



BabcockPower

Technical Publication

# Recent Experience in the Inspection and Assessment of Boiler Header and Steam Drum Cracking

*by*

Brian P. Holbrook  
Manager, Stress Analysis and Structural Steel  
RILEY POWER INC.  
a Babcock Power Inc. company  
(formerly Riley Stoker Corporation)

James P. King  
Manager, Boiler Evaluation  
RILEY POWER INC.  
a Babcock Power Inc. company  
(formerly Riley Stoker Corporation)

*Presented at*  
Third Conference on Fossil Plant Inspections  
Sponsored by  
Electric Power Research Institute  
and  
Baltimore Gas and Electric Company  
August 13-15, 1991  
Baltimore, Maryland

RST-102

# RECENT EXPERIENCE IN THE INSPECTION AND ASSESSMENT OF BOILER HEADER AND STEAM DRUM CRACKING

by

Brian P. Holbrook  
Manager, Stress Analysis and Structural Steel  
and  
James P. King  
Manager, Boiler Evaluation

RILEY STOKER CORPORATION

## ABSTRACT

*A current industry concern is the increasing number of incidences of utility boiler header and steam drum cracking, found in units which have typically been in service more than twenty years.*

*The cracking is associated with both high temperature steam and lower temperature water carrying components. The failure mechanisms of stress rupture and fatigue are associated with the high temperature components, while fatigue due to thermal shock and/or corrosion are applicable to steam drum and lower temperature (water carrying) headers.*

*Case studies of recent and typical problems for headers and drums, including a methodology for assessing steam drum cracks are presented herein.*

## INTRODUCTION

During the past decade there has been an increasing number of incidences of failures or crack indications in utility boiler pressure components. This is primarily due to the aging of the steam generating equipment base. Also, the condition of the components has been severely impacted by the continued trend towards cycling and load-swinging modes of boiler operation. Of particular concern are the ongoing occurrences of header and drum internal cracking. This paper focuses primarily on case studies describing internal cracking in high temperature superheater inlet headers and main steam drums.

## BACKGROUND

Riley has evaluated many typical and several unusual cases of cracking and failures in headers and steam drums. An investigation generally consists of an on-site visit by a team consisting of stress analysis and metallurgical engineers, for visual and fiberoptic inspection and selective nondestructive testing, including replication, of the suspect component. If practical, a metal boat/core sample is removed for in-house laboratory examination, to determine the current component strength and the microstructure through the depth. After the metallurgical, mechanical and analytical evaluations, the probable cause with remedial

recommendations are forwarded to the client in a detailed technical report.

**Table 1** presents a listing of some typical problems and failures found in boiler header and drum components, together with their associated failure mechanisms. Note that the listing includes examples of problems found with virtually every major header component in a boiler. The prevalent mechanisms of failure are stress rupture (creep) and fatigue, often assisted by corrosion. Creep is due to long-term operation under stress, and temperature exposure at or slightly above the design value. Fatigue is associated with cyclic type operation, and can be induced by differential thermal expansion and/or by thermal transient (shock) effects. A high temperature header can be exposed to the effects of both creep and fatigue. Simplified creep and fatigue analyses, using linear damage techniques, can be utilized, and the results summed to determine the life expended to date for a critical header component. This information can then be utilized in calculating component remaining life based on the future mode of boiler operation.

A very common failure location is at the junction of a tube connector and header. Cracking, often leading to failure, has been found to exist at these locations, usually initiating in the toe of the external attachment weld. This cracking is often associated with, but not restricted to high temperature components. It has also been found to exist in risers to drums, and lower hopper and economizer header tube connectors. The most prevalent failure mode for header tube connector weld cracking is fatigue induced by differential thermal expansion. This condition can sometimes be accompanied or aggravated by an overtemperature condition. Typically, the cracking will initiate on the external surface on the tube side of the tube to header weld. The weld cracking is more likely to occur in tubes at the end of a header, and in

the shorter less flexible inlet tubes, which are more susceptible to both the axial (header) and radial (tube) thermal expansion effects, which occur during startup, shutdown, restart and load swing events. Reference 2 addresses this subject in detail.

