Nondestructive Testing Saves Time and Money

Survey of various forms of this technique in various applications in ammonia plants and related facilities shows it has been profitable to use.

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Nondestructive testing has grown strongly in recent years as a useful means of effecting measurable savings in ammonia plants as well as a wide range of related facilities.

Areas in which it is being profitably applied include ammonia reformers (catalyst tubes, risers, headers, pigtails), surface condensers, ammonia storage vessels, waste heat boilers, piping, centrifugal compressor trains (air, refrigeration, syn gas), and induced draft fans.

There are characteristic problems in each area, and different (sometimes unique) nondestructive testing tools for solving each problem. These tools include closed-circuit television inspection, tube deviation analysis, fluorescent penetrant testing, ultrasonic thickness testing, mechanical measurements, eddy current testing, ultrasonic shear wave testing, mechanical signature analysis, and dynamic balancing.

A basic discussion of several nondestructive testing applications provides the main text of this article. The emphasis in each case is on results; there are no "mights" or "maybes." Each technique has been field-tested and proved invaluable to ammonia plant operators.

The effectiveness of on-stream analysis has been accepted in the process industries. Portable vibration measuring instruments have become a familiar and useful tool to many plant operators. Automatic machinery protection monitors are often considered essential instrumentation in modern plants. Periodic predictive maintenance analysis programs are a common addition to plant maintenance or engineering functions.

Newer installations may include continuous vibration monitoring equipment for critical machinery. Computerized plants may also record levels automatically upon sensing a preset amplitude or a rate of increase. Systems having monitors may not be analyzed until failure is imminent.

In spite of the widespread application of predictive maintenance techniques, catastrophic equipment failures continue to occur. Some failures, particularly during start-up or shutdown, may be considered sudden and unavoidable due to grossly inadequate design or serious misoperation. However, experience indicates such instances are less common than has been suspected. More often, damaging failures are sustained because equipment condition simply was not adequately investigated.

Any large process machine is likely to be awesomely complex. A typical multi-stage turbomachine, for example, is composed of several dynamic subsystems, such as the shaft, wheels, bearings, casing, base, foundation, and ground. The system is influenced by internally generated mechanical forces, by process forces, and by various external forces. The subsystems are coupled, and, therefore, the input or response of any one will generally affect the entire machine.

Coupling effects are probably the most complicating factor from the viewpoint of a designer or on-stream analyst. Subtle changes in one area, for example bearing parameters, may adversely affect the operation of another major component, such as the rotor. Abnormal process forces may excite a sub-harmonic rotor motion which, in turn, excites structural resonant frequencies and thus causes an entire compressor building to quiver ominously. Or, piping vibrations induced by one machine may force the rotor in an adjacent machine to vibrate violently in one of its natural modes.

Mechanical signature analysis

All these problems generate secondary effects, chiefly noise and vibration. These secondary effects establish a mechanical "signature" for each particular system.

Analyzing machinery signatures is effective in evaluating machinery condition. It can predict two things: mechanical condition (satisfactory or unsatisfactory); and source of major exciting forces (unbalance, misalignment, bearing defects, seal failure, etc.).

Signature analysis may best be illustrated by a few brief case histories:

A simple unbalance in a 101-J centrifugal air compressor train is a good example. The low-speed gear rotor coupling of this particular train had been removed for balancing during a turnaround. After start-up, the gear case was rough (0.9 mil) at the normal operating speed of 6,800 rev./min. Vibration displacement signatures were almost purely sinusoidal at a frequency equal to 1 x rev./min. Higher frequency signals, detected with an accelerometer, indicated normal disturbance at the tooth meshing frequency, but no excessive amplitude levels. During start-up, the displacement amplitude vs. rev./min. graph was parabolic, indicating rotor unbalance.

Actually, the coupling on the gear rotor had been *unbalanced* in the balancing machine during turnaround. Mechanical signatures indicated this condition on start-up. Signature analysis helped provide a quantitative analysis which aided management in deciding to continue operation until a more favorable time for shutdown.

Another good example involves a high-pressure turbine in a 103-J syn gas compressor train. Under certain conditions, this machine would generate an audible low-frequency rumble, or "growl." This abnormal noise was accompanied by high vibration displacement amplitudes (0.90 mil on cap, 6.0 mil on rotor).

