and maintenance of integrity operating windows (IOWs). IOWs are a specific subset of these key operating limits that focus on maintaining the integrity or reliability of process equipment. Typically, IOWs address issues that involve process variables that, when not adequately monitored or controlled, can impact the likelihood and rates of deterioration, which may result in a loss of containment. IOWs are the link between operation and inspection, and help to detect and communicate changes in the process that can threaten the integrity and reliability of pressure systems. Excursions outside of IOWs should be communicated to relevant personnel who can assess the implications for piping integrity. Many companies have set up automatic notification via dashboards or emails so that all the relevant information can be presented for assessment as quickly as possible. API RP 584 provides guidance how to implement IOWs.

Inspection and Maintenance

Inspection, maintenance, and repair of piping systems can be difficult due to piping configuration and geographical layout. The piping inspection plan could consume a large portion of the maintenance budget if it is not designed, planned, and implemented properly. Generally, process plants (depending of the plant size) can have between 1,000-5,000 piping systems. For that reason, inspection resources for piping should be appropriately focused using systematic, consistent techniques, such as RBI and/or criticality analysis, to identify which system to inspect and what inspection methods to employ. The inspection plan should identify what, where, when, and how piping should be inspected.

API 570 "Piping Inspection Code" and API 580/581 "Risk Based Inspection" are two of the most widely recognized standards to help specify the in-service inspection and condition-monitoring program for piping systems. Other sources of good practice include guidance from Regulatory Bodies (e.g., UK's Health and Safety Executive), and industry associations (e.g., NACE; EEMUA).

Good Practices for Piping Inspection Plan Development

We can all learn from others. Why not use lessons learned and adapt them to our own situation? For piping inspection, the main areas of good practice are described below.

1. Focus on "critical piping"

The concept of asset criticality is a particular element of risk

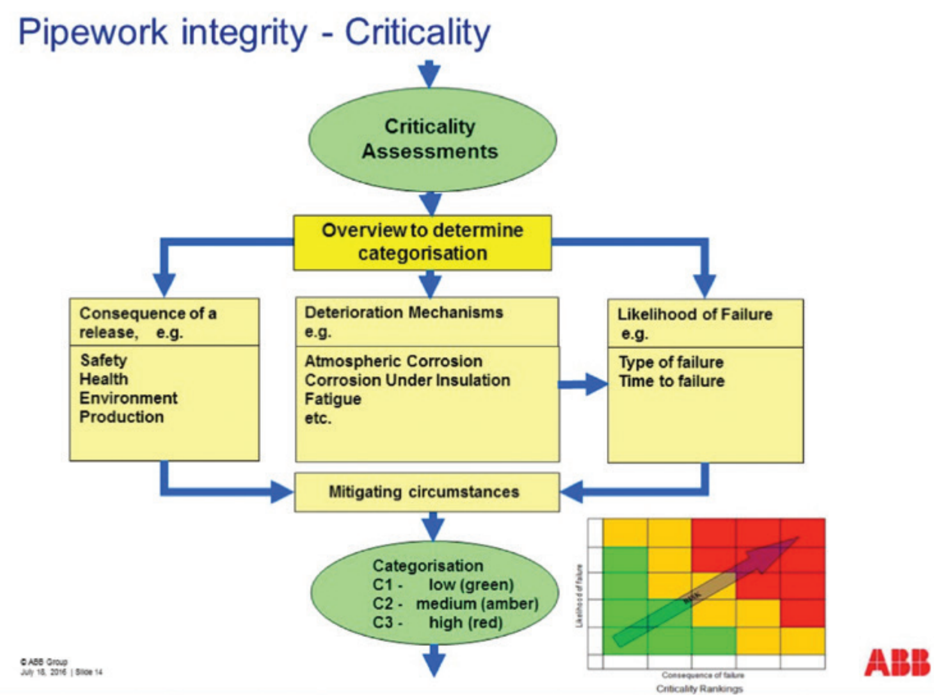

Figure 2. ABB Criticality analysis process.

management—this is the recognition that assets have differing importance (value), or represent different vulnerabilities, to the organization. Criticality will usually include, but is not limited to, the risks of asset failure or non-performance. The piping criticality ranking is used to help prioritize inspection work, define maintenance strategy, and to identify the most critical piping systems (see **Figure 2**). Some criticality criteria examples are explained below:

Legislation: Legislation in some countries may require piping to be classified in particular ways. As explained previously in this paper, the scope of such legislation often does not provide a sufficiently comprehensive approach to managing piping risk throughout its lifecycle. The result is that in addition to complying with relevant legislation, companies need to consider additional criteria.