## **HIGH TEMPERATURE SUPERHEATER INLET HEADER**

As a check on internal cracking and creep exposure, it is a normal procedure to select the high temperature superheater and reheater outlet headers for fiberoptic internal examination and metallographic replication. These components experience the more severe temperature and pressure operating conditions. In addition, the primary superheater outlet header is also often selected for inspection and evaluation, since it is exposed to the superheat temperatures prior to attemperation. In the past two years, Riley has had several experiences in the discovery and evaluation of internal cracking in the high temperature superheater inlet header. This case is considered unusual since the header is exposed to the cooler attemperated steam, and therefore has not been typically selected for evaluation in a condition assessment program.

In our experience, internal cracking has been found in five high temperature superheater inlet headers. In four identical boilers at one station, and in one boiler of similar design at another station. Riley performed a detailed evaluation of one of the four headers. The specified header material is SA106, Grade B carbon steel. The assessment program consisted of visual and fiberoptic inspection, review of operating records and expended life calculations.

The visual external inspection of the header and support components showed no abnormalities. However, the internal fiberoptic inspection, recorded on video tape, revealed the presence of fairly extensive bore

hole and longitudinal ligament cracking. The cracking is more prevalent at the steam inlet end of the header. The longitudinal cracks range from 1/4" to 3/4" long, are typically 0.040" wide at the mouth, and appear to be oxide filled. For this particular header the longitudinal hole spacing is 4 1/2" and consequently there were no crack link-ups between bore holes. The header was designed to the longitudinal ligament efficiency, and therefore the cracking is oriented in the longitudinal direction based on the governing value of hoop stress.

A review was performed of the available boiler operating data which consisted of, monthly logs, operational charts and some header thermocouple temperature values. The operational charts indicated some instability in the steam temperature values in the early stages of startup and restart events, especially when steam flow to the turbine is initiated. This initiation of steam flow is usually accompanied by a fairly severe steam temperature excursion which is experienced by the subject header components. This temperature transient is a ramp down from 770°F to 650°F in 2-1/2 minutes, followed by another ramp to 610°F in 3 minutes, for a total change in temperature ( $\Delta T$ ) of 160°F. Also, since the original specified design temperature for the header is 730°F, the component has also experienced some overtemperature exposure. Another item of interest from the records review was that a much higher value of spray water flow had typically been utilized to control superheat steam temperatures than the original predicted value.

Simplified fatigue and creep analyses were performed, as part of an expended life evaluation of the header components. As expected, fatigue was the dominant damage mechanism due to the effects of the many cycles of the severe steam temperature transient incurred during boiler startup and restart events. There was also a more minor

contribution to the cumulative damage due to creep. The results of the expended life analyses supported the presence of the internal header bore hole and ligament cracking.

Based on the results of the work tasks described herein for the high temperature superheater inlet header, the following recommendations were offered in the form of near term monitoring, analysis, and study items, which addressed the header cracking condition and overtemperature exposure until replacement is planned.

1. Monitor the length and width of the header cracks on a scheduled basis, at least during each maintenance outage. Perform fiberoptic inspections, with access via cut tubes at known crack locations. Take fiberoptic photographs for documentation of any crack growth.
2. To supplement the Item 1 monitoring, measure the crack depths at several locations, by use of the current injection technique. These values would then be used as input to more detailed fracture mechanics and finite element analyses to determine more definitive expended life values.
3. Conduct an engineering study, to provide the current boiler performance characteristics of the primary and secondary superheaters. Particular emphasis should be placed on steam temperature control, including use of spray water, during startup, restart and low

load operation. The results with recommendations of such a study would be beneficial in providing proper desuperheater spray requirements and superheater surface and tube material requirements in line with the current operational modes employed for the boiler.

4. In conjunction with Item 3, consider the incorporation of a two spray nozzle system for attenuation. The first spray nozzle is a low capacity, variable orifice nozzle that provides excellent spray water atomization at low spray flows. In series with this nozzle is a high capacity, fixed orifice spray nozzle with a separate water control valve. The two nozzle arrangement provides steam temperature control over the load range, with turndown capabilities of 20 to 30:1 or better depending on the control scheme incorporated into the system.

## STEAM DRUM INTERNAL CRACKING

Since 1989 Riley Stoker Corporation has been involved with several cases of ligament cracking within steam drums. The cracks have been primarily located within a circumferential ligament boiler bank tube field, and have propagated down into the tube bore holes. In all cases, the discovery of the cracking has been visually established utilizing routine maintenance inspections of the inside surface of the drums. **Figure 1** illustrates the inside surface of a steam drum having bore hole cracking. Common characteristics have included units that do not have economizer systems regulating feedwater into the drum, or which have damaged feed water distribution

systems within the drums. **Figure 2** illustrates the case of a disconnected feedwater pipe within a steam drum.

