Yankee dryer crevice corrosion evaluation

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ABSTRACT: A Yankee dryer was found to have crevice corrosion at the clamp fit of the head and shell flanges. The severity of this corrosion caused high stresses due to corrosion jacking forces. A replacement dryer was ordered. Nondestructive examinations (NDEs) were performed to track corrosion growth and verify Yankee dryer structural integrity during the last year of operation. These tests included head tilt, shell runout, acoustic emission, and ultrasound. After the dryer was replaced, further nondestructive examinations were conducted to augment the original NDEs. Finally, sections of the dryer head were cut out to validate nondestructive examinations. Investigations of two other Yankee dryers with the same problem are also discussed.

KEYWORDS: Corrosion, corrosion mechanisms, crevice corrosion, drum driers (dryers), evaluation, nondestructive tests, test methods, yankee driers (dryers).

A worldwide problem of Yankee crevice corrosion surfaced in the mid-1980s, and an actual Yankee (Yankee A) head failure prompted an in-depth look at this crevice corrosion problem. Another Yankee (Yankee B) was found to have a serious level of crevice corrosion. This Yankee was replaced. Yankee B was shipped to Beloit Walmsley for nondestructive examination (NDE), disassembly, inspection, repair, and reassembly. A significant amount of information was gained from this effort. Patterns of crevice corrosion were identified. Methods of NDE and techniques for tracking crevice corrosion were developed. This knowledge was used to analyze another Yankee (Yankee C).

Crevice corrosion occurs at the clamp fit of the head/shell flange interface of a Yankee dryer. Thermal stresses during the papermaking operation provide the forces that tend to create a small gap at the outside diameter of the head/shell fit. Corrosion then begins in this gap and grows in size, creating jacking forces which stress the head flange and, to a lesser degree, the shell flange. As the corrosion grows, stress increases and can crack the head flange when stress exceeds the rupture strength limits of the cast-iron flange.

Yankee A was the first reported crevice-corrosion-induced failure in the United States. A brief history of this event is given below. Yankee B was removed from service because of crevice corrosion. Details of the disassembly and repair of this dryer provided the background information for the NDE program implemented on Yankee C during its last year of service.

An advanced stage of crevice corrosion was found on Yankee C. This report covers the NDE results during the last year of operation, and the nondestructive and destructive tests done after the dryer was removed from service. The results of this effort are: (a) NDE methods that can verify the structural integrity of a Yankee dryer and (b) methods to determine the severity of crevice corrosion in a Yankee dryer. **Figure 1** shows crevice corrosion and where it can cause head cracking.

Yankee A

The first reported Yankee head failure was on Yankee A. The series of events which led to identifying the crack were as follows:

February 1985

- Drilled pumping ports and pumped sealant in tending side (TS) head/shell interface to stop steam leaks.
- Refinished shell surface with full-face metallizing.

July 1985

- Picking problems (TS) and severe blade bounce

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- Runout showed 1.0-mm bulge, 508 mm in from TS edge at Bolt 111.
- 0.20–0.25-mm gap found at spigot fit. Suspected head/shell slippage.
- TS head runout was 2.2 mm axially. Very little runout on drive side (DS) head.
- Magnetic particle (MT) and radiographs at shell bulge area showed no problems.