Industry/Company Standards: Industry standards may specify additional requirements for classification (e.g., API 570). API 581 provides a comprehensive quantified risk-based approach. However, these may or may not be too detailed for the majority of piping in a particular facility. Many companies have found that a qualitative approach using word models is more effective in classifying the piping by considering the broad consequence of piping failure. The consequence assessment considers explosion, fire, toxicity, environmental impact, and other potential effects associated with a failure. These should also include the business impacts (such as loss of production, loss of reputation, and cost of repair/remediation). The word models used as the basis for this approach should be

Table 1. An example of a word model for assessing business consequence.

	Business Consequence
1	Negligible loss of production
2	Minimal throughput loss> 1 week Major throughput loss <1 day
3	Plant shutdown for days Major reduction 1 to 5 days Unit down for < 1 week
4	Significant production loss Unit down > 1 week
5	Major loss of productivity Weeks off line Site Shutdown

Table 2. An example of a word model for assessing likelihood of the failure scenario.

	Likelihood of Failure
1	No history of occurrence or remote probability. Unreasonable to expect failure to occur and not aware of failures on similar plants elsewhere.
2	No real history of problems or slight probability. No failure since commissioning but failure possible or has occurred on similar plants elsewhere.
3	Some history or probability of occurrence. 1 failure since commissioning or significant issue on similar plants elsewhere e.g. reasonable doubt exists that the equipment will last for the proposed run length.
4	High probability of occurrence. One failure in the last five years, e.g. high corrosion rate, would lead to failure if unattended.
5	High probability of occurrence. More than 1 failure in past 5 years, or at least one failure in the last run or evidence that a problem will occur in this run.

developed to suit the particular circumstances of the company (e.g., process technology, range of hazards, local environment, etc.). Such a pragmatic approach is easily understood by all the parties involved in piping integrity, it can be readily applied to the majority of plant piping, and the impact of planned plant modifications can be readily assessed.

Failure Mode, Effect and Criticality Analysis (FMECA): FMECA is a systematic procedure for the analysis of a system to identify the potential failure modes, their probability of failure, and their effects on system performance. It can be a qualitative or quantitative analysis. Mil-Std-1629, IEC 60812 and NORSOK Z-008 are examples of standards that provide guidelines for FMECA analysis.

2. Understand the ways in which the piping can fail

An effective risk-based assessment can only be carried out with a sound knowledge of the ways in which in the piping can fail. This includes an understanding of its vulnerabilities, such as:

- Damage mechanisms (e.g., internal corrosion, external corrosion)
- Design limitations (e.g., number of cycles to avoid fatigue failure, locations of high stress)
- Local effects (e.g., injection points, dead legs)
- Vulnerable components (e.g., bellows expansion joints, pipe supports)
- Current condition of the piping.

Such a deterioration assessment should be carried out by a team with the necessary range of expertise—design, materials/corrosion, operations, inspection, maintenance, and process safety. As many companies do not have such resources internally, external specialists should be brought in, as appropriate. From these vulnerabilities, the team should determine how the piping is likely to fail (e.g., catastrophic sudden failure, initial small leak that might gradually develop into a structural failure). There can often be more than one "credible failure scenario."

3. Determine the likelihood of piping failure

The assessment team should determine the likelihood of occurrence for each of the failure scenarios. As with the consequence assessment, a series of word models can be very effective for this assessment. This is particularly the case in the early stages of the development of a piping strategy, when perhaps knowledge of the piping systems, their condition, and inspection/maintenance/operational history may be limited. **Figure 2** summarizes a typical broad classification process, leading to a "High/Medium/Low" categorization of piping.

4. Carefully determine the scope and frequency of inspection

The extent and frequency of inspection of piping depend on the forms of deterioration that can affect the piping and consequence of a piping failure. API 571 provides a substantial list and details of damage mechanisms affecting oil and gas facilities.

A widely used method for determining piping inspection intervals is based on the "half of the remaining life" concept. However, this type of fixed-time approach may not be most appropriate for all piping. This is particularly the case where the fluid composition changes over time, such as in offshore installations, or refineries which are likely to experience varying crude oil composition, or waste treatment facilities that are required to handle a wide range of chemicals. This approach may also not be appropriate when deterioration mechanisms are localized. In such cases, a simple statistical approach is unlikely to give adequate focus to specific vulnerabilities.

