HEALTH CARE FOR AGING EQUIPMENT

Collaboration between ASME and API extends Fitness-For-Service principles to industries beyond refining. By David A. Osage and Umberto D'Urso

In the early 1980s, a continuous digester, the device that turns wood chips into pulp under pressure in a pulp mill, failed catastrophically because of caustic stress corrosion cracking in the upper, impregnation zone of the structure.

Fast forward 20 years later to a different digester, where inspectors were finding numerous cracks during each annual shutdown. All the cracks were deemed in need of repair because no one knew the critical size of the flaws, or if the equipment was acceptable for continued service. The extensive repairs often prolonged the shutdown, at considerable cost of lost production, but one of the members of the inspection team remembered the cost and trauma of the failure in the 1980s.

To determine which flaws truly needed repair, they decided to seek expert-level help in applying the new API/ASME Fitness-For-Service (FFS) standard to determine critical crack sizes prior to inspection. That assessment showed that critical crack sizes were, in fact, quite large. This allowed the establishment of threshold crack sizes for guidance during the inspection and repair efforts, helping the team to better manage the repair scope to fit within the shutdown window, thus avoiding costly production losses.

The methodologies used by this company have been based on the American Petroleum Institute's Recommended Practice 579 Fitness-For-Service, which was originally created for the refining and petrochemical industry. To date, well over 10,000 fitness-for-service assessments have been performed without incident worldwide in the refining and petrochemical industry according to these rules.

The rules have been adapted for wider application and can now be used to establish critical crack size for nondestructive evaluation in an entirely different industry. In the pulp mill, sufficient safety could be maintained while operating equipment with flaws, as long as the assessment was performed in accordance with standardized rules to determine acceptability.

As illustrated in the case study above, the assessments can be performed before an inspection is conducted. This not only guides the selection of the sensitivity of the inspection or nondestructive evaluation method and the scope of the inspection, but also avoids having to perform an assessment on a rush basis if flaws are found

An ASME/API Joint Committee was created to broaden the application of the technology and methodologies of API 579 to pressure equipment applications outside the petroleum industry. The resulting standard, API 579-1/ASME FFS-1 2007 Fitness-for-Service, is based on key elements of the API standard as modified by the needs and experiences of ASME members. Industries that rely upon the inspection of pressure-containing equipment—fossil fuel, nuclear, and others—are starting to take notice.

+ what is fitness-for-service?

Construction codes and standards for pressurized equipment provide rules for the design, fabrication, inspection, and testing of new pressure vessels, piping systems, and storage tanks. These codes typically do not provide assessment procedures to evaluate degradation due to in-service environmentally induced damage, or flaws from original fabrication that may be found during subsequent inspections.

The publication of the API 579 in January 2000 provided rules for the damage mechanisms commonly encountered in the refining and petrochemical industry along with consensus methods for reliable assessment of the structural integrity of equipment containing this damage or flaw. It was written to be used in conjunction with the refining industry's existing codes for pressure vessels, piping, and aboveground storage tanks. Soon after, the as-

David A. Osage is president and a principal engineer of the Equity Engineering Group in Shaker Heights, Ohio, and chair of the API/ASME Joint Committee on Fitness for Service.

Umberto D'Urso is an ASME project engineering administrator, and secretary to the Joint Committee.

sessment procedures started to be used to evaluate flaws encountered in other industries.

An FFS assessment is a quantitative engineering evaluation that is performed to demonstrate the structural integrity of an in-service component containing a flaw or damage; it can also be used to evaluate equipment that does not meet current design standards or operates under more severe conditions than originally expected. The results from a fitness-for-service assessment may be used to make decisions to run, rerate, repair, or replace pressurized equipment that contains flaws identified during an inspection. An assessment can establish that the equipment can continue to be operated safely. The steps in an FFS assessment in accordance with API 579-1/ASME FFS-1 are shown at the bottom of this page.

API 579, produced by the Fitness-For-Service Task Group of API's Committee on Refinery Equipment, has become the de facto international FFS standard for pressure-containing equipment in the refining and petrochemical industries. Based on advances in technology and user feedback, an addendum was issued in 2001.

