Yankee dryer joint corrosion: cause, prevention, and repair

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ABSTRACT: This paper discusses the causes and prevention of Yankee dryer head failures relating to head/shell joint crevice corrosion. Using detailed nonlinear finite element models, the general behavior of through-bolted head-to-shell joints is presented. Emphasis is placed on the need to determine susceptibility to joint corrosion and how to measure its severity. General stress levels are calculated that result from applying field head tilt measurements to the computer models. Once the joint behavior is understood, options exist to remove the corrosion jacking deposit.

KEYWORDS: Corrosion, corrosion mechanisms, corrosion prevention, crevice corrosion, drum driers (dryers), finite element analysis, maintenance, mathematical analysis, models, nonlinear programming, reaction mechanisms, Yankee driers (dryers).

Webster's dictionary defines *rust* as "the reddish brittle coating formed on iron, especially when chemically attacked by moist air and composed essentially of ferric oxide." Rust is typically a liability to design integrity. Companies constantly attempt to inhibit rust generation resulting from the corrosive attack of component surfaces. The paper industry routinely faces machinery degradation due to corrosion that causes reduced component life and, at times, failures.

Yankee dryers have not been immune to the initiation and development of corrosion buildup. Specifically, severe corrosion buildup in the head-to-shell juncture was first identified in 1985. This initial case study led to the discovery of the head being cracked. Subsequent instances of head-to-shell joint corrosion buildup alerted the industry to better understand the reasons for corrosion's occurrence and severity. The problem was exposed through paper presentations and extensive roundtable discussions at TAPPI's Yankee Dryer Safety Subcommittee meetings. Concurrently, one Yankee dryer builder initiated extensive analytical and experimental studies to understand the general behavior of the head-to-shell juncture. These studies culminated in design changes that theoretically eliminated one possibility for crevice corrosion in the joint. During this period, work also focused on understanding the failure mode being experienced in the field.

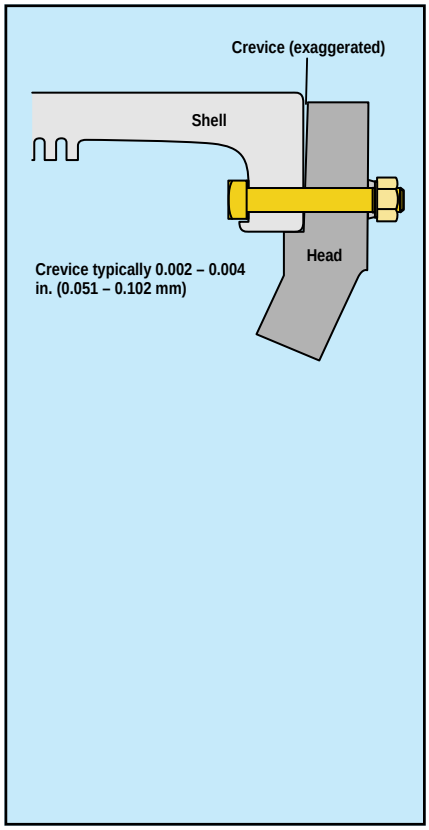
The following discussion outlines the mode of failure commonly experienced in the field. Detailed nonlinear finite element analysis has shown how and where the failure will occur when significant corrosion-jacking stresses are present in the head-to-shell juncture. Additional discussion describes how these computer models were used in formulating a viable repair of Yankee dryers in the field; this can enhance head-to-shell joint functionality and extend dryer life while minimizing machine downtime.

Reasons for crevice corrosion

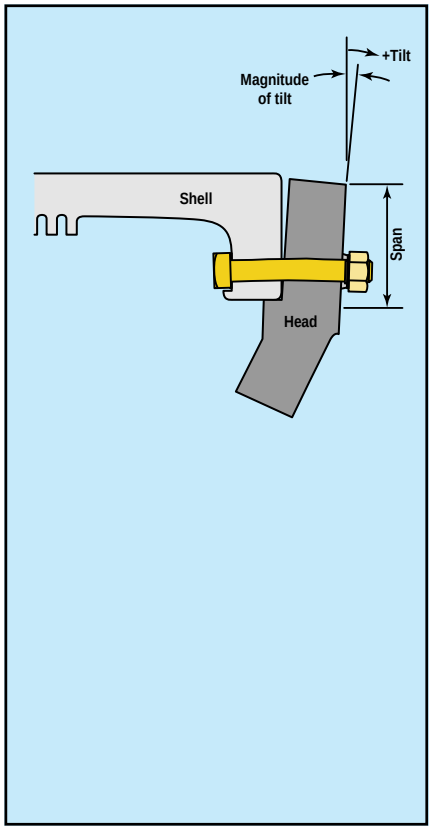
Yankee dryers are the major component of the creping process. Typically, a Yankee is used to transport, press, and dry the wet web and provide the necessary product attributes with the creping blade. These functions account for loadings on the vessel from the pressure roll, internal steam pressure, shell thermal gradients, and shell surface wear from doctoring. As part of the Yankee dry-