In addition to those common characteristics mentioned, variations in cyclic duty and/or the conversion of the unit to cycling or peaking service, operation of the unit exceeding specified heat up or shut down rates and extensive pitting or corrosion on the inside surface of the drums have also been found to be contributory. **Figure 3** illustrates the corrosion and pitting present in a circumferential ligament field where cracks have occurred.

The methodology employed by Riley in the investigation and assessment of the ligament and bore hole cracking consists of the following items:

- Drum Inspection - This phase represents a detailed visual inspection of the internal drum surface after the removal of all components which may conceal the extent of cracking. This includes baffles, dryer cartons, feedwater distribution pipes and troughs.
- Acquisition of Data - A mapping of all crack parameters including the specific location and orientation with respect to the ligament field, bore holes and length and depth measurements of the cracks is included in the acquisition of data.
- Surface Replication - Replication and documentation of specific cracks which were adjudged to be most critical is undertaken. Consideration is given to the size of the crack, the joining of several cracks in a specific ligament and the relationship of the extent of cracking with respect to a closely spaced ligament field.

- Assessment of Data - Modified area replacement and ligament efficiency calculations are performed to establish the criticality of the cracking. In addition, a fracture mechanics/finite element study is performed to further substantiate the results.
- Establish a Course of Action - Based upon the results of the data assessment, Riley has recommended utility programs which have included:
  - continued operation of the unit at reduced pressure with the establishment of a crack growth monitoring program.
  - repair of affected crack areas by grinding and/or welding.
  - review of plant operating procedures to include the control of drum feedwater temperature and water chemistry, or to control cyclic operation which causes frequent fluctuations in feedwater temperature.
  - drum replacement.

### SPECIAL CONSIDERATIONS

For those specific cases considered, the acquisition of the crack data is particularly significant. As will be explained in the analytical section, the evaluations have only been undertaken when the cracking has been limited to the circumferential area between tube bore holes. In general, the method used to evaluate the effects of the circumferential cracking is a comparison of the area replacement and ligament efficiency techniques as established within ASME Boiler and Pressure Vessel Code, Section I (1). Therefore, the evaluations were undertaken only when a specific cracking pattern within the circumferential ligament was evident. **Figure 4** illustrates the bore hole cracking in the circumferential ligament direction after dye penetrant examination. The cracking is often

branched in nature making the evaluation and acquisition of the data difficult. The crack data consists of obtaining the two length measurements of the crack. The measurements are used to estimate the projected ligament areas over which the cracks may exist. Should the ligament contain several cracks, the areas of the cracks in the specific ligament are summed. It should be recognized that the acquisition of the data is very subjective and the results may not be conclusive. Therefore, a further step involving a fracture mechanics evaluation was undertaken in conjunction with the crack measurements to substantiate the results made by the area replacement and ligament efficiency calculations. In general, the use of crack areas in the area replacement and ligament efficiency calculations represents a conservative estimate in determining the derated maximum allowable working pressure of a steam drum where cracking is present on the inside surface.

### ANALYTICAL APPROACH

The effects of the ligament and borehole cracks and their impact on the area replacement calculations are performed in accordance with paragraphs PG-33, PG-52 and PG-53 of ASME Code Section I (1). For the purposes of these calculations, crack-like penetrations in the drum shell are accounted for by the exclusion of the areas created by the cracks from the original drum metal in the ligament calculations. This method accounts for the loss of metal areas as a result of the cracking, where the crack area is subtracted from the ligament metal area which would normally be available. **Figure 5** illustrates the area replacement technique which compares areas of material loss to the areas available for replacement.

As in any area replacement calculation, the first step is to determine the minimum required vessel thickness at the original design



pressure. Assuming an equal distribution of metal area on both sides of the bore hole in question, the area replacement rules require that an equal amount of metal in excess of the minimum shell thickness, at 100% efficiency, be available to account for that area which has been removed by the bore hole. The area available is subsequently modified by the subtraction of the total crack area between the two specific bore holes from the area normally available. The area is further modified by the "F" factor from PG-33 (1), which basically compensates for the variation in pressure stress from the longitudinal to the circumferential direction. Thus, it is important to note the earlier specified requirement that the cracking pattern is predominantly circumferential in nature.

