THIELSCH ENGINEERING, INC.
195 Frances Avenue, Cranston, RI 02910
Tel: (401)467-6454 Fax: (401)467-2398

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EQUIPMENT INTEGRITY is Essential to Risk Management

BY HELMUT THIELSCH AND FLORENCE CONE

A company's risk management philosophy invariably affects the profitability of its operations and may, if neglected, even affect its ability to survive. There are many instances where avoidable catastrophic equipment failures have resulted in plant closures, injury to personnel, loss of life and environmental damage. In addition, excessive deterioration of equipment resulting in leaks or malfunctions can lead to breakdowns that, if they occur frequently, increase operating costs to levels where company plants or units are no longer financially viable, forcing their closure. In many instances, these plant closures could have been avoided if the equipment were safely operated and maintained. Ever-increasing safety concerns — driven by Occupational Safety and Health Administration (OSHA) regulations, other regulatory requirements and tightening environmental compliance laws — further emphasize the need for a sound risk management philosophy regarding preventive equipment maintenance.

EQUIPMENT RISK MANAGEMENT

Risk managers and insurance underwriters recognize that plant equipment is subject to wear and tear that ultimately leads to breakdowns or deterioration of performance. As a result, plant managers periodically schedule equipment outages designed to identify and eliminate potentially catastrophic or leak-type failures. If needed, maintenance personnel can then perform repairs to ensure safe and efficient operations.

There are four types of equipment maintenance and assessment strategies that inspectors and maintenance personnel can use. The first is known as a condition assessment, and involves assessing equipment or components to determine their structural integrity, performance reliability and functional capacity during a scheduled outage. For all equipment, the condition assessment covers design and operating considerations; fabrication and materials of construction; examination approaches, including nondestructive and/or destructive testing; and repair and replacement considerations and cost-benefit analyses.

The second strategy is reactive maintenance, which involves making repairs when a machine or component fails. Since reactive maintenance only occurs when there is an equipment malfunction, it involves little or no routine maintenance. The third strategy is predictive maintenance, designed to monitor the performance of equipment and machinery in their actual operating environments. This maintenance approach involves the use of examination techniques such as infrared thermography, strain gage testing and vibration monitoring and analysis.

The fourth maintenance and assessment strategy is preventive maintenance, which includes programs designed to repair or rebuild equipment and machinery prior to failure. Typically, this approach uses nondestructive testing techniques to identify when repair is necessary, thereby helping to reduce overall maintenance costs by minimizing emergencies. Preventive maintenance is often established only after an initial equipment failure, and although it can be costly, this expense is minor compared to the costs of repair and business interruptions.

Regardless of the maintenance program in place, equipment failures are often unpredictable. Equipment failures result from any one or a combination of many different conditions. Typically, these conditions involve either mechanical or thermal fatigue, corrosion or erosion. Operational problems such as excessive pressure, overloading, overheating and fires can also cause or contribute to failures. Malfunctions can stem from inadequate designs, improper use of materials or deficiencies in the manufacture, assembly, welding or heat treatment of equipment.

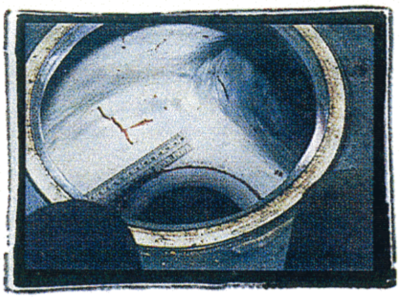
These issues apply to all types of plant production equipment, most of which consists of carbon and alloy steels. However, various other materials such as high-carbon alloys, nonferrous and lined materials or nonmetallic materials such as glass, plastics, fiberglass, concrete and combinations of these are also applicable and can be subject to costly leak-type or catastrophic failures. Therefore, it is extremely important that plant personnel understand the characteristics and performance of materials in various types of equipment.

EQUIPMENT LOSS CONTROL

Inspectors and maintenance personnel must be aware of several factors applicable to equipment and inspection maintenance operations. These include: 1) meaningful inspections by nondestructive inspection techniques; 2) realistic scheduling of inspection periods (depending on the type of equipment involved); 3) accurate interpretation of inspection results; and 4) repair or replacement considerations.

The first of these steps is meaningful and proper inspections. When nondestructive testing reveals defects or deterioration, maintenance personnel must evaluate the equipment to determine if the problem is due to an original manufacturing defect. In this context, the word "defect" means any flaw condition recognized by any of the applicable engineering and construction codes as acceptable or rejectable, and any other conditions existing in a component or material. Inspectors must then determine if the defect could lead to an equipment failure, or if the defect is "benign" and will thus not result in breakdown. This determination may then differentiate the defect from a condition of progressive deterioration.