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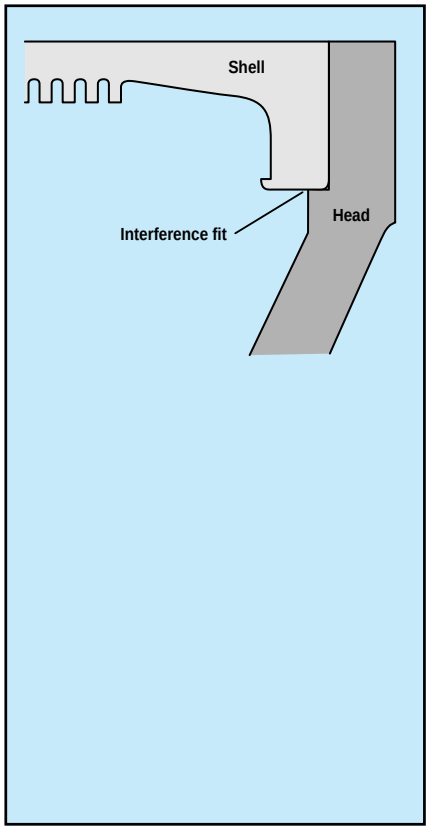
1. Head-to-shell joint gapping



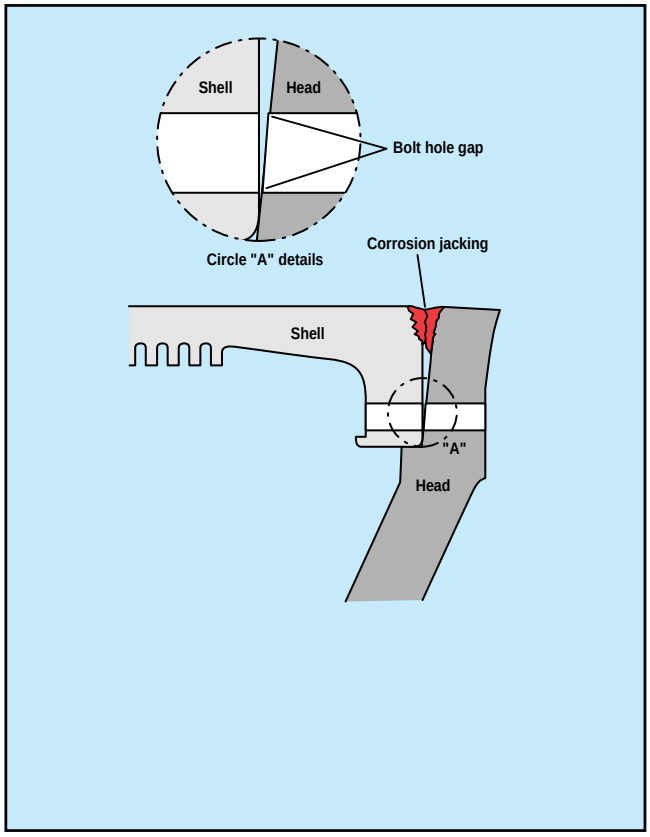
2. Head tilt



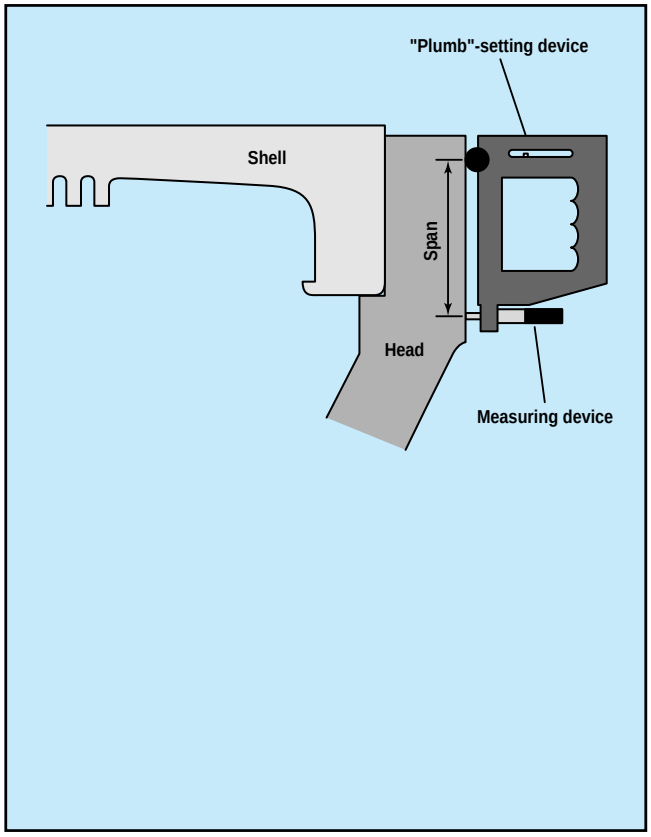
3. Head-to-shell spigot fit



4. Head-to-shell bolt hole gapping (corrosion jacking)



5. Typical tilt gauge



ing process, special chemicals are used for sheet release and adhesion, and in some cases, edge sprays are used to control sheet edge dryness, all of which can accelerate corrosion in the joint.