By comparison of the crack areas in a specified ligament to the area available for compensation, the relationship between area requiring replacement and area available for replacement can be determined. If the area required is larger than the compensation area available the cracking is significant, and the original ligament efficiency needs to be reevaluated in order to determine a reduced value of maximum allowable working pressure for the drum.

The ligament calculation is performed in accordance with PG-55 (1). The ligament calculation is based upon the average diameter of the hole and the distance between the holes considering the mean diameter of the drum shell. The ligament efficiency is then calculated as the ratio of the hole diameter minus the spacing between the holes divided by the hole diameter. In calculating the average hole diameter, the area of the tube bore hole is again modified by the addition of the cracked areas in a particular ligament and dividing by the actual thickness of the drum shell. **Figure 6** illustrates the technique involved in the development of the crack areas. The modified drum efficiency is then

used in the formulas of PG-27.2 (1) to establish a revised maximum allowable pressure for the drum.

### SUMMARY OF STEAM DRUM CRACKING EVALUATION

It is important to note the specific nature of the steam drum cracking which has been considered in the evaluation, in addition to the assumptions made with respect to the calculations performed. The acquisition of the crack data is part of the overall program to monitor the existence and growth of cracks over a relatively short period of time. The reproducibility of the crack data makes the method highly subjective, and the repeatability of the calculations at any given time is often difficult to achieve. However, as an interim measure, until the drum surface can be properly weld repaired or ultimately replaced, the technique described herein can serve as a short-term alternative.

The replication technique is used to substantiate, record and reproduce crack data. **Figure 7** illustrates a circumferential drum ligament which has been polished in preparation for a surface replica. This technique has been used by Riley to monitor selective cracks in specific ligaments. The cracks are identified and a replica is taken for specific crack locations for future monitoring purposes.

Large scale replicas are taken at ligament field locations. This provides a permanent record of the cracks and pits in each field. Subsequent replication of the same locations, at a later date, provides quantifiable measurement of changes in shape, area and number of cracks. In the laboratory, the replica is enlarged using a photo microscope and a point count of the crack area is graphically obtained. Based on a comparison of the data at two specific time intervals, a determination of crack growth can be made.

**TABLE 1**  
**TYPICAL HEADER AND STEAM DRUM PROBLEM AREAS**

<b>OBSERVATION</b>	<b>FAILURE MECHANISM</b>
<b>HEADERS</b>	
Economizer Inlet Header: Internal Cracking	Thermal and Corrosion Fatigue
High Temperature Header: Internal Cracking	Creep-Fatigue
High Temperature Header: Swelling	High temperature Creep
High Temperature Header: Local Bulging	Creep, Thermal Expansion or Abnormal Event
Header External Laminations:	Fabrication Defects
Header External Cracking:	Thermal Shock or Thermal Expansion
Header Tube Nipple Cracking:	Thermal Expansion Fatigue
Reheat Inlet Header Sagging:	Support Problem, Abnormal Event or Overtemperature Exposure
High Temperature Superheater Inlet Header: Internal Cracking	Thermal Fatigue
Lower Hopper Header to Header Tee Weld Cracking	Thermal Expansion Fatigue
<b>DRUMS</b>	
Internal Surface Pitting:	Oxygen Control in Feedwater
Internal Ligament and Bore Hole: Cracking	Thermal and Corrosion Fatigue
External Nozzle Weld: Cracking	Thermal Expansion Fatigue



