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SUBJECT: Forwards description of difficulties encountered & summary of investigations re RCS loop weld insp program.

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AEP:NRC:0980Q

Donald C. Cook Nuclear Plant Unit 2
Docket No. 50-316
License No. DPR-74
UNIT 2 RCS LOOP WELD INSPECTION PROGRAM

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555

Attn: T. E. Murley

October 28, 1988

Dear Dr. Murley:

During the Cook Nuclear Plant, Unit 2, Steam Generator Repair Project, difficulties were encountered welding the reactor coolant piping elbows to the steam generator nozzles. As a result, the NRC, which participated in a number of discussions, presentations and on-site inspections, made recommendations concerning these welds.

The attachment to this letter describes the welding difficulties encountered, summarizes the results of our investigations, presents our conclusions regarding the installed welds and describes supplemental measures that are being taken to provide additional assurance regarding the integrity of the installed welds. We believe that the NRC concerns and recommendations have been addressed and that the actions described in the attachment close any open items regarding the welding issue.

This document has been prepared following Corporate procedures which incorporate a reasonable set of controls to ensure its accuracy and completeness prior to signature by the undersigned.

Sincerely,

M. P. Alexich
Vice President

12

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1/1

MPA/eh

Attachment

cc: D. H. Williams
W. G. Smith, Jr. - Bridgman
R. C. Callen
G. Charnoff
G. Bruchmann
A. B. Davis - Region III
NRC Resident Inspector - Bridgman

ATTACHMENT TO AEP:NRC:0980Q

UNIT 2 RCS LOOP WELD INSPECTION PROGRAM

A. Introduction

During the steam generator repair project at Cook Nuclear Plant Unit 2, difficulties were encountered welding the steam generator primary nozzles to reactor coolant pipe elbows. The purpose of this attachment is to describe the welding difficulties encountered, summarize the results of our investigation, state our conclusions regarding the full acceptability of the installed welds, and describe supplemental measures we are taking to provide additional assurance regarding the integrity of the installed welds.

B. Description of Welding Difficulties

The steam generator nozzle to reactor coolant elbow weld joint is a compound bevel, single-U groove weld oriented in the 6G position (Figure 1). The nozzle is cast carbon steel (SA-216 Grade WCC) on which 308L stainless steel buttering is applied with a flux-cored arc welding process over an initial underlay of 309L. The root passes of the nozzle to elbow weld are 308 stainless steel manual gas tungsten arc welds, and the fill is 308 deposited with an automatic gas tungsten arc welding machine. The difficulty encountered was in obtaining complete fusion along the 308L buttering interface when welding progressed above the change in joint bevel. Sporadic weld pool behavior and poor wetting were observed when the gas tungsten arc weld was made over the flux core deposited buttering. Visually observable cracking occurred on the nozzle side of the joint due to poor fusion at the nozzle caused by the tight joint access, poor wetting, and the force of gravity. The poor fusion at the nozzle created a notch at the interface between the weld metal and nozzle buttering from which a crack was propagating as a result of shrinkage stresses in the deposited layer.

The surface cracking was relieved by welding technique changes. To reduce shrinkage stresses in the joint, bead width was reduced by eliminating torch oscillation and depositing stringer beads. Bead sequencing was changed to start each layer at the nozzle side of the joint first and progress towards the elbow side. These welding technique changes relieved the surface cracking by reducing shrinkage stresses in the weld joint. Although shrinkage stresses were reduced, the tight joint access continued to cause lack of fusion defects after the cracking problem was solved. The lack of fusion defects were embedded in the weld, occurred in the middle 1/3 of the thickness of the weld joint, and were detectable by radiography. Lack of fusion detected by radiography is a linear indication per ASME Section III, and is required to be repaired.

As a general practice during welding of the steam generator nozzle to reactor coolant elbow welds, informational radiographs were taken of repairs, and at roughly 1/3 fill, 2/3 fill, and full weld fill before the final code-acceptance radiographs were taken. During fabrication of the eight steam generator nozzle to reactor coolant elbow welds, almost 100 in-process informational radiographs were taken in addition to the final code-acceptance radiographs. This extensive radiography provides a high level of assurance that relevant radiographic indications were detected and repaired.