It is not enough to base future inspection plans only on prior reported history of equipment condition. A fundamental understanding of the process/operating conditions and resulting deterioration and failure mechanisms is required in order to establish and maintain an inspection program, along with an IOW program.

RBI is commonly regarded as good practice and the most appropriate methodology to define the scope and the inspection interval of piping systems, especially for those piping systems with high and medium criticality. RBI is a condition with consequence-based approach and provides a rational basis for focusing inspection efforts. The risk analysis that supports the RBI program may be qualitative, quantitative, or a combination of the two (semi-quantitative). In each case, the risk analysis approach should be used to systematically screen for risk, identify areas of potential concern, and develop a prioritized list for more in-depth inspection or analysis.

Quantitative RBI Analysis: Quantitative analysis by definition performs analyses using numbers for inputs and is an analysis based on probabilistic models (i.e. Weibull reliability models). In risk analysis this can occur in either the probability or consequence analysis or both. Quantitative risk analysis is distinguished from the qualitative approach by the depth and integration of detailed analysis. The challenge with this analysis is not only the validity of the software algorithms, but also the information required, the quality of this information, the experience of the resource involved in the analysis and the time frame. Quantitative studies require more data and provide more metrics. As they require more data, they are less prone to inconsistencies due to opinions.

Qualitative RBI Analysis: Data inputs based on descriptive input using engineering opinion and experience as the basis for the analysis of probability of failure and consequence of failure can be used as an effective basis of RBI assessment. Results are typically categorized as high, medium, and low (as described above). The value of a qualitative analysis is that it enables completion of a risk analysis in the absence of detailed quantitative data. The benefits of the qualitative approach are achieved by an expert team carrying out the assessments in a flexible, yet auditable, way. The team can look at a wide variety of scenarios, which increases the understanding of plant teams. Experience across the industry suggests that qualitative RBI is an effective and efficient approach for the majority of equipment. The challenge of the qualitative approach is the

Figure 3. ABB RBI Qualitative process.

reliance on opinion. Since RBI is based on relative risk it is an added challenge to assure consistency from team to team and iteration to iteration. Qualitative approaches also provide a snapshot in time and are more static. If consistency is lost, the analysis is not valid.

Semi-quantitative RBI Analysis: A semi-quantitative analysis is an analysis that includes aspects of both qualitative and quantitative analyses.

The choice of approach depends on many factors such as: objective of the analysis, number of facilities and equipment items to assess, available resources, quality of information, time frame, and complexity of facility. API 580/581 and ASME PCC-3 provide guidance on these approaches.

If RBI is not being used (i.e., low criticality piping system), the interval between piping inspections should be established and maintained by using the corrosion rate, the remaining life assessment, the piping classification, and the piping inspector's/plant engineer's judgement.

5. Specify the inspection

How does one determine the type of NDT to use, select appropriate locations to inspect, and decide how much piping to inspect? The type of NDT technique to be applied will depend on the type of damage mechanism likely to occur and if it is internal or external. ASME PCC-3 table C-1 provides a useful reference to help to identify the inspection method. The challenge for piping inspection is that many of these examination methods depend upon proper access and surface preparation and thus will not be appropriate for all situations. The single most frequent damage mechanism leading to pipe replacement is corrosion. A key to the effective monitoring of piping corrosion is identifying and establishing Condition Monitoring Locations (CML). CMLs are designated areas in the piping system where measurements are periodically taken. Ultrasonic (UT) thickness measurements are obtained within examination points on the pipe. "A good practice is to develop a piping circuit layout and associated CMLs identified on inspection isometric to aid the inspector in performing inspection tasks." Previous papers in Inspectioneering have discussed corrosion loops, corrosion circuits and CMLs. Corrosion rates depend on a range of factors, including the presence of certain contaminants and areas of increased velocity. Elbows, reducers, mixing tees, control valves, and orifices are examples of vulnerable areas where accelerated corrosion can occur because of increased velocity. Normally these are areas where an inspector would locate additional CMLs in a piping circuit. However, areas of no or low flow, such as dead-legs, can cause accelerated corrosion and may need additional CMLs. Corrosion Under Insulation (CUI) is generally recognized as the greatest single threat to piping integrity. The costs of inspection and possible remediation can be significant. The industry has given much attention to developing inspection approaches that can avoid removing extensive amounts of insulation. Some good practices for CUI management on piping include:

- Define vulnerable areas (such as areas of damaged insulation, dead legs, penetration points, etc.). Remove the insulation for localized inspection.