September 1985

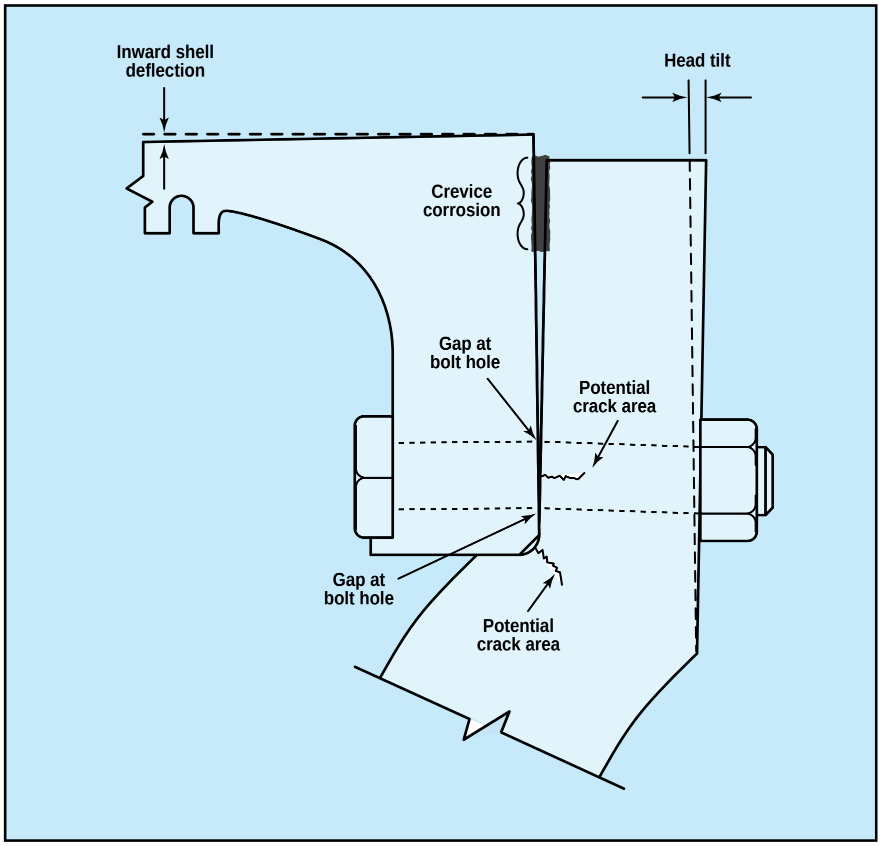
- Shell "bulge" covers approximately half of dryer circumference.
- Ultrasonic tests (UT) and repeat MT tests showed no evidence of failure.
- Strain gauge tests, while pressurizing the Yankee with air, showed no failure.
- Decision made to install body fit bolts to eliminate suspected head/shell interface slippage.
- Began reaming bolt holes for body fit bolts. Found cracked head at bolt pitch circle.

Yankee A was then taken out of service. A new head was ordered and field installed in early 1986. When the TS head was removed, a heavy band of corrosion was found at the head/shell clamp fit from the outside diameter extending inward from 38 mm to 75 mm.

Yankee B

In early November 1985, Yankee B was being pumped with sealant to correct steam leaks at the TS head/shell interface. During this outage, a check of the head/shell clamp fit showed gaps at several circumferential locations. A 0.05-mm feeler gauge could be inserted to a depth of 140 mm at one location. This raised concern because of the Yankee A experience. A meeting was scheduled with the Yankee supplier, Beloit Corp., on November 19 to define a program of nondestructive examination for Yankee B. At this meeting, the following course of action was defined:

1. Yankee crevice corrosion



- Measure shell runouts at three locations near TS edge.
- Measure head flange runouts.
- Conduct MT and UT examinations of the head and shell flange areas (externally).
- MT internal area near head/shell joint
- Check spigot fit.
- Change bolts in leak areas and pump with sealant.
- Torque check all head bolts.
- Reduce dryer maximum allowable working pressure (MAWP) to less than 150 psig.
- Order new TS head for Yankee B.
- Order replacement dryer for Yankee B paper machine.

On December 8 and 9, these actions were taken, with the following results:

- Shell runout maximum was 0.86 mm on the tending side and 0.31 mm maximum on the drive side.
- Maximum head runout appeared to be about 0.89 mm on the tending side and 0.23 mm on the drive side.
- Internal and external MT tests gave no indication of cracks.
- External ultrasonic testing of the flanges showed no cracks but did reveal the gaps between head and shell flanges, even in areas where feeler gauges could not be inserted.
- No clearance was found at either TS or DS spigot fit.
- Head bolt torque check gave no rotation of any nut.

Following these tests, there was no evidence of cracking in the stressed areas of the head/shell interface and adjoining areas. The supplier was concerned about stress corrosion cracking of some head bolts and recommended replacing bolts in specific areas. There was also a concern about dryer pressure stresses, especially under "sheet off" conditions. MAWP was reduced from 150 psig to 90 psig to minimize the corner stress at the head/shell interface. With these changes implemented, the dryer was operated at the reduced MAWP until replacement in January 1987.

Following replacement in 1987, the original Yankee B was shipped to Beloit Walmsley for tests and repair. NDE was conducted on the dryer prior to dismantling. There was no evidence of cracking. Head tilt, shell runout, spigot fit, and head/shell flange gap readings were essentially the same as those taken previously at the mill. In addition to the mill tests, the following were done:

- Drop check tests to measure the distance from the outside of the head flange to the shell flange
- Borescopic checks at the TS head spigot fit area via holes drilled from the head flange face
- Hydrostatic pressure test at 100 psig.