+ a landmark decision

While API was developing fitness-for-service methodology for the refining and petrochemical industry, ASME had also begun to develop standards for in-service fixed equipment, and formed the Post Construction Committee in 1995. But with two fitness-for-service standards development activities in place, there was bound to be an overlap. In fact, many people were serving on both committees.

Realizing the duplication of effort and potential conflict in parallel standards, ASME and API agreed to form a joint committee to develop a single FFS standard for equipment operated in a wide range of process, manufacturing, and power generation industries. The goal was to produce a globally accepted, technical methodology for evaluating and repairing flaws in boilers and pressurized equipment, and to promote the widespread adoption of these practices by regulatory bodies. The first meeting of this joint committee took place in February 2002.

The API/ASME Joint Committee, which now has 39 members in 11 interest categories, includes the original members of the API Committee that developed Recommended Practice 579, complemented by a similar number of ASME members representing similar areas of expertise in other industries, such as chemicals, power generation, and pulp and paper. In addition to owner representatives, it also includes substantial international participation and subject matter experts from universities and consulting firms.

The agreement to produce a joint standard on fitness-for-service technology is a landmark decision that will focus resources in the United States to develop a single doc-

STEPS IN A FITNESS-FOR-SERVICE ASSESSMENT AS IDENTIFIED IN API 579-1/ASME FFS-1

1 **Flaw and Damage Mechanism Identification:** The first step in a Fitness-For-Service assessment is to identify the flaw type and cause of damage. The original design and fabrication practices, the material of construction, and the service history and environmental conditions can be used to ascertain the likely cause of the damage. Once the flaw type is identified, the appropriate section of the standard can be selected for the assessment.

2 **Applicability and Limitations of the FFS Assessment Procedures:** The applicability and limitations of the assessment procedure are described in each section, and a decision on whether to proceed with an assessment can be made.

3 **Data Requirements:** The data required for an FFS assessment depend on the flaw type or damage mechanism being evaluated. Data requirements may include: original equipment design data; information pertaining to maintenance and operational history; expected future service; and data specific to the FFS assessment, such as flaw size, state of stress in the component at the location of the flaw, and material properties. Data requirements common to all FFS assessment procedures are covered in one section of the standard. Data requirements specific to a damage mechanism or flaw type are covered in the section containing the corresponding assessment procedures.

4 **Assessment Techniques and Acceptance Criteria:** Assessment techniques and acceptance criteria are provided in each section. If multiple damage mechanisms are present, more than one section may have to be used for the evaluation.

5 **Remaining Life Evaluation:** An estimate of the remaining life or limiting flaw size should be made for the purpose of establishing an inspection interval. The remaining life is established using the FFS assessment procedures with an estimate of future damage. The remaining life can be used in conjunction with an inspection code to establish an inspection interval.

6 **Remediation:** Remediation methods are provided in each section based on the damage mechanism or flaw type. In some cases, remediation techniques may be used to control future damage associated with flaw growth and/or material degradation.

7 **In-Service Monitoring:** Methods for in-service monitoring are provided in each section based on the damage mechanism or flaw type. In-service monitoring may be used for those cases where a remaining life and inspection interval cannot adequately be established because of the complexities associated with the service environment.

8 **Documentation:** Documentation should include a record of all information and decisions made in each of the previous steps to qualify the component for continued operation. Documentation requirements common to all FFS assessment procedures are covered in one section; requirements specific to a damage mechanism or flaw type are covered in the section containing the corresponding assessment procedures.

ument that can be used in all industries. This agreement will help avoid jurisdictional conflicts and promote uniform acceptance of FFS technology. It will also provide an opportunity for the pooling of resources of API, ASME, and two other interested organizations, the Pressure Vessel Research Council and the Materials Properties Council, to develop new FFS technology and methodology.