Shaft motion under these conditions was periodic and composed of two major frequencies, one of which was twice the other. In this case, the higher frequency was 1 x rev./min. (10,600 rev./min.) and the lower frequency was a sub-harmonic of exactly ½ x rev./min. (5,300 rev./min.). This type of response is often indicative of aerodynamic disturbances in a high-speed machine. Frequencies of 1/3 x rev./min. and 1/4 x rev./min. may indicate the same problem. Sub-harmonics are usually easy to identify since the waveform will be periodic. Oil whirl, by way of contrast, would involve a continuously changing signal because the so-called "half-frequency" is actually only 40 to 48% of rev./min.

In this particular case, it was determined that amplitudes could be controlled by varying first-stage steam pressure to the condensing turbine. Increasing the pressure caused vibration amplitudes to reduce. Simultaneously, the sub-harmonic frequency component disappeared.

When steam pressure reached some lower limit, the high-pressure turbine became unbalanced and the rotor began shuttling or oscillating axially. This aggravated inherent nonlinearities in the rotor-bearing system, and the sub-harmonic rotor motion was generated.

Signature analysis helped to detect the cause of this potentially destructive problem and set up operating procedures to prevent its recurrence.

Eddy current inspection

Needless and costly shutdowns often are due to unpredicted tube failures in reactors, heat exchangers, reboilers, condensers, strippers, etc. The condition of any heat exchanger is usually difficult to evaluate with field evaluations such as visual inspections, hydrostatic tests, and destruction of random tube selections.

Eddy current, or Probolog, inspection presents results obtained in field investigation of tubing such as copper, brass, austenitic stainless steel, Monel, Incoloy 800—in fact, all nonmagnetic materials.

Maintenance of most tubular equipment involves hydrostatic testing. Generally, when a leak occurs, a hydrostatic test is made, the leakers are plugged, and the bundle returned to service in hopes that all potential leakers have been found. In most cases the bundle is soon out of service again, and another hydrostatic test is performed.

Unlike the common hydrostatic test, Probolog inspections can provide valuable information such as:

1. The exact location of any defect in each tube.
2. The extent of any crack or defect.
3. The degree of pitting from corrosion and/or erosion.
4. The degree of wall thinning from corrosion and/or erosion.
5. Any detrimental metallurgical changes in the tube walls.

Thus, it is possible to predict service life of materials and schedule replacement of questionable tubes prior to failures in service.

Exchanger maintenance programs which incorporate regular eddy current inspections can result in appreciable savings in both labor and material costs. Use of the Probolog instrument by a well-trained technician for exchanger tube inspections can readily provide detailed information to evaluate tube condition.

The instrument's operating principle is as follows. An alternating current-induced magnetic field will cause eddy currents to flow in metal objects near the coil. The eddy current density will be greatest at the surface of the metal adjacent to the coil and will decrease rapidly in the metal as the thickness increases. A strip chart gives a record of instrument response to various defects in the sample material. This calibration test is repeated several times during the course of a typical inspection to confirm the integrity of the testing system. In addition to strip chart displays, meter readouts and oscilloscope presentations are employed. A storage oscilloscope has proved invaluable for detecting defects under baffles.

Prior to commencing a Probolog inspection it is necessary to establish a calibration standard using similar materials. Then the inspection is conducted, as in all nondestructive testing, having a known against an unknown. This instrument has been very much misused and probably misunderstood. But when properly used by a well-trained technician, the results are reductions in downtime and retubing costs which often result from random failures.

Analysis of tube deviations

When industry began to use the large high-pressure, single-train, ammonia plants, reformer catalyst tubes began to present problems (and still present a large number) associated with lost production.

The tube deviation analyzer was developed to detect carburization/oxidation to foresee future problems with catalyst tube failures. This has not been a phenomenon in all reformers, but it has happened in more reformers than has been publicized.

To date, we have inspected a total of 31,912 catalyst tubes throughout the world—the United States, Canada, Australia, Trinidad, Brazil, Argentina, Venezuela, Saudi Arabia, Iran, Greece, Pakistan and Holland—with what we consider very good results in the cases where internal corrosion, commonly referred to as carburization-oxidation, has existed. The method has been used successfully by many, many large organizations to evaluate remaining tube wall life.

In the beginning, it was anticipated that destructive testing and metallurgical examination would not be necessary, but in a short time it became obvious that metallurgical examination was imperative to evaluate damage to the internal surface of the tube, creep damage, cracking, etc.