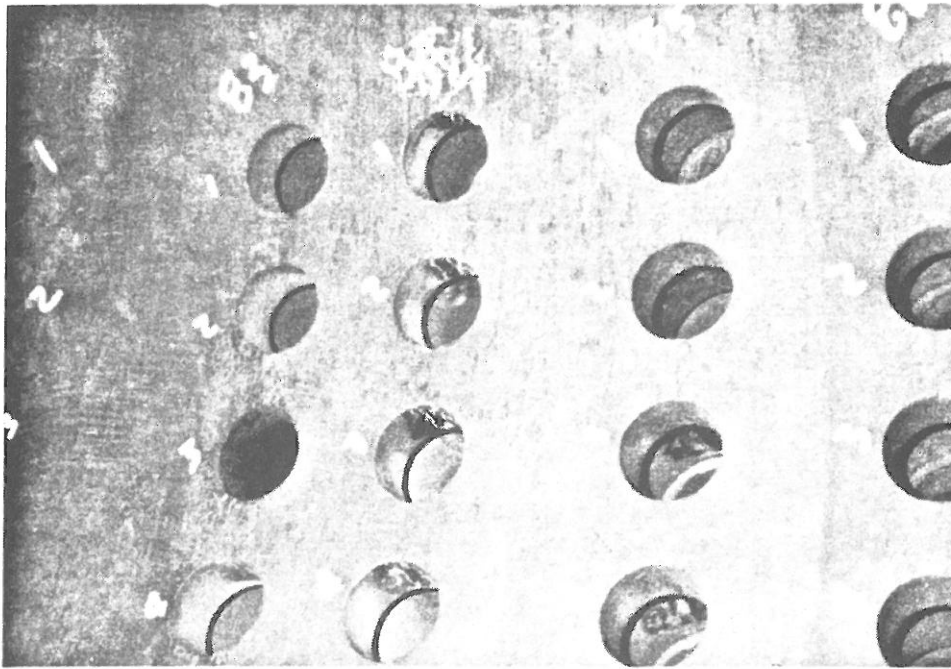


Figure 1 Inside surface of steam drum having bore hole cracking in the circumferential ligament

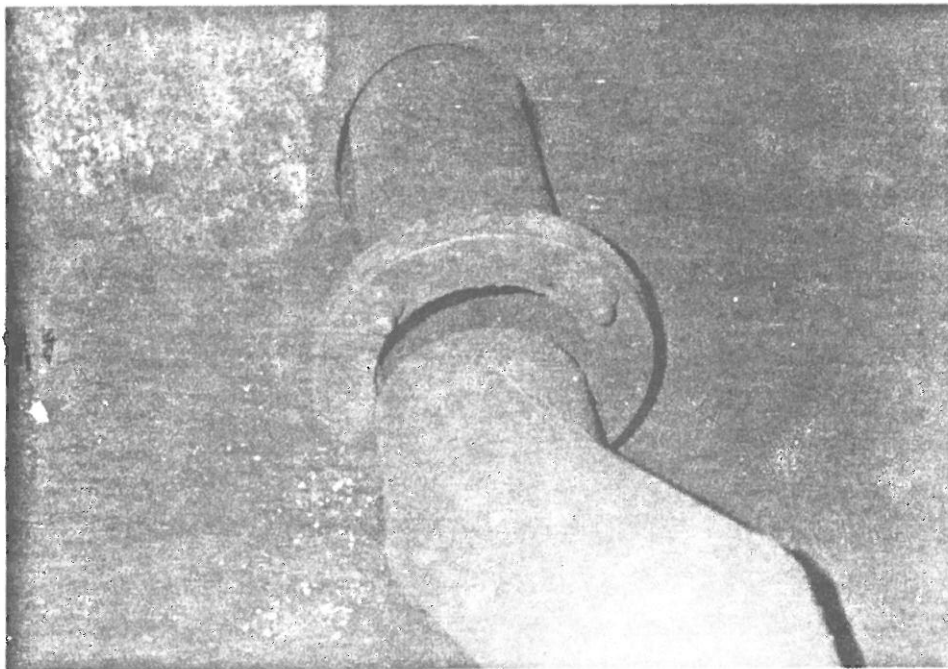


Figure 2 Feedwater distribution pipe broken at nozzle connection inside the drum head