TS measurements showed four lobes (high spots) on the Yankee shell surface. The maximum highs were approximately 305 mm in from the TS shell edge. These four lobes coincided with four "low" areas of head tilt and drop check measurements. This also coincided with the four areas where feeler gauge checks showed a gap at the outside diameter of the head/shell clamp fit. A dial indicator was positioned about 305 mm in from the TS shell edge at one of the positive lobes while head bolts were loosened in this area. The bulge decreased by 0.41 mm when head bolts were loosened. From the time of the original inspection to this point, the major concern for stress was in the areas of the head/shell flange gaps and the coincident dryer shell bulges.

After the dryer was disassembled, it became evident that the areas of concern were where there were *no* gaps in the head/shell fit and where there were shell runout "lows". This knowledge was later applied to nondestructive examination done on subsequent Yankee dryers with crevice corrosion.

After NDE was completed, the dryer was dismantled for inspection and rework. The significance of head/shell crevice corrosion was found in this inspection. TS head/shell clamp fit surfaces showed the following:

- A band of densely packed corrosion existed from the outside diameter of the head to 32–57 mm inward for the entire fit area, except for the four areas where head/shell gaps and shell bulges were found. Minor corrosion extended further inward toward the bolt circle. From the bolt circle inward to the spigot fit, there was no corrosion.
- The four areas of head/shell gaps were areas that had previous steam leaks and showed little or no corrosion.
- Corrosion jacking forces at the outside diameter end of the clamp fit had pushed the head flange out axially and deflected the shell flange inward. While the areas with little or no corrosion did not exhibit as much head and shell deflection, the stiffness of the flanges allowed a bridged gap across the noncorroded area, creating the measurable gap that initiated the concern for this dryer in late 1985.

A corrosion band was also found at the outside diameter of the DS head/shell clamp fit but not nearly as thick or as wide as seen on the tending side.

Steam leaks had originated at the spigot fit and generally occurred over a distance of 130 mm to 250 mm circumferentially into the corner cavity formed by the shell flange chamfer. This was evidenced by striations of the fit surfaces rather than any major steam cutting. From the corner cavity, a single steam cut path generally proceeded to a bolt hole. From the bolt hole outward, several smaller steam cuts branched out for 25 mm to 50 mm, then dissipated. One major steam cut was found on the DS clamp surfaces at bolt no. 1. Depth of the cut was measured to be 1.5 mm on the shell flange between the inside diameter of the flange and bolt hole no. 1. After remachining these flanges, the residual cuts were filled with Belzona.

TS and DS shell flanges and the DS head flange were remachined. Flange thickness after machining fell within original specification tolerance. The new TS head was machined to fit, and the dryer was reassembled using body fit head bolts. The dryer was then hydro tested, ground, and returned to the mill in April 1988.

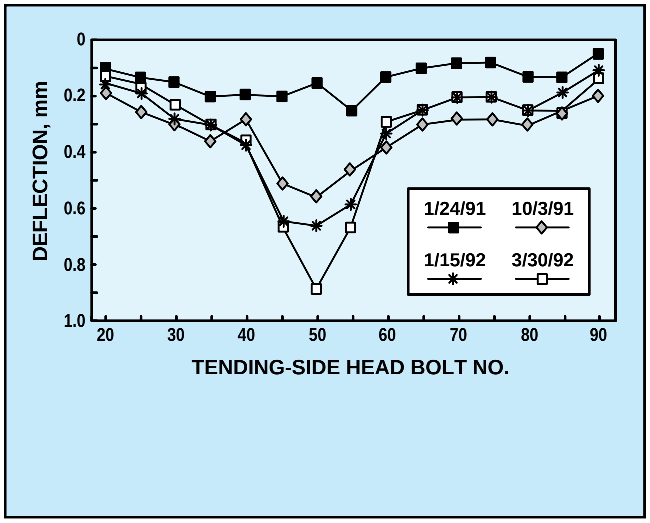
The investigations of Yankee A and B established:

- Dryers with head/shell corrosion can have gaps in the head/shell fit in areas with little or no corrosion.
- Shell runout "lows" can be created by corrosion jacking forces.
- Shell runout "highs" can be created by a partially cracked head, which relieves the corrosion jacking force.
- It is essential to determine whether the "high" or the "low" is the problem area.