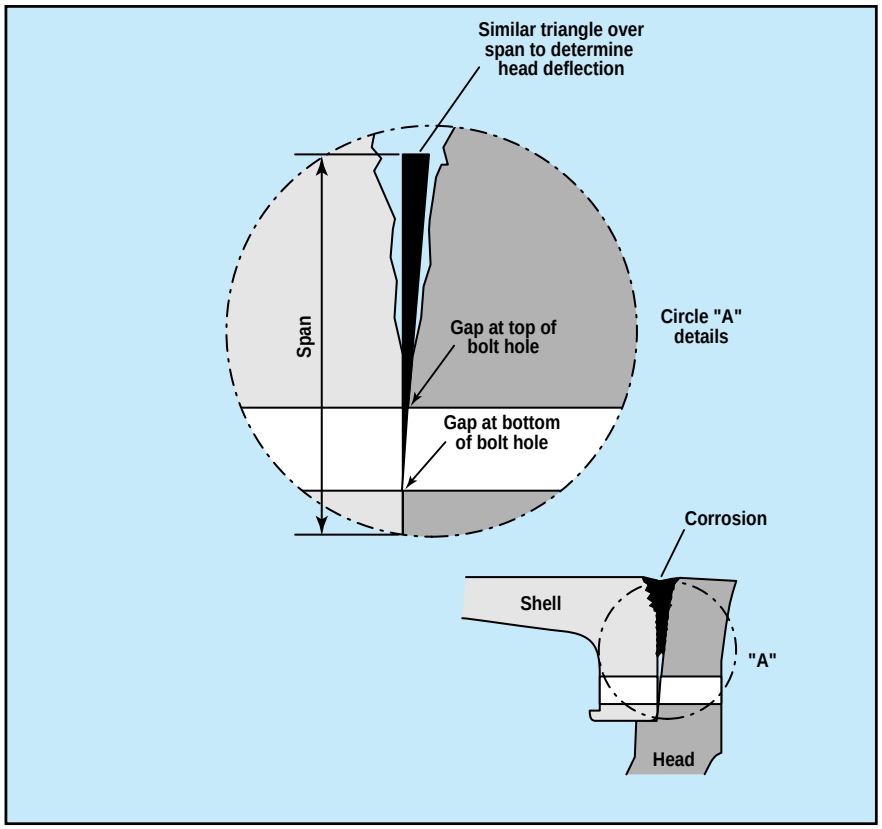
The relatively recent problem with corrosion in the head-to-shell joint has caused speculation as to how and why it so suddenly emerged and subsequently became a safety issue in Yankee dryer operation. Reviewing the applied loads, no dramatic changes were identified to explain the problem. Preliminary investigations focused on design integrity and understanding possible failure modes. These evaluations provided valuable insights on how the head-to-shell juncture behaves under different loading conditions. Extensive computer analysis of through-bolted Yankee designs revealed that, under operating conditions, a crevice can exist at the head-to-shell juncture, as shown in **Fig. 1.**

The magnitude of this crevice was typically 0.002–0.004 in. (0.051–0.102 mm), depending on certain geometrical relationships, design characteristics, and bolt preload. A gap is a requirement for crevice corrosion; theoretically eliminating a crevice should stop corrosion growth.

During the TAPPI 1991 Engineering Conference, Gerry Schreiner of James River presented his practical findings to the Yankee Dryer Safety Subcommittee about the head cracking resulting from crevice corrosion. His presentation emphasized the following points:

- It is a worldwide problem on both old and new dryers.
- Machine glaze and wet-crepe processes rarely exhibit the problem.
- Dry-crepe processes are most susceptible to the problem.
- Closed-water systems, resulting from the energy crisis of the 1970s, contain corrosion-supporting elements.

6. Absolute head tilt determination



- The gapping effect at a joint periphery fosters crevice corrosion.
- Corrosion initiation is from the outside inward.
- Felts, traditionally too wide for the sheet width, compound high moisture levels at the joint.
- All types of joint designs and diameter sizes are at risk.

This presentation emphasized a proactive approach to monitor various aspects of the shell and heads to detect the existence of crevice corrosion.