+ reactive FFS

FFS assessments provide significant economic and safety benefits to owner-operators. They ensure the safety of plant personnel and the public while older equipment continues to operate, provide major savings in unnecessary repairs, reduce shutdown time for repairs, and help extend equipment life of aging infrastructure to increase long-term viability. The procedures can be used for evaluating and rerating pressure vessels designed and constructed to the ASME Boiler and Pressure Vessel Code, piping systems designed and constructed to the ASME B31.3 Piping Code, and aboveground storage tanks designed and constructed to API 650 and API 620.

FFS offers a more sophisticated assessment of metallurgical conditions and stress analysis than the more conservative calculations typically found in construction codes. An FFS analysis can more precisely identify whether in-service equipment is fit for its intended service, or whether fabrication flaws or deterioration during operations threaten its integrity.

The traditional use of FFS has been mostly to react to problems: Damage or flaws are found during a shutdown inspection; a leak or fire occurs and damaged equipment needs to be operated until a replacement can be found; equipment is out of current design-code tolerances.

For example, an FFS assessment was performed for a hydrogen processing vessel in a refinery. An inspection had discovered cracks in the ring groove radius region of a ring joint flange. The results of the assessment based on finite element stress analysis and fracture mechanics concepts indicated that the driving force for crack propagation was high for a localized region near the ring groove radius, but the driving force decreased significantly for deeper cracks. The assessment also showed that the highest stresses occurred during the bolt-up operation. The chemistry, grain size, microstructure, and hardness of the material indicated that the material had good resistance to hydrogen-assisted crack growth during downtime and to crack advance during service.

Based on the results of the FFS assessment, a recommendation was made to start up the unit without repairing flange cracks. Because it avoided an unnecessary repair and an extension of the shutdown duration, the refinery realized a substantial cost savings by making the assessment.

FFS also can be used to evaluate fabrication flaws. A new pressure vessel in a petrochemical plant was dropped during field erection, resulting in shell distortion in excess of ASME Code limits. A fitness-for-service assessment was performed to evaluate the integrity of the distorted shell under internal pressure loading. A finite element model of the distorted geometry was constructed based on field measurements provided by the owner. The field data points were read directly into the solid modeling program. The assessment included an evaluation of the collapse strength under internal pressure loading as well as a fatigue assessment.

The results of the FFS assessment indicated that the vessel shell was acceptable for future operation at the original design conditions. The use of FFS technology eliminated the need for expensive repairs to the new vessel as well as significant costs associated with unplanned operational interruption.

+ proactive techniques

The principles of API 579-1/ASME FFS-1 offer proactive opportunities for assessments to evaluate changes in design codes, brittle fracture screening, remaining life assessments of high-temperature equipment, NDE flaw-sizing guidelines, and shutdown planning. The proactive use of FFS technology has proven to be invaluable to owner-operators.

For example, a black liquor evaporator in a pulp mill had been designed to operate under vacuum conditions, and the vessel owner was interested in increasing the vacuum pressure to achieve production increases. Although the vessel was not designed and built to the ASME Code (not required for design conditions), code calculations were initially used to determine if the vessel could be operated at the new target pressure.

Calculations showed that the current shell thickness in some areas was not sufficient even for current operating conditions. In reality, the vessel did not lend itself to allowable pressure calculations using the ASME Code equations because of its complex geometry, but that was what was available.

Facing the need to actually lower operating pressure, methods from API 579-1/ASME FFS-1 were used to help determine the true allowable operating pressure for this vessel. Finite element models were built to accommodate the complex geometry and to utilize stiffening effects of components not considered in basic code-type calculations. Results of this evaluation showed that the vessel was actually fit for continued service at its current operating conditions, but would require some external stiffening to accommodate the higher pressure. The FFS evaluation also showed precisely where such stiffening was required.

Having initially believed that it might have to actually reduce production because of the underdesigned vessel, the owner could move forward with its planned production increases with minor modifications to the vessel.

+ FFS in the fossil utility industry

High operating temperatures, near or in the creep range, can degrade metallurgical properties and produce damage not seen at lower temperatures. The construction codes for components in this temperature range only provide the basic requirement for the design, but actual component behavior is strongly dependent on the history of operating conditions and service environment.