An example of an original manufacturing defect involves the casting shrinkage observed during the inspection of the valve body shown in Figure 1. This valve body was located in the feedwater system in a fossil-fuel powered generating station. The manufacturer stated that this valve needed to be replaced. However, another inspection of this valve, performed more than six years later, confirmed the absence of crack progression. This valve has now been in service for about 15 years without any evidence of crack progression or deterioration.



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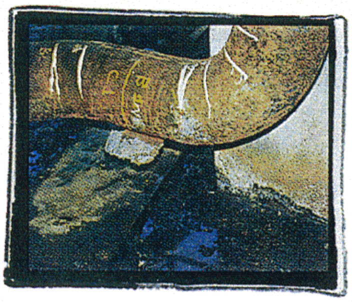

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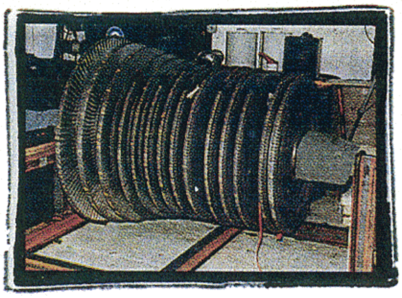

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The second inspection strategy involves realistic inspection periods. Inspection intervals should be scheduled to allow realistic appraisals of equipment deterioration rates. For a plant intended never to experience a failure — which is, of course, totally unrealistic — maintenance personnel should probably perform inspections on a daily basis. More, realistic inspection intervals may require annual inspections for certain types of equipment, or three-year or five-year inspection intervals for other types. When operating conditions change, or become more severe, the time intervals may have to be reduced.

The pipe shown in Figure 2 was a six-inch diameter carbon steel line that ruptured at a refinery. Apparently, during service the water and sulfur in the process fluid combined to form sulfuric acid. This acid collected in a low spot when the line was out of service and produced general corrosion. Eventually, the pipe burst. The process fluid then ignited, resulting in an extensive fire.

Accurate interpretation of inspection results is the third maintenance strategy. When nondestructive examinations are performed, defects may be detected that were not noticed when the plant was originally constructed. However, inspectors often have a tendency to interpret "newly discovered" defects as representing conditions that did not exist in the original structure. The inspector is then led to assume that the equipment is seriously deteriorating through cracking or corrosion, and is thus approaching a point of failure.

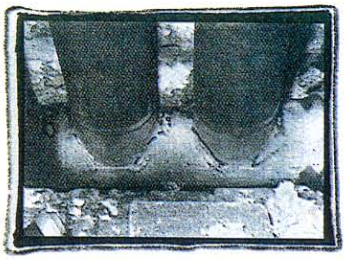
The turbine rotor shown in Figure 3 was inspected nondestructively using a technique known as a "wet florescent magnetic particle examination." This inspection revealed linear "indications" on almost every blade. The engineering firm that performed this inspection interpreted these indications as progressive cracking. Thus, the rotor was shipped to a rebuilding shop for repairs. A subsequent metallurgic evaluation of several representative blades confirmed that these indications involved forging laps, which are an original manufacturing condition. These laps were inconsequential and did not in any way impair the serviceability of the turbine rotor. Unfortunately, by the time the inconsequential condition of the superficial forging laps was discovered, each of the blades had been damaged during the removal process. This highlights the fact that considerable experience in the characteristics and behavior of materials is necessary to properly interpret equipment integrity to determine if such a superficial defect existed in the original equipment material, casting or weld, or developed during service.

The fourth inspection strategy includes repair and replacement considerations. To determine if repair or replacement is needed, inspectors must perform a thorough equipment analysis to ascertain the causes of the failure. This may require a nondestructive examination, a visual examination or an examination of the microstructure of the metal by replication or sample removal. If inspectors misunderstand the actual causes of failure, incorrect conclusions regarding repairs may be drawn.

When repeated inspections demonstrate that the failure rate of a given piece of equipment is relatively constant, maintenance personnel may decide to delay the repair or replacement to a more convenient time. It is generally far more costly to replace equipment at an inopportune time than to wait until a replacement component is manufactured.

Benign defects pose unique problems. In many instances, inspections reveal benign defects that had not propagated during the prior operation of the equipment and would be unexpected to propagate during its remaining life. When these defects are repaired, the repairs produced stresses significantly greater than the stress condition arising from the original defect. With the higher welding stresses produced by the unnecessary repair, in time a failure would then develop in equipment that would not have occurred if the repair had not been undertaken.

The header installed in a methanol reformer shown in Figure 4 is a case in point. The header had casting shrinkage defects in the crotch of several tees. These defects were then repaired. Shortly thereafter, more severe cracking developed at the locations of the repair welds. Tees in which the original casting shrinkage cracks were not removed by grinding and repair welding never failed.