Identification and measurement of crevice corrosion

Growth of Yankee dryer head-to-shell crevice corrosion does not exhibit immediate operational instabilities. During the corrosion growth process, shell deformation changes caused by the corrosion are masked by:

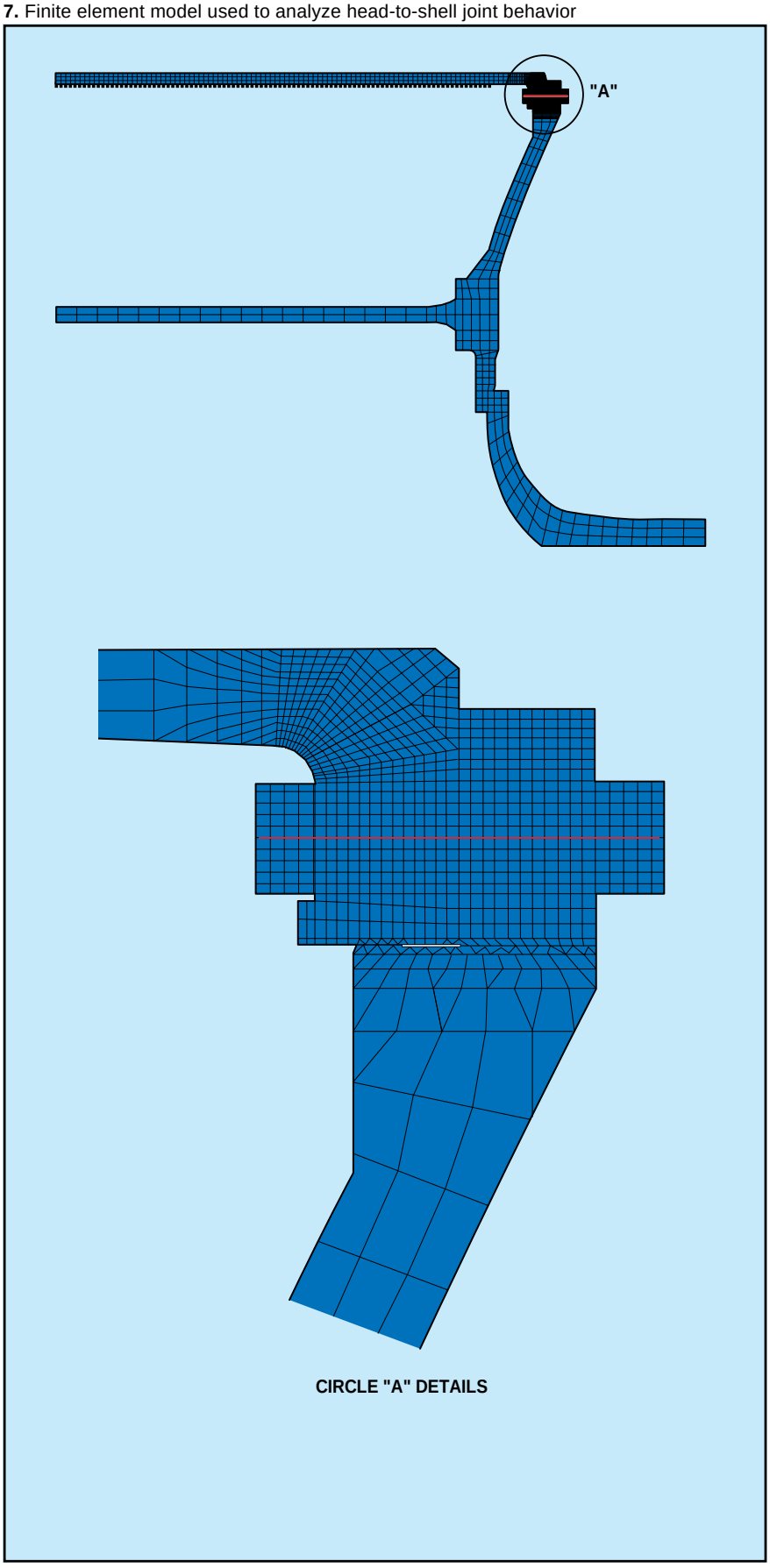
- Natural shell wear from creping and cleaning doctors
- Regular grinds of the shell surface to maintain production efficiency and product quality.

These two compensating factors eliminate measurement of shell radial runout as a means to quantify cumulative growth of crevice corrosion. Proven indicators of cumulative crevice corrosion growth are:

- Head tilt (**Fig. 2**)
- Head-to-shell spigot fit loss (**Fig. 3**)
- Gapping between the head and shell flanges, as measured in the bolt holes (**Fig. 4**).

Special gauges are used to measure head tilt and establish crevice corrosion severity. A typical gauge is shown in **Fig. 5.**

7. Finite element model used to analyze head-to-shell joint behavior



These gauges must be able to obtain an accurate plumb to the dryer head surface, span a significant portion of the head flange outside face, and incorporate an accurate means to measure the out-of-vertical position of the head flange. Final head tilt magnitudes are not absolute unless reference tilt readings were recorded at Yankee manufacture.

A good assessment can generally be made regarding corrosion severity and growth rate, but a specific value of head tilt that causes crevice corrosion cracking is less predictable. A valuable reference is established with initial head tilt measurements. This provides for a means to monitor head tilt changes and ascertain crevice corrosion growth. These measurements require consistency of the measuring procedure with regard to vessel temperature and internal pressure.