The API 579-1/ASME FFS-1 standard was recently used to conduct a remaining life evaluation of a seam-welded, hot reheat piping system of a fossil fuel power station. This system had been in service for about 28 years and, from records, appeared to have been base-loaded for most of its service life.

The past 10 years saw a change in operation to a load-following unit, where a greater number of thermal cycles were encountered. The piping system was evaluated dimensionally, weld and base metal chemistry was verified, and long seams and girth welds were evaluated using TOFD, or Time of Flight Diffraction examination technique. This system had been inspected previously using this inspection technique, and prior results were available for comparison. The defects indicated with this inspection matched prior results and no evidence of change was noted. Girth welds showed limited signs of micro voids, which indicated minimal creep damage.

> **“Industries that are saddled with aging infrastructure—including numerous tanks and vessels—would benefit greatly.”**

The data from inspection was evaluated using API 579-1/ASME FFS-1 to assist in determining severity and remaining life.

The FFS assessment indicated that less than 5 percent of fatigue life and somewhere between 20 percent and 70 percent of high-temperature creep life may have been used, depending on assumptions in the operating history and the condition of the material. Based on the API 579-1/ASME FFS-1 recommendations, the pipe is acceptable for now, but may be at risk with additional operating hours and cycles.

+ regulatory acceptance

The release of a joint ASME/API standard could represent a significant change in jurisdiction in the refining industry that could translate to other industries. If a code or standard references API 579-1/ASME FFS-1 and the code is adopted into a law, then owner-operators would be required to use the new FFS standard. Currently, the API Code for in-service inspection of pressure vessels and piping systems, API 510 and API 570, provides a reference to API 579-1/ASME FFS-1 for performance of FFS assessments.

Doug Sherman, a consultant with Corrosion Probe Inc. in Austin Texas, specializes in the pulp and paper industry. He believes that gradual acceptance of the standard by insurance carriers and jurisdictions outside of the petroleum industry is occurring faster than he initially thought it would.

“There still seems to be a somewhat widely held belief that these methods have been developed for, and proven by, the petroleum industry only, and it will take some more time to prove them in other industries,” he said.

Regulatory acceptance of API 579-1/ASME FFS-1 is critical to the greater application of the fitness-for-service standard in both the United States and internationally. At present, FFS assessments are most likely to be used in the refining and petrochemical industries, as these industries have been leaders in developing this technology. However, as illustrated in the case studies above, other industries are starting to take a strong interest in the FFS approach.

Louis Hayden, ASME’s incoming vice president of Pressure Technology Codes and Standards, believes that API 579-1/ASME FFS-1 will prove to be a big step forward.

“It helps to have ASME behind this standard to give it more than just the petroleum industry image,” he said. “The methodologies will work in many industries, just like integrity management methods will work in many industries.”

Industries with aging infrastructure—including numerous tanks, vessels, and other such equipment—would benefit greatly. However, knowledge of fitness-for-service assessment methods is not widespread outside the petroleum industry. The approach is new to many owner-operators. And, even when it is used, the most common FFS applications are still evaluations of equipment deterioration to make reactive run/repair/replace decisions rather than one of the more dramatic, proactive uses addressed in API 579-1/ASME FFS-1, such as evaluating remaining life.

“The ASME involvement does give it more universal clout,” Sherman said. “An understanding of equipment damage mechanisms is an essential step in adopting FFS methodology, and WRC 488 [i.e., *Damage Mechanisms Affecting Fixed Equipment in the Pulp and Paper Industry*, a bulletin from the Welding Research Council] has been a great help in the pulp and paper industry in this regard. The proper identification of the flaw type and associated damage mechanism is a key step in a fitness-for-service assessment. I think national and international governing bodies could eventually accept the new standard—especially with it coming from both API and ASME. Without the ASME involvement, I think it would take much longer.” ■

Kathy Powers, marketing and communications director for the Equity Engineering Group, contributed to this article.