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Radiant Superheater Outlet Header Crack Assessment and Replacement

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Presented at
Power Generation '93 Conference
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Abstract

In September of 1992, extensive bore-hole ligament cracking was discovered in a Radiant Superheater outlet header at Cajun Electric Power Cooperative's Big Cajun II Unit 1. Based on the results of an engineering analysis of the cracked header, the unit was returned to limited service until such time as the header could be replaced in April of 1993.

As the age of steam generating units increases, more and more high energy headers are experiencing ligament cracking, as was the case with Cajun Electric. In most documented cases, this phenomenon is due to thermal fatigue from cycling operation.

This paper outlines one utilities's experience in dealing with a potentially serious problem, addressing safety concerns while minimizing financial impact on the company. The scope of this paper covers the operating history of the unit, the discovery of ligament cracking, and the steps taken to assess and minimize risk while allowing for continued operation in the interim period until the header was replaced.

SCOPE

During a forced outage of Cajun Electric's Big Cajun II Unit 1 in September of 1992, extensive bore-hole ligament cracking was discovered in a P22 radiant superheater outlet header. Based on the results of an engineering analysis of the cracked header, the unit was returned to service derated until such time as the header could be replaced in April of 1993. The scope of this paper covers the operating history of the unit, the discovery of the ligament cracking, and the steps taken to assess and minimize risk during operation in the interim period until the header was replaced.

HISTORY

Cajun Electric Power Cooperative's (CEPCO) Big Cajun II Units 1 and 2 are identical 560 MW Riley-Stoker Turbo boilers (**see Figure 1**), which burn low-sulphur western coal (8200 BTU/lb). Each unit was designed to operate at 2620 psig, 1005/1005°F, with a steam flow capacity of 4.3 million lbs/hour. The units began commercial operation in 1980-81. Since that time, Unit 1 has logged approximately 85,000 hours of operation, with over 200 starts. Both boiler units were originally designed to be baseloaded; however, as is the case with many baseload designed boilers, the units are subjected to daily load cycling from 35 to 100 percent of full load capacity.

During the first two years of operation, Units 1 and 2 experienced severe steam temperature control problems. Outlet steam temperatures ran as much as 200°F above design. The installation of additional steam attemperation, along with control system modifications, improved temperature control considerably. Main and reheat steam temperatures could be operated at design, while Radiant Superheater outlet (RSHO) steam temperature continued to run approximately 100°F above design.

The Riley boilers utilize a split-header design for the outlet of the Radiant Superheater comprised of two 45 foot headers positioned end-to-end across the full width of the boiler. The headers are constructed of P22 (2 1/4 Chrome-moly) 20" 0D X 3.5", nominal wall, and weigh almost 20 tons each. They are located 200 feet above grade in the penthouse enclosure at the top of the boiler.

CRACK DISCOVERY

Initially, tube failures on the RSHO header terminal tubes occurred on Unit 2 in the boiler penthouse. A total of eight tube failures occurred between March of 1991 and August of 1992. All eight failures were thick-lipped stress ruptures due to creep fatigue of the T22 material as confirmed by metallurgical analysis. During repair of these tubes, bulging and swelling of adjacent tubes was discovered. However, testing of the RSHO headers, including replication, hardness testing, internal fiberoptic video, wet fluorescent magnetic partial testing, and bore-hole dye penetrant testing, revealed no significant findings.

In September of 1992, Unit I was forced out of service due to a failed terminal tube on the East RSHO header. This was the first known creep-related RSHO terminal tube failure on Unit 1. During this forced outage, more bulged and swollen tubes were discovered similar to the ones found previously on Unit 2. In addition, several minor cracks in the tube-to-header welds were found. When the tube which had failed in service was cut away from the header, severe cracking was discovered in the tube bore holes at that section. The cracks originated at the ID surface of the header and ran in a circumferential path through the ligament field between the bore holes. Less severe cracks ran longitudinally along the axis of the header.

Upon discovering the cracks, Babcock and Wilcox (B&W) Field Service was brought in to assess the extent of the damage. Video of the header internals revealed cracks in adjacent ligament fields. Even with a moderate layer of steam-side scale on the I.D. of the header, the cracks were plainly visible with sharp, clean edges that appeared brittle in nature.