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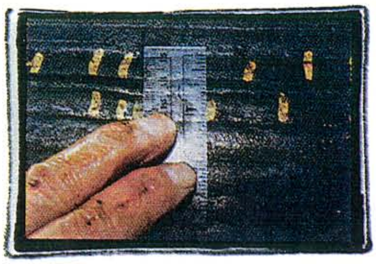

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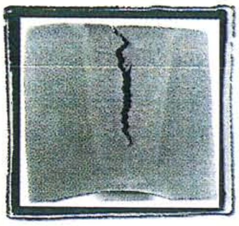

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REPLACEMENT CONSIDERATIONS

The progressive deterioration of equipment also creates unique replacement considerations. When inspectors recognize that a defect is progressive, or when leaks have occurred, they must determine whether to repair or replace the component. At this point, plant owners, manufacturers, underwriters, inspectors and consultants often have different philosophies. More often than not, the original equipment manufacturer will recommend replacing the equipment unless it is still under warranty.

Although underwriters generally prefer repairs, a plant owner with business interruption insurance may insist on replacement, whereas an identical plant without business interruption coverage will opt for repair. In either case, the repair-welded equipment can be as suitable for continued service as the new replacement equipment if it is the same type, design and construction.

The header shown in Figure 5 was located in a boiler at a paper mill. The header had an outside diameter of 30 inches and a wall thickness of 2 5/16th inches. After approximately 20 years of service, the header developed a leak at the location of a longitudinal seam weld, shown in Figure 5. The crack was about 20 inches long. Inspectors decided to replace the header. This, however, resulted in a prolonged business interruption.

The superheater outlet header in a steam power plant, shown in Figure 6, was furnished with an outside diameter of 18 inches and a wall thickness of 3.35 inches. It had developed an 84 inch long crack in the seam weld. A plug sample removed from the header confirmed that the cracking was due to operating stresses caused by a failed clamp in conjunction with excessive machining of the underside of the seam weld during the original fabrication. This plug sample, which illustrates the cracking and the reduction in wall thickness resulting from the machining, is shown in Figure 7. Maintenance personnel successfully repaired the header by removing the crack, followed by careful low stress welding (Figure 8). Since the repair, the header has been operating without problems for six years.

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WHEN TO REPAIR?

The decision to repair or replace a component requires the consideration of many factors. Inspectors must accurately recognize the causes and effects of progressive deterioration or failure of the equipment, and their effects on repair decisions. The vessel shown in Figure 9 had a multilayered construction used in the processing of urea. An operating upset condition allowed the product to flow down over the outer shell underneath the insulation. In a short period of time, stress corrosion cracking developed through several plate layers. The original equipment manufacturer required the vessel to be shipped back to the shop and repaired. However, the vessel was successfully repaired in the field, resulting in a multimillion dollar savings to the plant owner and its insurer.

Similar comments apply to the acetic acid vessel operating at a pressure of 10,000 pounds per square inch shown in Figure 10. The stainless steel liner on this vessel had cracked after about one year of service, causing the acetic acid to come into contact with and corrode the two-inch thick carbon steel shell below eight inches of compressively wrapped layer bands and general layers of wrapper. After extensive training of field personnel, the vessel was successfully repair-welded in the field at a high preheat temperature with a special low stress welding procedure, as shown in Figure 11. The vessel was subsequently returned to service.

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In cases where production schedules are so tight that equipment cannot be brought off-line, a temporary repair can sometimes be performed. The deaerator shown in Figure 12 is a case in point. This deaerator, located at a paper mill, developed a leak. Based on the location of cracking, i.e., in the base material of the shell of the deaerator, the inspectors considered it likely that the crack was related to a doubler plate on the inside diameter surface of the deaerator. They then concluded that the cracking would not progress further.

A "box" carefully designed to ensure vessel integrity was subsequently welded over the leak while the deaerator remained in service. The deaerator remained in use for three years until it could be brought off-line and repaired at the location of the through-wall crack in the shell. As suspected, the cracking was located in the toe of a doubler plate weld (Figure 13).

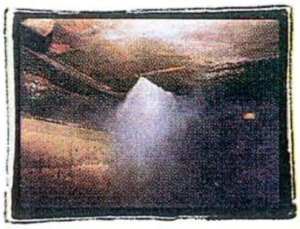
When permanent repairs are not practical, but the replacement involves a long lead time, engineers may be able to perform a temporary repair and reduce the costs associated with business interruptions. The Yankee dryer, which is used in the production of tissue paper, developed through-wall cracking in the shell as a result of corrosion (Figure 14). Since the Yankee dryer is constructed of gray cast iron, permanent repairs by welding were not feasible. Maintenance personnel extensively evaluated the dryer and determined that a temporary repair by mechanical stitching would be the best option. The dryer was repaired (Figure 15) and returned to service at near normal operating conditions. As a note of interest, plant managers originally intended to operate the dryer for six months until a replacement could be obtained. Due to difficulties encountered in casting the shell of the replacement dryer, the repaired dryer was in service for close to 18 months.