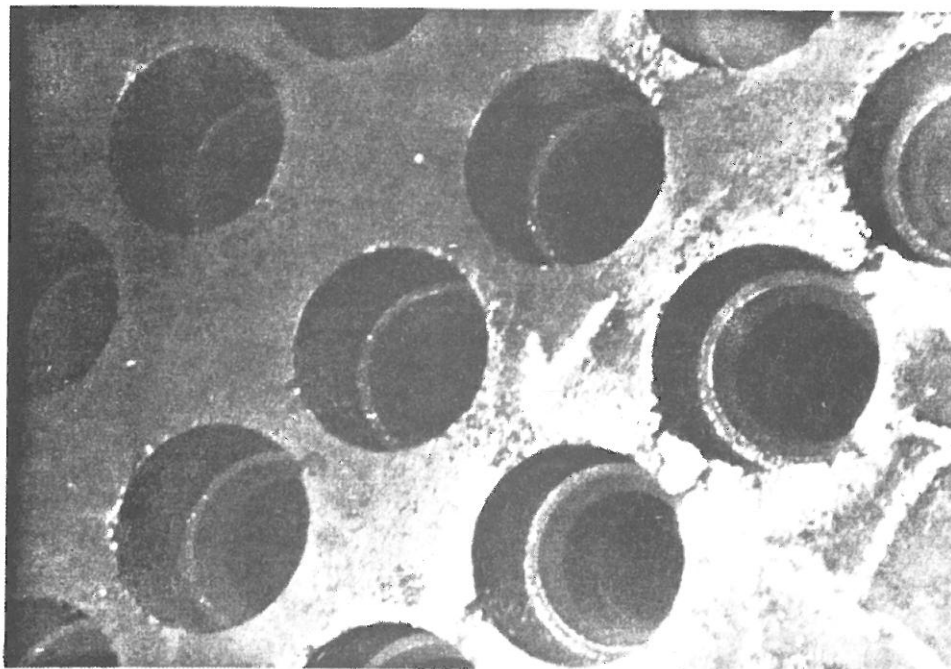


Figure 3      Pitting on inside surface of drum & circumferential link-up of bore hole cracks

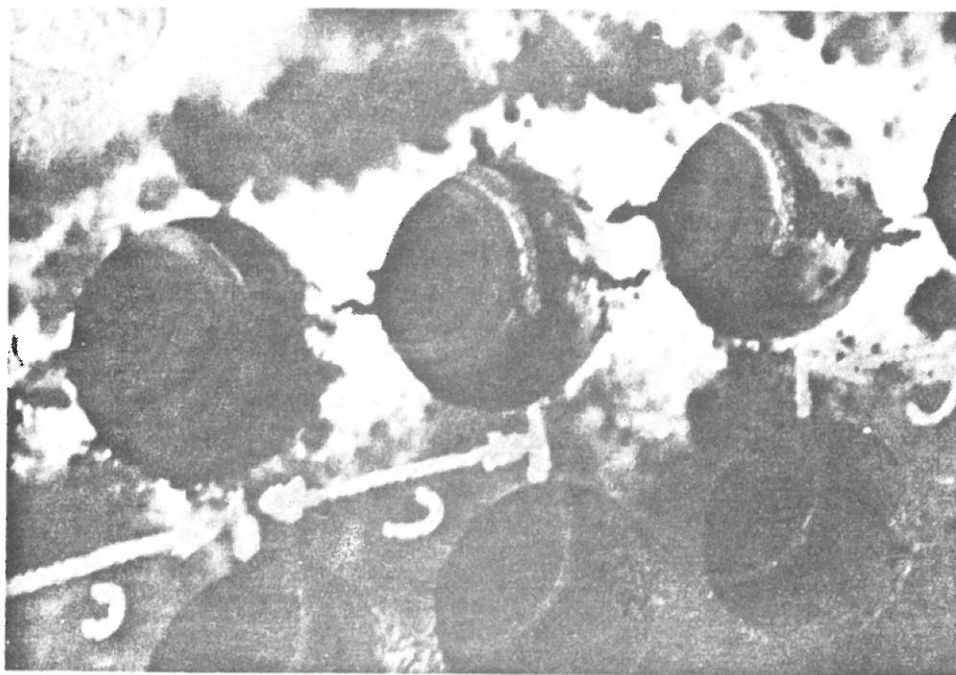


Figure 4      Circumferential steam drum bore hole arrangement. The photograph illustrates the appearance of cracks after dye checking.