After complete examination of any typical primary reformer, removal of a tube is minor because it represents in most cases the general condition of the remaining tubes in a particular reformer. Evaluation of any catalyst tube requires extensive investigation *prior* to an inspection to establish a reliable calibration standard and to determine the material, the O.D. of the tube and the wall thickness. We have been very fortunate in being supplied samples of tubes which have failed and potential failures from responsible companies. It has been very constructive for industry to have supplied these samples to establish calibration curves for future inspections.

The normal time for this phenomenon to happen to a catalyst tube has been published in other papers. It is not likely to happen the first two years and in some cases up to six years. However, we have found it existed, in some cases, as early as one year and in many cases it never occurs.

The procedure for conducting tube deviation analyzer inspections is to establish the calibration curve, evaluate the particular tubes in question, and give constructive evaluation as to any damage caused by carburization/oxidation.

A report by D. B. Roach states that when I.D. corrosion exists, in most cases it does not exceed growth of 0.150 mil/yr. We agree to this maximum, but in most cases feel it will be less. At the Ammonia Safety Symposium of September, 1973, P. A. Ruziska stated that in his particular case removal of catalyst tube when I.D. corrosion has reached 200 mil is a safe factor. He assumes that there is material soundness of the catalyst tube to operate for an additional 10,000 hr.

It is our opinion that when the internal corrosion reaches one-third deterioration of the catalyst tube wall it is normally associated with the early third-stage creep damage and cracking, and should be removed prior to stress rupture failure.

The tube deviation analyzer is only one of the techniques used to detect significant change in magnetic permeability, and it cannot evaluate creep damage at the midwall such as fissuring, etc. This technique is also very valuable as it does not require the removal of the catalyst.

Other types of nondestructive testing such as measuring the growth of the tube by caliper, strapping, etc., in our opinion have not proven successful in most cases. The use of ultrasonics has a potential but to date has not been proven entirely successful. The tube deviation analyzer has its limitations but has proven very successful and is only a tool for industry to obtain information in the cases where this phenomenon of carburization/oxidation or I.D. corrosion exists.

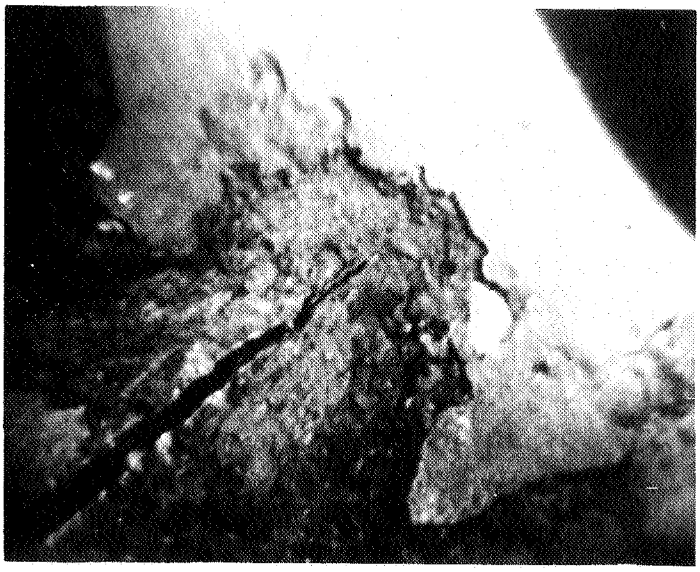

Figure 1. Heavy scale adjacent to a rupture in a waste heat boiler tube.

Figure 2. Hole in end cap of waste heat boiler tube.

Closed-circuit television useful aid in visual inspection

In certain instances, failure modes may be detectable only by visual inspection. Common examples are internal cracks in waste heat boiler tubes, reformer catalyst tubes, and reformer riser tubes. These defects are not accompanied by secondary effects which can be measured externally.

A new method of visually inspecting such formerly inaccessible areas employs a closed-circuit television system. The system referred to here is equipped with a camera head (vidicon tube and lens) which is only 1-9/16-in. in diameter. This is particularly suitable for waste heat boiler tube application.

Defects are easily viewed on a standard television monitor. The magnified image may also be photographed to provide a permanent record. Defects are magnified approximately four times when a 9-in. monitor is used. Photographs from various plants and equipment are shown in Figures 1-7. Each was originally photographed directly from the monitor with a Polaroid camera.