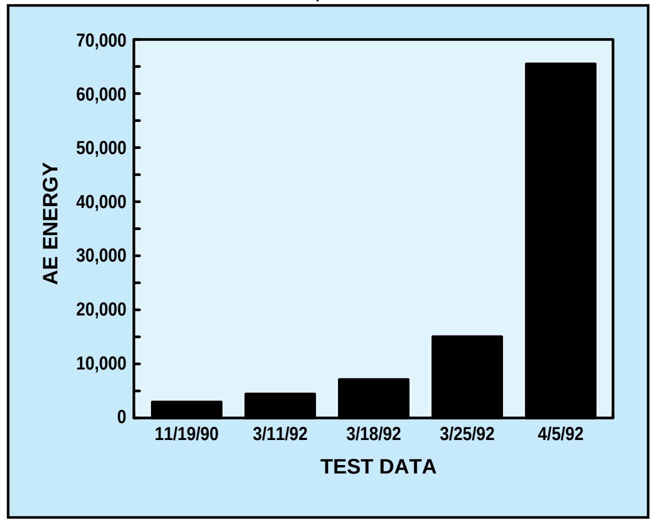
Yankee C

Yankee C began its operational life in September 1964. Over the next 25 years, the only significant events were eight grinds and occasional pumping of sealant to correct head/shell fit steam leaks. Information from disassembly of Yankee B created a major concern for dryers that visually indicated crevice corrosion at the head/shell interface. Visual examination of Yankee C showed evidence of significant crevice corrosion,

2. Yankee C shell runout



3. Acoustic emission data to 80 psi



especially on the TS head/shell flange interface.

Nondestructive examination was performed on Yankee C to determine relative fitness for service. NDE included head tilt, shell deflection, and acoustic emission (AE).

Acoustic emission examination involves placing high-temperature piezoelectric sensors on the Yankee dryer. These sensors detect relative energy released from damaged areas in cast iron when stress (e.g., steam pressure) is applied. Sensor activity is quantified by "sensor hits" and the "relative energy" of these hits. Test results indicated advanced stages of corrosion jacking of head and shell flanges. The tests also indicated that the dryer did not have a crack. We decided to immediately order a replacement for Yankee C. A program of continuing tests was also initiated in November 1990. The key measurement was shell deflection changes at every fifth head bolt location at each scheduled maintenance shutdown. Since the Yankee had not been resurfaced since December 1988, monitoring shell surface deflection changes would reveal:

- Corrosion jacking force growth
- A change in shell deflection direction would indicate relieving of jacking forces due to the initiation of a head crack.

During the last 16 months of operation, extensive NDE was performed on Yankee C. These tests included shell runout, head tilt, spigot fit, and acoustic emission. None of these tests indicated a weakened structure, but they pointed toward a highly stressed head casting.

Shell runout measurements were taken at scheduled shutdowns. These tests showed an increasing shell deflection in areas of known, major crevice corrosion (**Fig. 2**). Instructions were given to "lock the steam valve" if the shell deflection changed direction, since this would indicate a weakening of structural integrity of the head.

Head tilt measurements were taken by two different methods: a mechanical tilt gauge and proximity probes. These measurements gave somewhat mixed results but tended to show an increase in head tilt in corroded areas.

Spigot fit measurements showed no changes during the last four years of operation.

Several AE tests were taken during the last few months of operation. These indicated more activity than a new dryer but did not indicate a loss of structural integrity. The last AE test was taken at the final operating shutdown for Yankee C. Results of this investigation showed AE activity had increased to a level of concern. Results of AE tests on Yankee C are shown in **Fig. 3**.

Post-removal tests on Yankee C

Following the removal of this Yankee from service, a series of follow-up tests was done in an effort to qualify existing NDE test methods. Since this dryer was scheduled to be scrapped, the nondestructive examination was followed by destructive tests to verify NDE results. The area investigated was centered around TS bolt 50 (bolts 40 to 60), which had shown the greatest change in shell deflection.