The crank shaft shown in Figure 16 failed as a result of fatigue. Due to its size, inspectors determined that it would take one year to furnish a replacement. As a result, they performed a repair by welding. The plant operated the compressor for several years until the replacement crank shaft was obtained. The shaft is now available as a spare.

Another option is to repair a broken part when it is convenient. This approach may require operating the equipment with progressive defects, cracks and/or leaks provided, of course, that safety considerations are not compromised. In some instances, however, replacement is the only option. For example, the stainless steel vessels used in the processing of a PVC slurry resulted in extensive fissuring and cracking in the welds as a result of chloride stress corrosion cracking. Due to the thick consistency of the process fluid, the vessel never leaked. Instead, the cracking and fissuring became progressively worse until the bottom head-to-shell weld failed catastrophically.

No matter what types of equipment are used, intimate knowledge of engineering materials is essential to the cost-effective and safe operation of equipment. The lack of a realistic understanding of engineering materials, as well as the origins and causes of boiler and machinery failures, needlessly costs industry and its insurers billions of dollars each year. These unnecessary costs result from poor decisions such as repairs of equipment for defects that would not result in service failures; repair of equipment subject to "distortion" (changes in the shape of metal), impact indentations or other cosmetic conditions of damage or change that do not affect equipment safety, integrity or performance; and equipment that could be readily repaired by welding, mechanical stitching or other methods. Since equipment replacement generally takes a much longer time than permanent repairs, costly business interruption losses will often result.

Other ill-considered repair decisions include repair methods or procedures that cause recurrence of failures; repairs conducted by inexperienced or unqualified personnel, which lead to premature failure; and the performance of repairs resulting in an unscheduled prolonged outage that causes major business interruption losses when the repair could have been delayed until an efficiently planned outage was scheduled. Finally, repairs made by maintenance personnel who do not understand the cause of failure can lead to significant problems, particularly if a better repair method could have been utilized to solve the problem.



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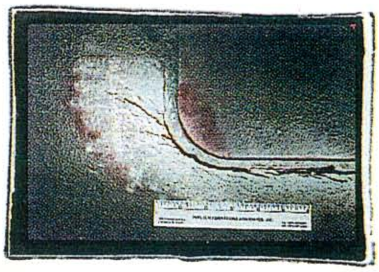

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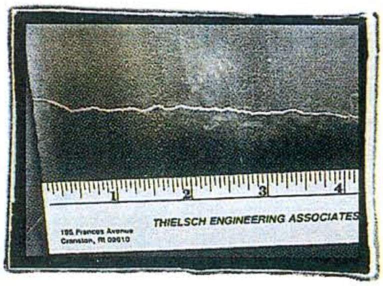

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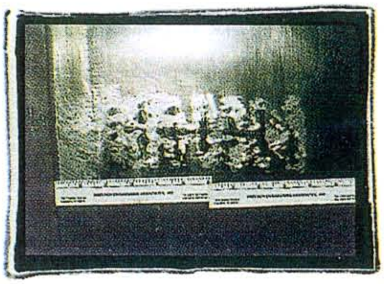

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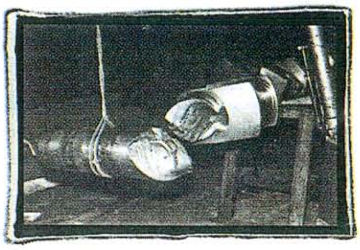

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SAFETY FIRST

In all aspects of equipment maintenance and repair, plant managers should never compromise when it comes to safety. If the continued operation of equipment may lead to a catastrophic failure, or a leak condition that affects the health of personnel or causes environmental damage, the equipment must not be operated under any circumstances.

Essential safety considerations include ensuring that the equipment is in compliance with all applicable design and construction codes, including the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME), the various sections of the Code for Pressure Piping also issued by the ASME, the standards held by the American Petroleum Institute, as well as applicable standards issued by other professional organizations such as the American Welding Society.

When repairs of pressure vessels and equipment are involved, plant managers should follow the requirements of the National Board Inspection Code issued by the National Board of Boiler and Pressure Vessel Inspectors. Meaningful quality assurance by qualified and experienced personnel, as applied to the manufacture, fabrication, erection and inspection of equipment is also essential. These activities must also comply with the requirements of OSHA 29 CFR 1910.119 covering Process Safety Management. Finally, all decisions related to equipment must be in compliance with environmental regulations as covered by the Environmental Protection Agency's 40 CFR 68, as well as other federal, state and local ordinances. RM