Based on the preliminary video data, the worst cracking appeared to be in the tube bundles adjacent to one of the header outlet nozzles. Less-serious cracking was seen in the ligament fields of at least five other tube bundles. Ultrasonic shear-wave testing was used to determine the depth of the cracks in the worst areas. The deepest ligament crack as measured from the ID of the header towards the 0D was 1.7 inches. The header nominal thickness at this point was 3.5 inches, leaving 1.8 inches of sound ligament wall (**see Figure 2**). The data available at the time was not sufficient for B&W to make recommendations regarding the fitness for service.

Riley Stoker Corporation (RSC), was called in to examine the crack and provide CEPCO with an option in regards to continuing safe operation of the unit. The initial examination focused on fact finding as to the size of the cracks and to what extent the rest of the header was cracked.

Field metallurgical examination indicated that the exterior metal was still in good condition with no evidence of creep damage in the base metal of the header. With this information, preliminary minimum wall thickness calculations were performed. A recommendation was made to replace the header. If the unit was returned to service, it should be derated and operated as a base loaded unit. These recommendations were made for the short term, and it was recommended that additional evaluations be performed to determine how long the unit was capable of operating. This effort would take sixty days.

Based on the initial findings and recommendations made by RSC, CEPCO returned the unit to service on September 24, 1992. Two main issues were addressed in arriving at a decision to operate. First and foremost, CEPCO management and engineers were confident that the existing condition of the header posed no unusual risk to plant personnel and equipment in the short-term. When completed, the results of the fracture mechanics study performed by Teledyne Engineering would be evaluated to determine if continued operation was advisable in the interim period until the header could be replaced.

Secondly, the best preliminary estimate for delivery of a replacement header (in-kind or otherwise) was approximately six months, with an additional month required to install the header. An economic analysis indicated that a six-to-seven month unplanned shutdown of Unit 1 would have a damaging effect on the financial situation of CEPCO, whereas derated operation for that same period could be tolerated.

The imposed reductions in temperature and pressure resulted in a 35 percent capacity derating of approximately 185 megawatts. The unit was removed from dispatch control, and was base-loaded for the next six months. All of the steam safety valve settings were lowered to ensure that the interim operating pressure limits could not be exceeded. Steam temperature and RSHO header terminal tube metal temperatures were monitored closely to ensure compliance with the reduced temperature limits. Operational changes, such as modified sootblowing to allow boiler slagging, and changes in pulverizer operation, made boiler operation at the lower temperature limits possible.

FRACTURE MECHANICS STUDY

Riley subcontracted Teledyne Engineering Services to perform a separate independent evaluation of the header crack, and an estimate of the expected growth of the crack over the next six months. In addition to Teledyne's work, the Riley Stoker Stress Analysis Department, performed a separate evaluation using ASME Code compliance calculations based upon remaining sound material in the ligament area.

The Teledyne work involved developing a finite element computer model of the header to determine the strength of the remaining material of the header and fracture mechanics to determine the crack instability. The analysis showed that the pressure required to cause the metal to lose additional strength at the crack, to be greater than 4.3 times the derated pressure. In addition, the resulting crack growth over the six month period until a new header could be delivered, was insignificant, and would not weaken the critical section of the header. The analysis also took into account the header deadweight hanger loads.

As a separate and independent evaluation, a series of calculations were performed to determine the soundness of the remaining header metal. This entailed performing area replacement and ligament calculations. The calculations were based on the worst crack depth and crack length. This method of calculation accounts for the loss of metal area due to the crack. The conclusions of both Teledyne and Riley were that the header would leak before break, and that the unit could operate for the next six months at a derated condition (both temperature and pressure) until a replacement header could be fabricated and installed.

Riley offered the following operational guidelines[1] to CEPCO at the conclusion of the evaluation:

A. Eliminate any type of unit cycling, thus operate base loaded until the header sections are replaced.

B. Reduce steam/metal temperatures to 900°F alarm and 940°F trip on the radiant superheater outlet header.

C. Inspect other steam headers as soon as possible and to complete inspection of the present header to establish the extent of damage.

REPLACEMENT OPTIONS

With the unit back in operation, attention now turned towards procuring replacement headers. It was decided that both the East and West headers would be replaced at the same time. There were several reasons behind this decision. First was the fact that while there were no known flaws in the West header, the material condition was not known to any degree of certainty. Both headers should have seen nearly identical service therefore, until the cause of the cracking in the East header could be determined, the remaining life of the West header would remain questionable. Secondly, there would be an obvious economic advantage, both in header fabrication cost and construction cost, in replacing both headers at the same time. Finally, due to the physical arrangement of the boiler and Penthouse, removal of the West header at a later date with the East header still in place would be extremely difficult.