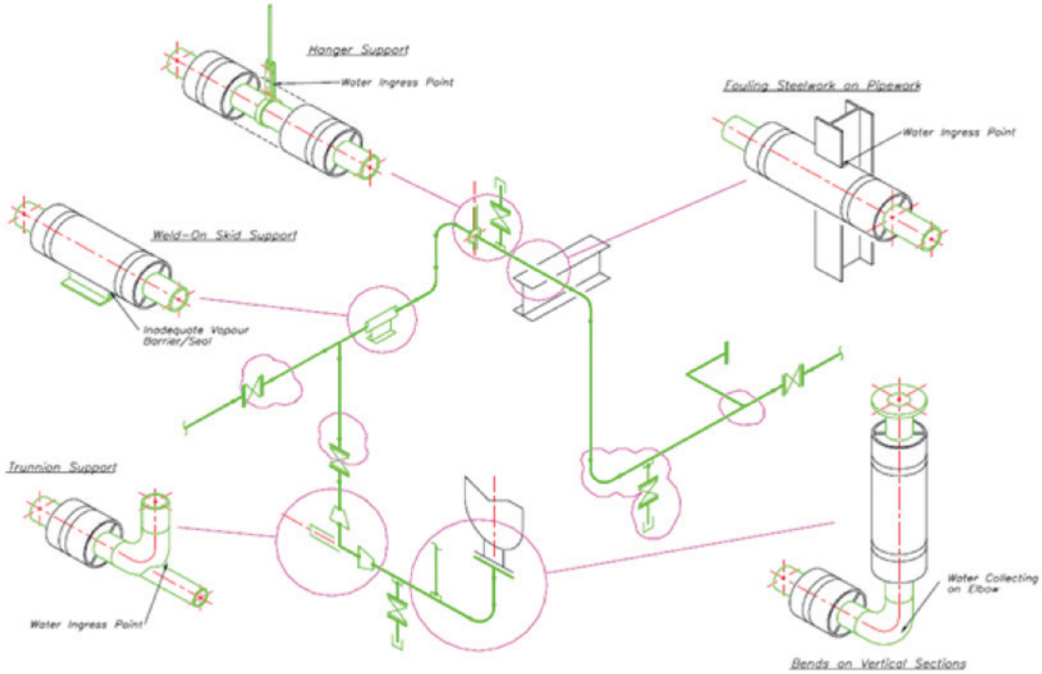

Figure 4. Vulnerable areas for CUI in piping.

- Define percentage of insulation to be removed and technique to be applied (e.g., using API 581 "Inspection effectiveness table).
- Review with process engineers the necessity of insulation. For example if the piping's insulation is required for personnel protection, the insulation could be replaced by a metallic 'cage'.
- After inspection, reapply the protective coating (where required). Then reapply the insulation. All coatings and insulation should be applied following good practice procedures to provide maximum protection and minimize moisture ingress.

API 583, API 574, API 581, NACE RP 0198 and EFC55 provide guidelines and good practices for managing CUI in piping and equipment.

6. Assess the inspection results

The piping inspection plan should be designed with the following philosophy: plan to inspect, inspect to detect, detect to assess, and correct or repair to keep the piping operating in a safe and reliable way. The piping's inspection tasks normally generate a large quantity of data that if not collected, recorded and analyzed systematically, critical information about the piping integrity condition could be overlooked.

Who assesses the piping integrity?

Piping integrity should be assessed by a "Competent Person" (CP) who has sufficient training, knowledge and experience to carry out the required assessment. The level of competence required will depend on the complexity of the situation. Different organizational arrangements and practices exist in different countries. For example in the USA, API 570 authorized inspectors create the inspection strategies, assess the deterioration rate, the remaining life and time to next inspection. In the UK, the CP assesses the condition, the change in condition compared to previous inspections, and authorizes the piping to remain in service until the next inspection. The CP will also review the appropriateness of the "Scheme of Examination" and suggest suitable changes, and may carry out or request further inspections and assessments.

It is important that the CP who carries out the inspection and integrity assessment is independent from the production organization. This objective can be met by various organizational structures. Typically, it means the inspection team reports to a senior manager who reports to the plant manager, and not directly to operations or maintenance functions.

What is the basis of acceptance criteria?