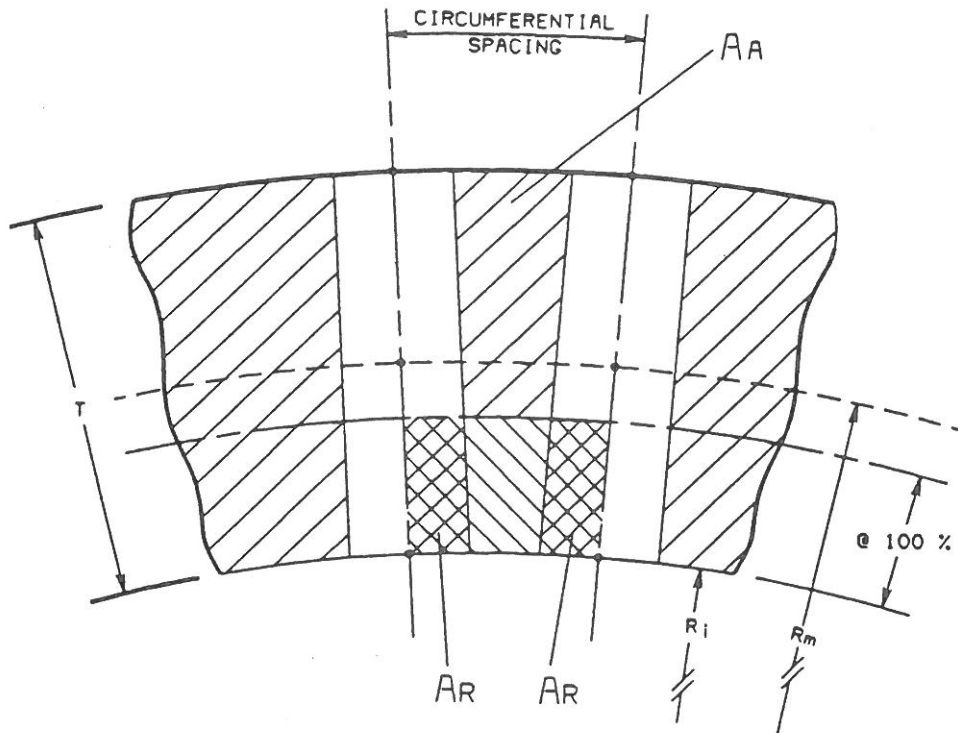


Figure 5 Area Replacement Technique

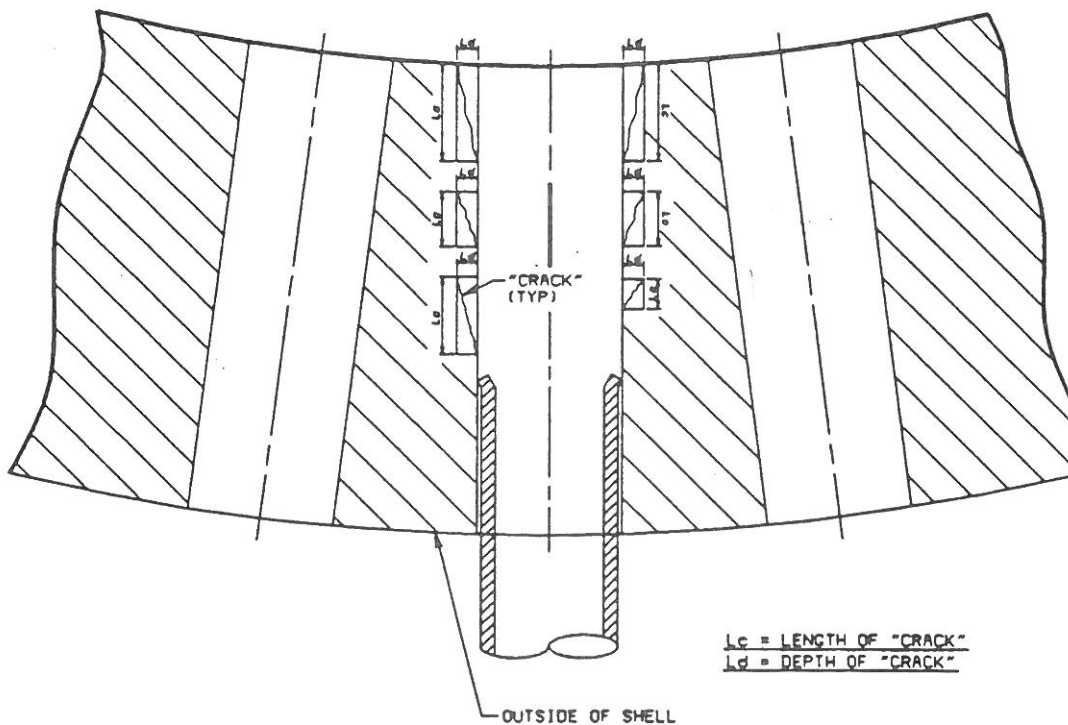


Figure 6 Example of the development of areas for the circumferential bore hole cracking