Results included:

- Spigot fit check indicated no change from the original checks performed in 1985.
- Dial indicators were mounted 305 mm from the TS shell edge at bolts 45, 50, and 55. Head bolts 40–60 were then loosened. Shell deflection moved outward a maximum of about 1.0 mm in the area of bolt 45 to bolt 50, 305 mm in from the TS edge.
- After bolts 40–60 were removed, the gap between head and shell flanges was measured at the bolt circle. The gap at bolts 48 and 51 exceeded 1.0 mm.
- UT scans of the head at the head bolt circle gave no indications.

- UT scans at the spigot fit showed some differences at the areas of bolt 48 and bolt 51. These indications could not be positively identified as a casting failure.
- Borescopic examination of bolt holes showed no evidence of head cracking at the bolt circle.
- Eleven-millimeter holes were drilled through the head to the spigot fit at bolts 48 and 51. Borescopic examination of the head spigot fit corner showed one questionable area, which may or may not have been a failure initiation.
- In retrospect, the UT examination should have been done before the head bolts were loosened to maintain maximum stress on the head flange. Also, one head bolt should have been removed before the 20 were loosened to measure head/shell flange gap at the bolt circle under stressed conditions.

Destructive tests

To document if shell deflection readings were partially due to wear, five holes were drilled through the Yankee shell approximately 300 mm from the TS shell edge (between first and second rib) to facilitate shell thickness measurement. These holes were located at high and low points of the shell runout patterns taken when the dryer was still in service. Minimum to maximum thickness variations were only 0.1 mm, which is probably within the accuracy limits of the measurement. This proved that shell runout measurements taken during the last 16 months of operation were from shell deflection, not shell wear.

Following nondestructive examination, a section of head was cut out from the centerline of bolt 44 through the centerline of bolt 54. Visual examination showed a band of dense corrosion extending inward from the head outside diameter approximately 46 mm. In the area of bolt 48, this corrosion band was measured to be about 3.2 mm thick.

The clamp fit and spigot fit surfaces of the head section were cleaned for visual examination. No cracks were found using a 7X magnifying glass. This was followed by a wet fluorescent magnetic particle test, which showed the start of a casting failure or surface fragmentation at the spigot fit corner. This fluorescent trace extended for the full circumferential length of the removed head section. This result prompted the decision to make a radial cut through the head section to allow a detailed cross-sectional analysis of the spigot fit corner.
Cross-sectional samples of the spigot fit corner were sent to two independent firms for analysis. Both firms indicated a crack had not been initiated, contrary to indications from wet fluorescent magnetic particle examination.

Conclusions

Yankee C head/shell clamp fit was highly stressed in the area of bolt 50. This is based on:

- Inward shell deflections occurring over time, as recorded by readings taken during the last 16 months of operation and confirmed by shell thickness measurements
- Outward deflection of the shell when the 20 head bolts were removed
- Gap measurements of the head/shell fit after bolt removal
- Wet fluorescent magnetic particle test indicated the initiation of a casting failure.

Properly executed nondestructive examination can indicate potential crack failure.

Shell runout tests about 300 mm in from the edge are probably the most sensitive in terms of reflecting change in corrosion jacking forces. However, there are two caveats to this test: (a) after each grind the runout returns to "0", and (b) runout readings are only significant if the corrosion is nonuniform around the fit circumference.

Head/shell flange gap measurements taken at a bolt hole in an area of known corrosion will give an indication of the magnitude of corrosion jacking forces.

Accurate head tilt measurements will provide continuing measurement of corrosion growth. An initial reference for all new dryers should be taken. Existing operating dryers should have reference tilts taken even though no corrosion currently exists. The key to this measurement is an accurate, calibrated tilt gauge.

Acoustic emission and ultrasonic tests conducted by qualified and experienced personnel appear to be developed sufficiently to predict imminent failure of a Yankee head.

Loss of spigot fit has been identified in some historical head failures. While this may well be a good "after the fact" indicator, it is not deemed to be a good predictor of failure.

Recommendations

Yankee dryers should be periodically inspected visually for head/shell crevice corrosion at the outside diameter of the interface. Once corrosion has been identified, a continuing program of NDE tests should be employed as an ongoing confirmation of fitness for service.

Spigot fit and head tilt reference data should be obtained for all Yankees.

A history of shell runout readings, taken just prior to each Yankee resurfacing, should be documented for potential use in determining total shell deflection and shell thickness variations.

The initiation of a casting failure may not show up as a loss of structural integrity because of the limited depth of the crack. This type of defect may also be difficult to identify by any means other than acoustic emission. TJ

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