Deterioration that could affect the piping's pressure containment or load carrying capability (i.e., wall loss in excess of the corrosion allowance) should be evaluated for continued service in accordance with a recognized standard (e.g., API 579-1/ASME FFS-1). This assessment should be carried out by an inspector or engineer with the relevant competence. Generally, an initial assessment (e.g., API 579 level-1 assessment can be made by an authorized piping inspector. More detailed assessment (e.g., API 579 level- 2 and 3) should made by an engineer. More detailed assessments usually require additional analysis (e.g., piping flexibility or vibration analysis). API 570 and 574 give the guidelines and the information to be followed on pressure design, minimum required and structural minimum thicknesses, including formulas, example problems and default tables of suggested minimums.

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API 579 Fitness-For-Service standard is considered an industry best practice for the assessment of flaws and other deterioration/damage within piping systems and pressure equipment. This standard has detailed chapters for a wide range of flaws/damage mechanisms, including general metal loss, local metal loss, pitting corrosion, blisters and laminations, weld misalignment and shell distortions, crack-like flaws, and fire damage. Note: the above standards assume that the piping has been designed and constructed in accordance with ASME standards.

BS 7910 is another standard applied to assess flaws in structures. BS 7910 is strongly orientated towards the assessment of defects in and around welds, and its most detailed procedures are for the assessment of fatigue and creep crack growth and the proximity to fracture. Corrosion in pipes is covered at a guidance level. Note: this standard is based on fundamental structural integrity irrespective of any specific design code.

7. Report and monitor trends

A record of thickness data obtained during periodic inspections provides a means of determining corrosion or erosion rates and expected equipment life. This task can be greatly assisted by an appropriate computer system whereby the data can be shown on graphs and diagrams or presented as tabulated information. In addition to wall thickness measurements, means of corrosion monitoring (such as corrosion coupons or corrosion probes) may be useful in supplementing the wall thickness measurements and in establishing the timing of these thickness measurements. Permanent records should be maintained throughout the service life of each piping system. As a part of these records, progressive inspection and maintenance records should be regularly updated to include new information pertinent to the operation, inspection, and maintenance history of the piping system.

Many operating companies communicate the integrity status of their piping (and other equipment) in a regular Asset Integrity Report. This may be an annual report for senior management and a monthly report for operational management. The report should summarize the inspection status (e.g., key findings, overdue and postponed inspections, etc.). A range of performance indicators should be included in the asset integrity report. Such indicators may provide warning of potential non-compliance with the integrity performance requirements (e.g., stream chloride content, piping inspection schedule compliance, IOW excursions, MOCs); or, they may provide data about incidents and failures of piping. Indicators which show patterns or trends are particularly useful (e.g., leakage frequency, corrosion rate, and remaining life).

Reality check! As engineers, we like to measure, analyze, and trend data and then review and improve our equipment and processes. So, measuring wall thickness to determine corrosion rates seems a natural focus of our attention. However, we should recognize the dangers of over-relying on this approach:

- Not all deterioration exhibits itself by metal loss (for example, stress corrosion cracking, embrittlement, fatigue).
- Corrosion itself is very rarely general or uniform.
- Wall thickness measurements must contend with the practicalities of the NDT technique which lead to limitations in the accuracy and reliability of the measurements.

All these factors combine to reduce the confidence in any single inspection approach, and complicate the reporting of the integrity status of our plants.

8. Use the integrity outcomes to revise the inspection approach

Investigation of asset-related failures, incidents and nonconformities should be performed for all piping. The investigation should determine not only the direct cause of the failure or "near miss", but also the underlying and contributory factors. This will enable a thorough analysis of the implications of the incident for your systems, procedures and practices, as well as the equipment. Only then can the outcome of the investigation be effectively used to update the piping inspection approach, and corrective actions taken to address all the causes of identified non-conformances in order to prevent, or reduce the likelihood, of future similar incidents.

A structured review of the integrity process, including key performance indicators, should be regularly carried out to monitor integrity performance so that positive trends can be reinforced and unfavorable trends can be corrected.

Learning

1. Real world application of RBI

Setting up an RBI program takes competent resources and time. In the authors' experience, many process plants do not have the information required to start an effective RBI approach. In many cases, plant teams do not even have a basic understanding of the condition of their piping. This is the unsurprising result of the factors described in Part 1 of this article, which led to a lack of attention to piping over many years.

Many RBI programs seem to start slowly - there is a lot of work to be done to identify the different piping systems, to gather design and operational data (fluid composition, operating pressures and temperatures, etc.), and to carry out the criticality assessment. Time passes, the piping continues to deteriorate, and no improvement in its integrity is achieved.