Spigot gapping, a separation of radial interference fit between the head and shell, is another common indicator of excessive corrosion buildup. This measurement requires the dryer be cooled for entry. Loss of fit between the head and shell is evaluated by inserting feeler gauges into the interface. Correlating loss of fit to an area of high head tilt is another measure of corrosion severity.

Bolt hole gapping is the best assessment of absolute head tilt severity due to corrosion jacking. This procedure also requires that the dryer be cooled. A bolt is removed, and right-angle feelers are inserted around the bolt hole at various positions. With these gapping measurements, a similar-triangle calculation is made to determine head deflection away from the shell, as shown in **Fig. 6.** A drawback to performing this measurement is the presence of sealant, which can inhibit accessibility.

Considering these three ways to monitor crevice corrosion severity, measuring head tilt is the preferred method.

Determining the severity of crevice corrosion

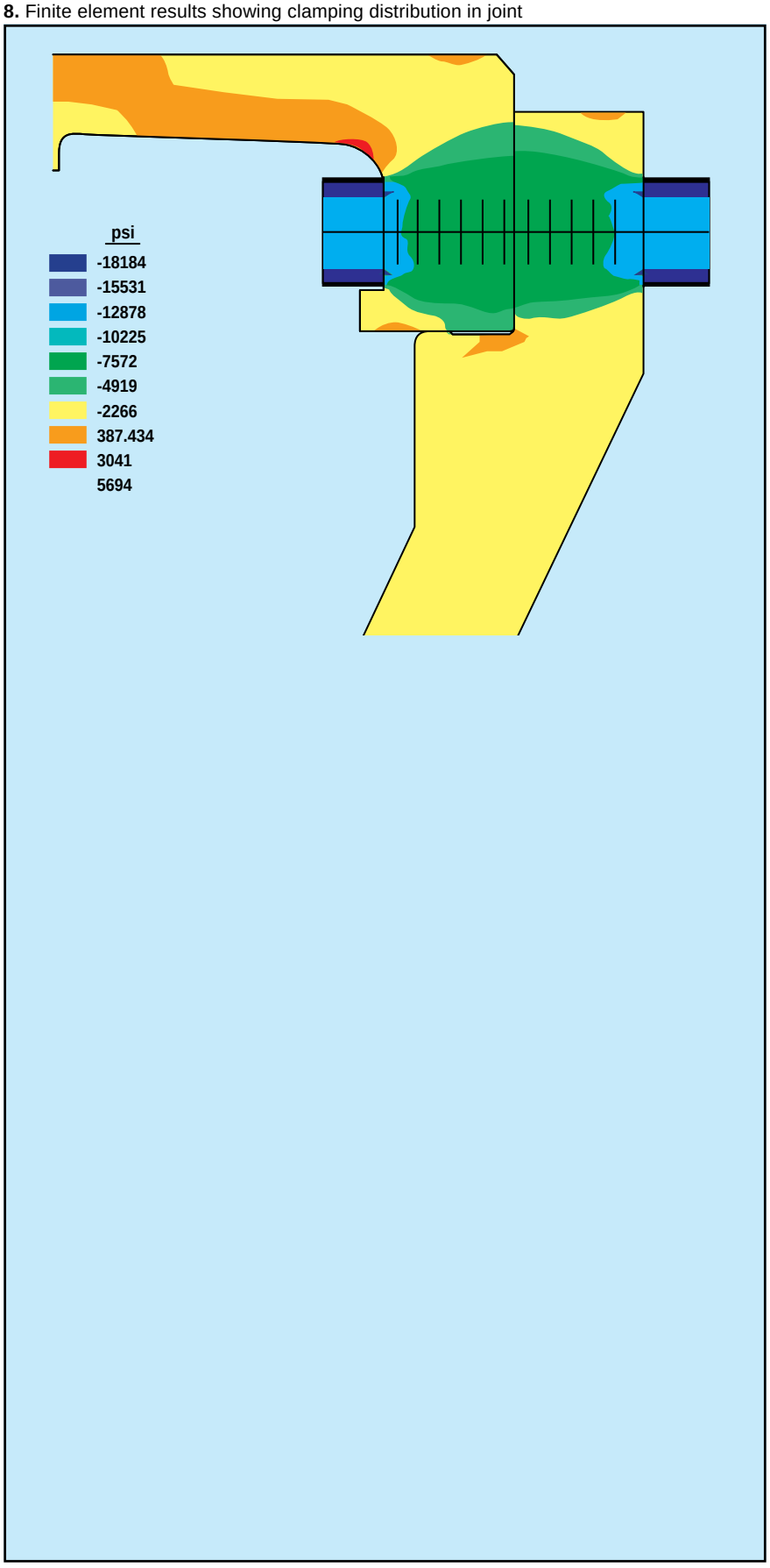
The discovery of crevice corrosion in Yankee head-to-shell joints prompted detailed computer analysis to scrutinize design behavior in this region. Nonlinear finite element models were initially used to understand specific deflection responses. These models accounted for design characteristics, bolt preload, and all the major static loads to which the vessel is subject during service. **Figure 7** shows a typical computer model used to examine joint behavior.