Several header material and design changes for load-cycling operation were considered in selecting replacement headers. Obviously, delivery was one of the most important selection criteria, and weighed heavily in the evaluation of design and material enhancements. Since the cause of the cracking in the East header was not known, it was difficult to determine what upgrades, if any, would prevent a similar occurrence. Also, it is likely that a significant portion of the P22 header material life was spent prematurely during the first two years of operation due to the temperature control problems mentioned earlier. With major improvements in the area of steam temperature control, an upgrade in material probably would not offer any significant enhancements. Newer materials, such as, P91 (9% chrome-moly) would offer a significant reduction in weight and improved resistance to thermal fatigue over P22, but the higher material and fabrication costs coupled with the longer lead time made this option less attractive. Finally, it was decided that the RSHO headers would not be the limiting factor for cycling operation, when the age and condition of the other boiler and turbine components were taken into account. Therefore, an upgraded design would not significantly enhance the remaining life of the boiler unit. After a review of available options, CEPCO elected to replace the headers in-kind.

Proposals for replacement headers were solicited from several vendors. Based on delivery schedule and cost, the project was awarded to Riley Stoker.

Upon release of the purchase order by CEPCO, the design was in full process so that the material could be ordered to meet the project schedule. The original drawings were used and updated to include new design standards and fabrication methods. With the review of RSC Construction Company, RCI Construction (RSC union Contractor) several design changes were made to help in the shipping of the header and installation of the new headers during the April 93 outage.

The procurement of the header pipe, block tees, terminal tube materials, including stainless steel safe ends, was made within one week of the order. The material procurement was the critical path to meet a delivery date of April 1, 1993.

The assembly of the header started the last week of January 1993. The work included making twelve girth welds, drilling four hundred ninety two tube connectors and welding the tubes in place. After all of the girth welds (3.5 inches thick, 20 inch OD.) had been x-rayed, none had to be reworked. Both header sections went into the stress relieving ovens, were dye checked twice, cleaned and painted prior to shipping on April 1, 1993.

DISCOVERY OF OUTLET PIPE CRACKS

In the process of removing the old headers, large cracks were discovered in the welds between the forged outlet tees and the outlet pipes on both headers. The cracks were discovered during machining of the pipe ends as they were weld-prepped. The outlet pipes are 20" 0D X 3.5" thick P22 material, similar to the headers themselves. The cracks originated at the ID of the pipes near the original weld root, ran the entire circumference of the pipes, and appeared to extend out towards the 0D nearly 50% through-wall in some areas. UT shear-wave testing performed by Riley indicated additional flaws in the downstream elbow welds on all four outlets, similar to the other cracks. Cracks were also discovered in the radiograph plug holes on all four outlets, though these were minor in nature and easily repaired. In all, eight 20" diameter welds were machined completely out and re-welded. No additional cracks were discovered downstream of the elbows.

CODE COMPLIANCE

The Louisiana Boiler Inspection Law requires an annual internal boiler inspection by a licensed inspection agency for operating license renewal. At the time the header cracks were discovered, the State license for Unit 1 was due to expire in three weeks. While the discovery of a crack or flaw would not necessarily force the State to revoke a current license, it might prevent the renewal of an expired license.

The National Board Inspection Code (NBIC) and the State law do not address cracks or flaws in welded boilers, but do allow operation of riveted-plate boilers with similar flaws, under certain conditions. The only options available for welded pressure vessels and boilers is repair or replacement of the flawed component. Obviously, repairing the header was not practical due to the header geometry, limited access at the cracks, and uncertainty in the condition of the base metal.

CEPCO's In-Service Inspection Agency, Factory Mutual Engineering, was notified of the cracks, and was given access to all data and staff involved with the problem, including the preliminary report by Riley Stoker which stated that in Riley's opinion, the flaws did not constitute an immediate safety concern to CEPCO, and that additional cracking should lead to leaks at the 0D of the header, as opposed to a catastrophic failure of the header wall. Representatives from Riley met with Factory Mutual and Cajun Electric, on Cajun's behalf, to discuss the findings of the header study, and address any concerns raised by Factory Mutual. Still, Factory Mutual declared the cracks an "existing condition" at the time of inspection, and issued a report to the State recommending that the unit not be allowed to operate until the headers were repaired or replaced. The issue was resolved only when the headers were replaced.