To move forward, a first step can be helpful—an initial visual inspection of the entire plant piping. This visual inspection should aim to provide an overview of the piping condition. To aid this initial inspection and reporting of the findings, the plant piping should be sub-divided into manageable "systems". The results from this can be used to identify if there is any "high criticality" piping that is in poor condition and in need of immediate attention; it provides the basic data to begin prioritizing the integrity program. This initial visual inspection is best done by an experienced team who understands the main deterioration mechanisms of the piping. They should also have a broad understanding of the consequences of failure of the piping so as to be able to flag up any significant concerns immediately. An initial "first pass" criticality assessment as described above can be very useful to inform the scope of this visual inspection.

This "first pass" inspection helps to structure the subsequent RBI program and helps to determine realistic timescales and resource levels.

2. Aging plant

The outcomes of integrity programs are largely a range of optimized inspection and maintenance tasks across planned shutdowns (turnarounds or outages), and opportunities for carrying out such tasks with the plant on-line (to minimize downtime). As described above, risk-based approaches can be used to focus resources on "critical" areas. However, the longer-term business requirements should also be incorporated into integrity programs. That is to say, long-term deterioration trends may require significant investment in remediation or replacement to ensure the piping is suitable for long-term use, irrespective of its process safety criticality. Asset life extension should therefore also be factored into asset integrity programs.

3. Fabric Maintenance

Across the process industry as a whole, the most significant threats to piping and its supports are from the external environment, rather than from the process fluids or process conditions. External corrosion requires a long-term concerted strategy. This applies especially to CUI, as mentioned earlier in this paper. The strategy should encompass wider issues, so-called "fabric maintenance" (care and attention to the "fabric of the installation", in other words, its general condition). This includes avoidance of damage to piping insulation and paintwork, and its timely repair if damage does occur. Such an approach often requires a "culture change," a proactive drive to raise the awareness of all plant and contractor personnel of their role in avoiding damage to piping, and adjusting working practices to support this objective.

In addition, many companies have learned that relying on routine inspection alone is not a cost-effective or reliable way of preserving the integrity of their piping systems. They have come to realize that carrying out "more inspection" is not adding any value - they have done enough inspection to know that the condition of their piping needs to be improved.

Where the condition of the piping (and its insulation and protective coatings) has deteriorated to a large extent, a "remediation-driven" approach tends to be more effective than an "inspection-driven" approach. This is because a planned remediation program on a geographic area basis is more practical, more cost-effective, and safer than a "find and fix" piece-meal approach which is the usual result of a traditional inspection program. A remediation program is a long-term commitment, requiring resources, careful planning and execution. Management commitment is vital right from the beginning.

CONCLUSION

This article highlights some of the good practices that can be applied to help organizations develop an optimal piping integrity strategy.

It is clear that failure (loss of containment) of piping systems is more likely to occur than the failure of pressure vessels, and the consequences are significantly greater, when measured across the process industry as a whole. Therefore, assuring mechanical integrity and reliability of piping has an important part to play in managing process safety, environmental hazards, and business risks. Doing this in a cost-effective way is not an easy task. It is important to understand that people, processes, and systems should be brought together within a clear framework (Asset Integrity Management System) in order to achieve the organization's business goals.

All piping should receive a certain level of attention throughout its life cycle. Using the approaches described in this article can help readers develop a proactive and risk-based piping integrity strategy. ■

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

CONTRIBUTING AUTHORS

LAZA KRSTIN

Mr. Krstin holds a Mechanical Engineering degree from Imperial College in London. He is a Fellow of the UK's Institution of Mechanical Engineers and was awarded with their Donald Julius Groen prize in 2010. He has specialised in piping design, inspection and maintenance for over 30 years, in roles that included Piping Function Head for Imperial Chemical Industries (ICI), and past Chairman of EEMUA's Piping Systems Committee. He is currently a Principal Consultant in ABB, helping companies around the world to develop their Asset Integrity Management Systems.

FERNANDO VICENTE

Fernando Vicente graduated from the Universidad Tecnologica Nacional Facultad Regional General Pacheco (Buenos Aires, Argentina) with a B.Sc. in Mechanical Engineering and holds a post graduate degree in Reliability Engineering from the Universidad Austral (Buenos Aires, Argentina). He holds API 510, 570 and 580 certifications and has been a Consulting Engineer in Asset Integrity and Reliability with ABB Ltd for 11 years. Mr. Vicente's project experience includes: Weibull analysis for asset and plant optimization, reliability culture implementation for big organizations, reliability assessments, fitness for service assessments, advanced finite element analysis, failure analysis, RCM and RBI implementation for the Oil & Gas industries.