Conclusions

Techniques and applications for nondestructive testing are really only limited by human imagination. New equip-

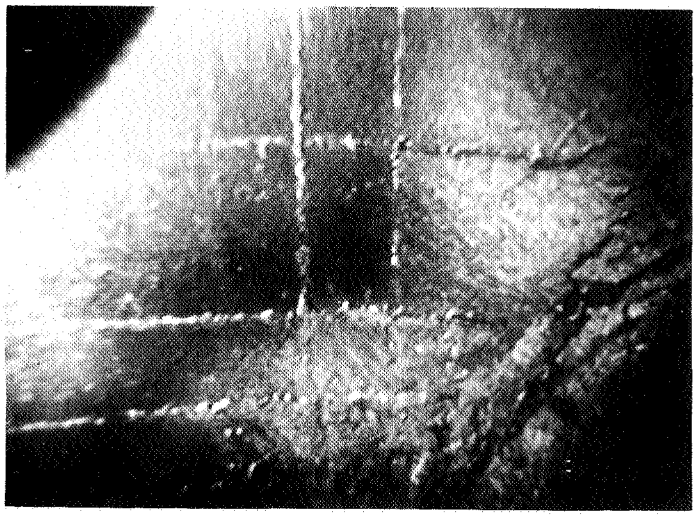

Figure 3. Heavy scale on internal surface of waste heat boiler tube.

Figure 4. Crack in weld of ammonia reformer catalyst tube.

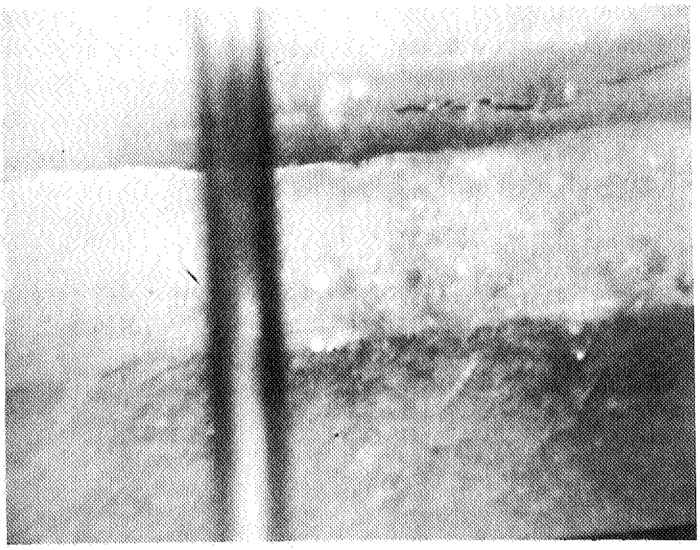

Figure 5. Crack in weld of ammonia reformer catalyst tube.

ment and new procedures develop so frequently that any list of available techniques grows quickly obsolete.

One way to demonstrate the reason nondestructive testing has grown in significance is to cite its impact for example in catalyst tube problems. If a plant manager can avoid a failure by removing a few defective tubes during a regularly scheduled turnaround, he can save a considerable amount of money. The technique of nondestructive testing can help him determine which tubes are defective and how soon they might be expected to fail.

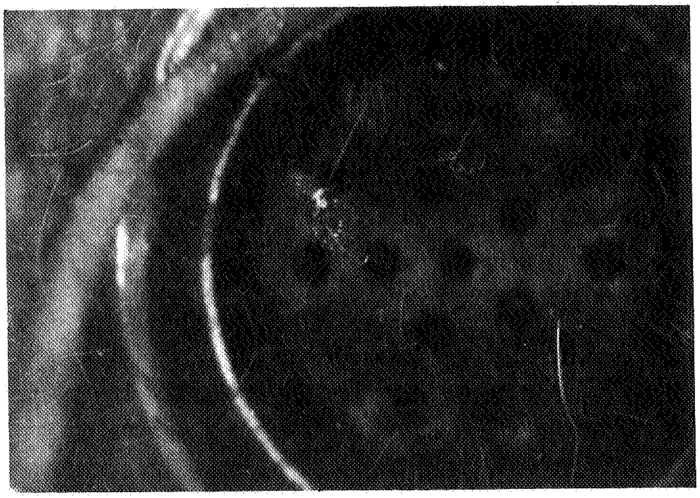

Figure 6. Broken tubing stuck in grid plate of ammonia reformer catalyst tube.

Figure 7. Crack in weld of ammonia reformer catalyst tube.

Without nondestructive testing, he may have only three unprofitable alternatives: 1) replace all the tubes (assuming replacement tubes can be obtained); 2) replace none and possibly suffer one or more failures at startup; or 3) replace some tubes on the basis of a kind of intuitive reasoning. #