ON-GOING CONDITION ASSESSMENT

Due to the age and operating history of the units, and in part to the discovery of the header and heavy-wall pipe cracks, Cajun has developed and implemented an on-going Boiler Condition Assessment program with Riley Stoker for units 1 and 2. Various metallurgical testing techniques are being used to evaluate the condition of all critical boiler components and headers as well as boiler external high energy steam piping.

Upon discovering the cracks in the Unit 1 RSHO header, Unit 2 RSHO headers were inspected at the first opportunity. Since that time, all of the major headers on both units have been inspected. As of this date, no flaws or cracks have been discovered in any other components in either unit.

SUMMARY

Sections of the cracked header and heavy-wall pipe weld specimens have been sent to Riley Stoker and an independent metallurgical lab for failure analysis. As of this writing, the results from the metallurgical tests are still pending. All of the crack surfaces in the heavy-wall pipes contained a heavy layer of steam-side oxide scale, indicating that they may have existed for several years. However, the header cracks appeared clean, sharp, and free of scale, and may have occurred fairly recently. It is possible that the damage observed in these two areas occurred at different times and could be the result of separate events or failure mechanisms. The hypothesis that the header cracking may have occurred as the result of a single or few operating events is of particular interest in that identifying the cause might prevent future occurrences. The fact that Unit 2 had significantly more tube failures but no header cracking may help to support this contention. The risk posed by the defects found in the heavy-wall pipe welds is probably significantly greater than that of the ligament cracks found in the header.

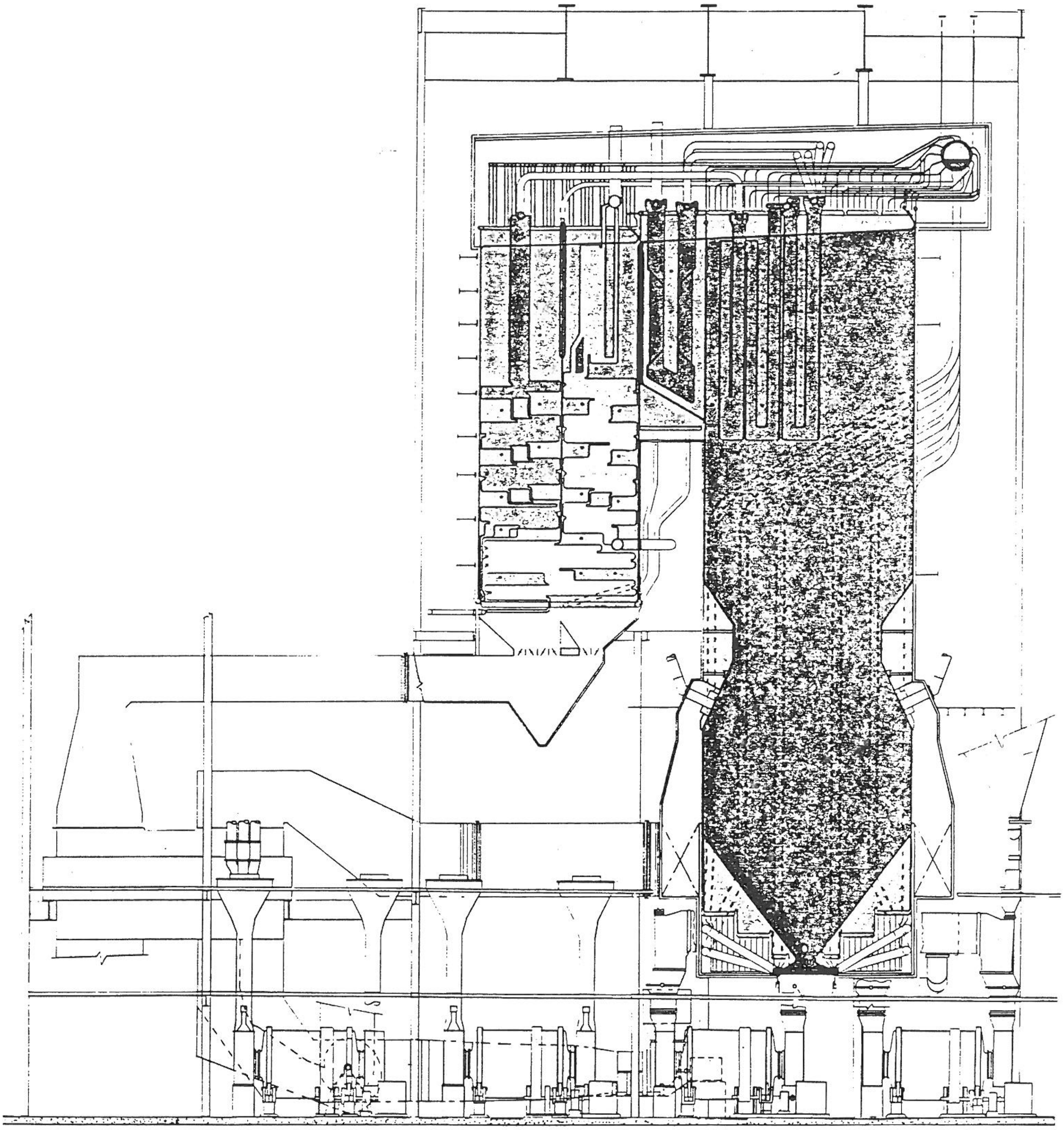
The involvement of the boiler OEM at the outset of the crack discovery was crucial in reducing the financial impact of the problem. Riley provided invaluable support through all phases of the header evaluation and replacement process.