The initial results revealed that a crevice could exist in the joint. It was determined that during papermaking conditions, this crevice would have an extreme magnitude gap of approximately 0.004 in. (0.102 mm). This depended on specific geometrical relationships and joint clamping forces. The relationship between the generated clamping cone in the joint, the radial distance from the head outside surface, and the bolt pitch circle diameter, as shown in **Fig. 8,** was determined to be a major factor in eliminating gapping.

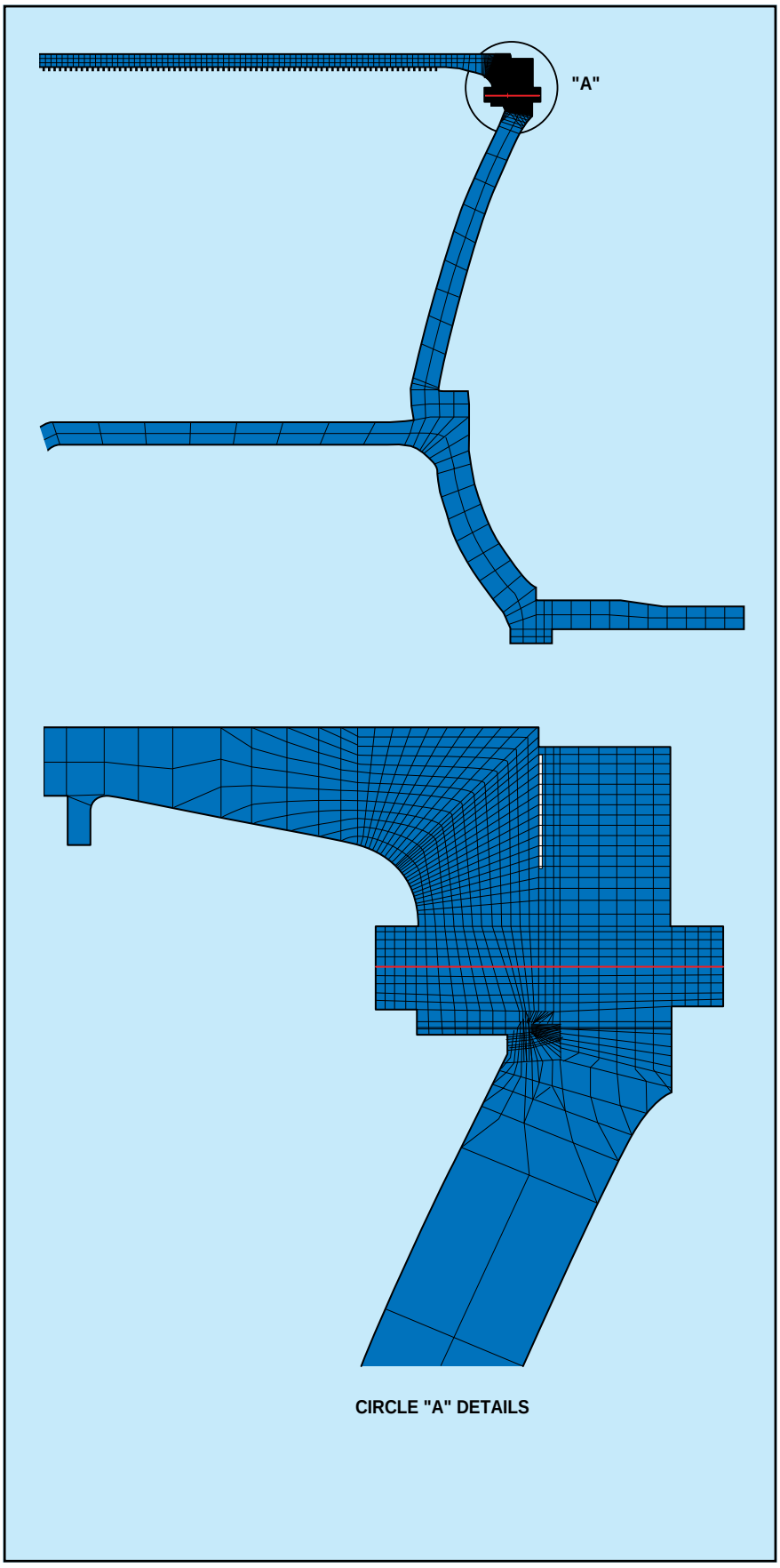
These studies also revealed that traditional design methods used to calculate bolt working stresses were inappropriate. Traditional calculation procedures do not account for bolt prestress or for the joint's capability to absorb applied loads. The computer analysis revealed a joint, with sufficient bolt prestress, had bolt working stresses typically less than 2000 psi. Subsequent experimental work, using strain gauges, verified the theoretical calculations.

Analysis also focused on predicting the predominate failure mode.