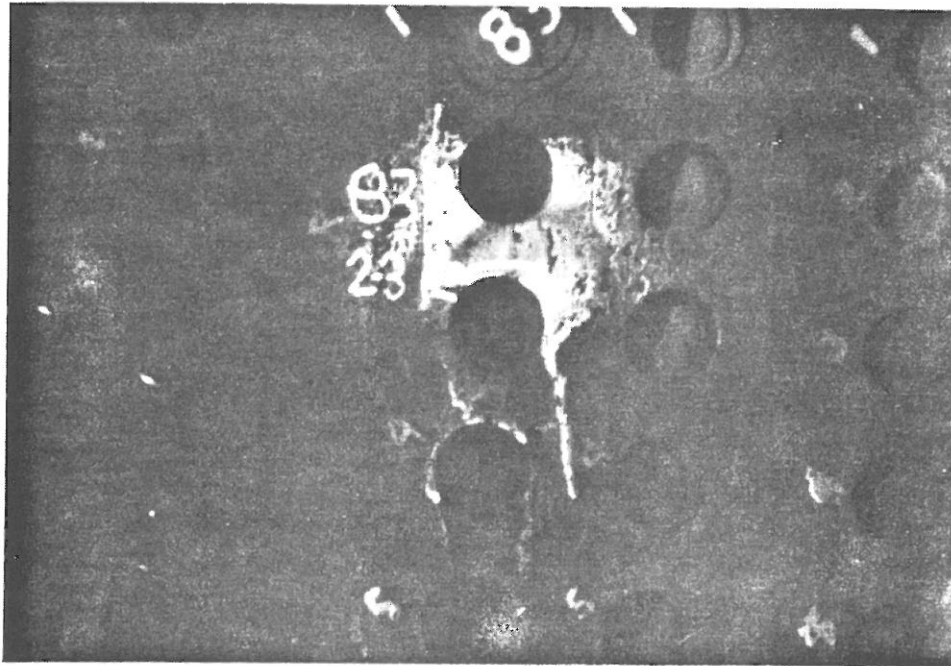


Figure 7 Drum circumferential ligament which has been polished in preparation for replication

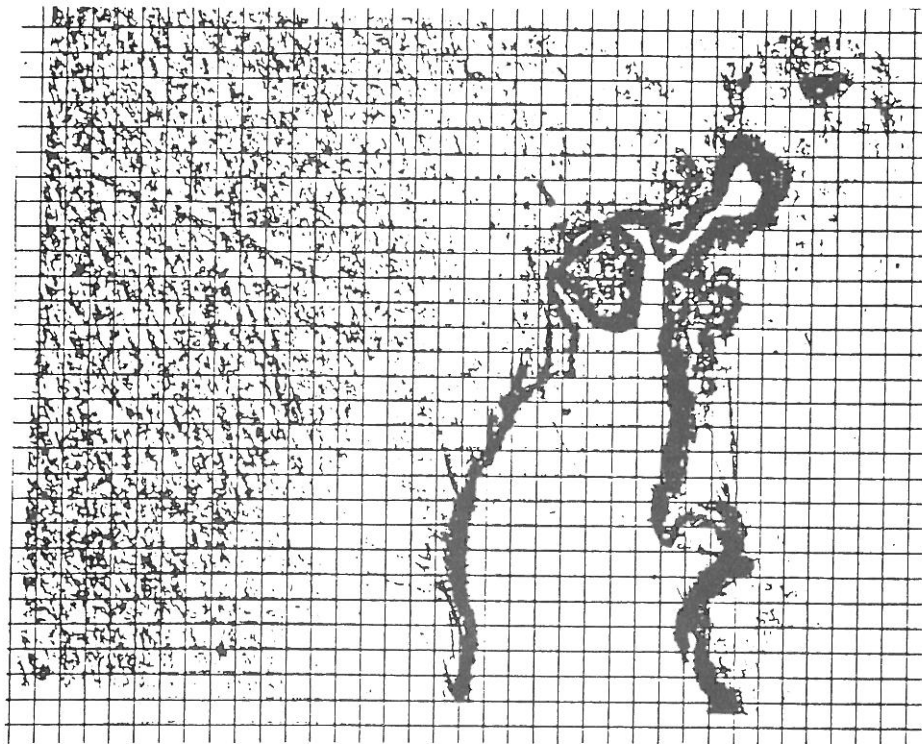


Figure 8 Example of point count technique on crack tip  
50X