REFERENCE PAGE

1. Metallurgical Report - Inspection of Radiant Superheater Outlet Header, Big Cajun II Boiler 1, New Roads, LA, October 13, 1993 by Dr. David Kalmanovitch

2. Radiant Superheater Outlet Header Assessment, Power Services Division Contract No. 93506, December 10, 1992 By Brian P. Holbrook, Manager of Stress Analysis Department

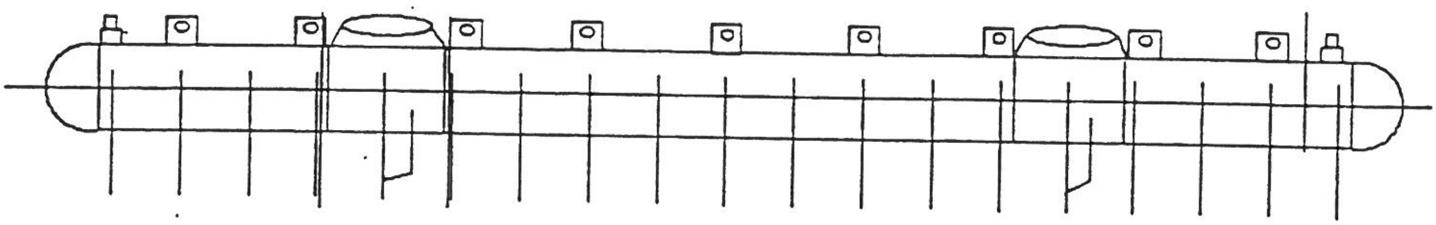
3. Evaluation of Big Cajun II Radiant Superheater Outlet Header by Teledyne Engineering Services, December 8, 1992.



BIG CAJUN NO. 2
UNITS NO. 1 & 2
New Roads, Louisiana
Cajun Electric Power Cooperative, Inc.

Two 4,300,000 lbs per hour — 2950 psig design — 2620 psig operating — 1005/1005F
Fired by Pulverized Coal
Bovay Engineers, Inc. and Burns & Roe, Inc., Consulting Engineers

FIGURE 1



FRONT VIEW

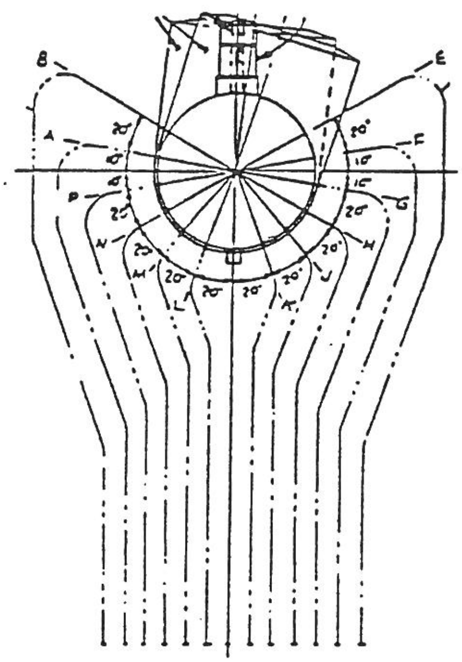


FIGURE 2