8. Finite element results showing clamping distribution in joint



9. Finite element model used to analyze corrosion jacking



Preliminary objectives were to obtain the stress levels resulting from corrosion jacking in the head-to-shell joint. This work involved modeling the jacking phenomenon associated with the buildup of corrosion in the joint, as depicted in **Figs. 9 and 10.**

The amount of jacking imposed was correlated with field measurements of bolt hole gapping to create the imposed head tilt. Results verified the existence of substantial tensile stresses in the head spigot corner, as illustrated in **Fig. 11.**

It was determined that an absolute tilt magnitude of 0.025 in. (0.635 mm) was needed across the reference point for a span of 3.5 in. (88.9 mm) to cause stresses that approached the tensile strength of the material. The general stress magnitudes could vary with design geometry and parameters, but it is important to realize that the stress levels would be large. Ultimately, when the vessel user discovers crevice corrosion, it is important to consistently and accurately monitor the joint as previously outlined. Additionally, repairing the vessel can relieve the corrosion-jacking stresses and restore head-to-shell joint functionality.

Removal of crevice corrosion

Removal of crevice corrosion is possible by implementing a substantial cutback of the head outside diameter. **Figure 12** illustrates the distance to tool metal off and remove corrosion-jacking forces that concentrate stresses at the head spigot corner.

It may also be necessary to reestablish any lost head-to-shell fit and to upgrade the bolt size for increased clamping forces, necessary to overcome permanent flange deformation from crevice corrosion jacking.

Various considerations must be addressed to proceed with corrosion removal:

- **Safety.** Does the dryer have extensive corrosion that requires immediate attention? This is a major determining factor in relation to the following two issues.
- **Remaining dryer life.** Is there sufficient shell thickness to warrant repair, i.e., replacement of the Yankee vs. rework?
- **Extent of repair.** Should the repair include a bolt upgrade or will limited service life dictate a cutback with replacement of similar-size bolts?

Additionally, the Yankee builder should provide calculations justifying the repair. This allows the vessel owner to involve local code jurisdictions and obtain appropriate authorizations.

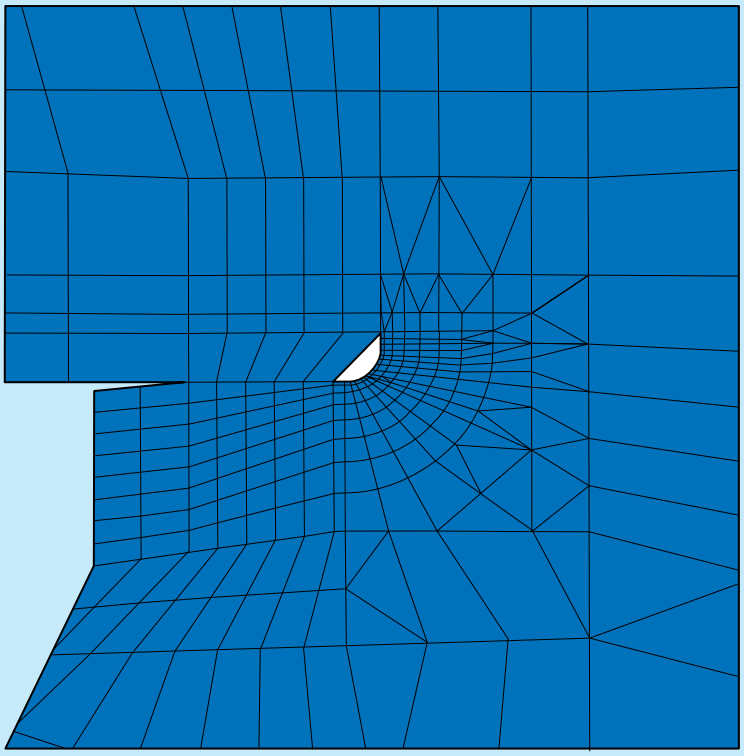
To date, nine repairs and upgrades have been completed, removing all the crevice corrosion and increasing bolt size. These repairs also eliminated the steam leaks associated with some of the corroded joints.

Summary

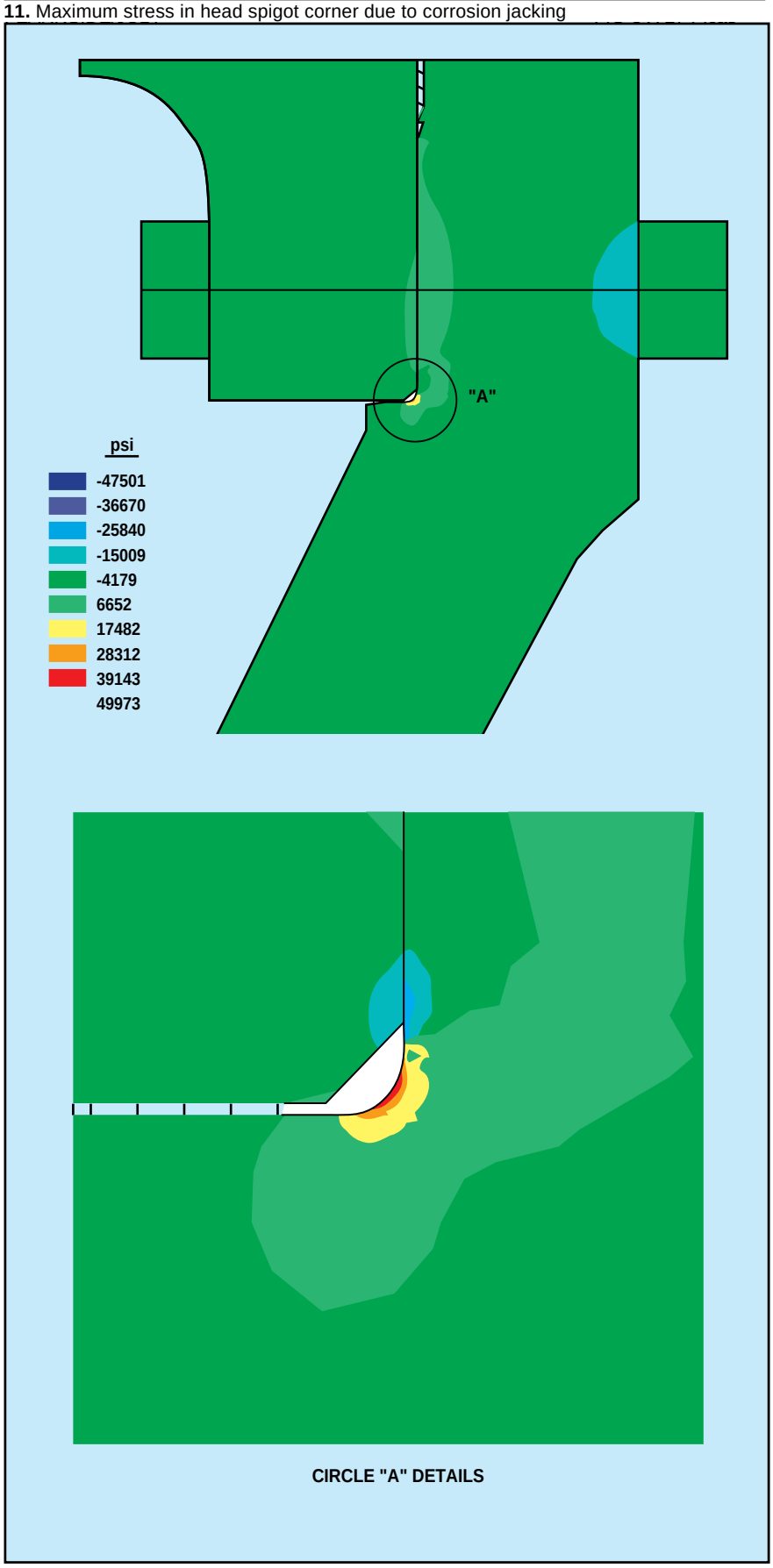
The following items summarize the items presented:

- Yankee dryer head-to-shell corrosion is a safety issue. The paper industry has recognized this and issued guidelines for assessment[1,2]. Instances of severe crevice corrosion have caused noncatastrophic failure of the Yankee head flange.
- The majority of cracking failures have initiated from the head spigot corner.
- Prudent and consistent methods are needed to identify and measure crevice corrosion. The most

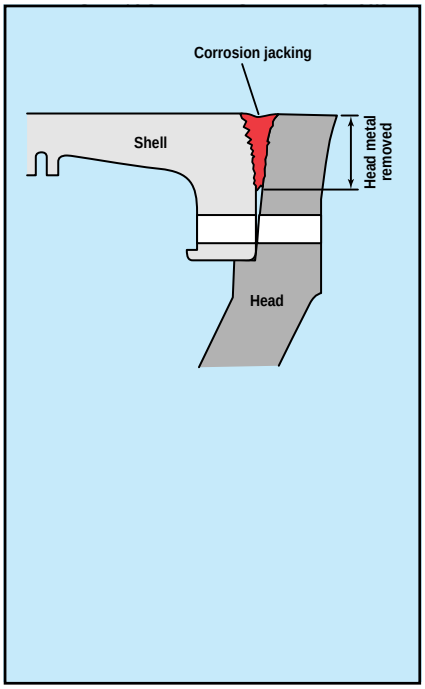
10. Finite element mesh of head spigot corner jacking corrosion study



11. Maximum stress in head spigot corner due to corrosion jacking



12. Corrosion removal via head cutback



convenient and reliable method is to periodically measure head tilt. Additional checks are to evaluate the spigot fit and to remove bolts for assessment of absolute tilting.

- Options exist to repair severely corroded head-to-shell junctures. Nine repairs have currently been completed by substantially reducing the head outside diameter to remove crevice corrosion deposits. Additionally, functionality can be addressed by stabilizing the joint; this eliminates steam leakage through an upgrade in the clamping forces.

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