C. Chemical and Metallurgical Analysis

The investigation of the welding difficulties included evaluation of chemical and metallurgical factors as potential causes and determination if any degradation of mechanical properties had occurred. During repair of steam generator 21 hot leg, a small piece of fracture surface was removed for metallographic examination. Drillings were also taken on the 308L buttering material for chemical analysis. Weld metal samples were also removed for analysis from steam generator 23 cold leg and steam generator 24 hot leg.

Drillings from the 308L buttering were sent to an independent testing lab for chemical analysis. As shown in Figure 2, the chemical analysis results are normal for 308L deposited weld metal. Chemical analysis of the all-weld metal specimens taken from steam generator 23 cold leg and 24 hot leg were normal for 308 deposited weld metal. There was no evidence of chemical elements as a contributing factor in the welding difficulties encountered.

Ferrite content in austenitic stainless steels is important to resist weld solidification cracking. Field measurements of ferrite content were taken using a Severn gage on both the 308L nozzle buttering and the 308 weld metal. As shown in Figure 2, the measurements were within the desired ferrite content range. Ferrite content estimates were also made by the Edison Welding Institute on the nozzle buttering and weld metal using metallographic examination. The metallographic estimates confirmed the field measurements. Ferrite content was within desired levels, and was determined not to be a contributing factor to the welding difficulties.

Three samples were taken from the steam generator nozzle to reactor coolant elbow weld and sent to Edison Welding Institute for metallurgical analysis. The samples from steam generator 21 hot leg contained one face of a crack fracture surface and 308L buttering material. Scanning electron microscopic examination revealed evidence of ductile rupture throughout the fracture surface. A microhardness traverse across the sample correlated to acceptable strength levels for 308L deposit, and a bend test revealed no signs of embrittlement. The microstructure was normal with no sign of degradation or ferrite dissolution, and there is sufficient theoretical basis and documented research to conclude that the heat of repair activities do not degrade the microstructure. The analytical data from the Edison Welding Institute investigation supports the conclusion that cracking originated at the fusion line and propagated due to tensile overload.

Two all-weld metal samples were removed from steam generator 23 cold leg and steam generator 24 hot leg. Metallurgical analysis by Edison Welding Institute revealed normal microstructures with no signs of degradation, and microhardness traverses across the samples correlated to acceptable strength levels for 308 deposit. Further, the service temperature is far below the range in which ferrite dissolution would occur during the steam generator lifetime.

The Edison Welding Institute was able to provide an explanation for the sporadic weld pool behavior and poor wetting noted earlier. This behavior is not uncommon when gas tungsten arc welding over deposits made by a flux-bearing process, such as flux-cored, shielded metal arc, or submerged arc welding. Flux entrapped in the microstructure of these deposits is remelted and acts on the gas tungsten arc welding pool to impede weld pool fluid flow and wettability. Welding technique changes compensated for these conditions. Metallurgical evaluation indicated that the 308L buttering material was not a primary cause of cracking.

D. Evaluation

In conclusion, a thorough investigation has been made of the potential causes of the welding difficulties encountered in Cook Nuclear Plant steam generator nozzle to reactor coolant elbow welds. This investigation has revealed no evidence of metallurgical degradation, and no reason to expect anything but the full mechanical properties of these weld joints. Numerous informational radiographs have been taken during the construction of these weld joints, and detected indications have been removed. Repairs have been completed on all steam generator nozzle to reactor coolant elbow welds, and they have been accepted by ASME Section III radiography. Section XI ultrasonic examination is in progress. In addition to the investigative efforts and code-required examinations described above, we have undertaken supplementary examinations to conclusively demonstrate the integrity of these weld joints.

E. Supplemental Examinations

In addition to in-process informational radiographs and final code acceptance radiographs, all Unit 2 steam generator nozzle to reactor coolant elbow welds have been radiographed at an angle to the weld joint. These radiographs were oriented along the 12.5^{o} joint prep angle shown in Figure 1. This was done to provide maximum detectability of any planar indications on the nozzle side of the joint.

Figure 4 shows the code required ultrasonic examination volume for preservice and inservice examinations of the steam generator nozzle to reactor coolant elbow welds. As discussed previously, all indications on these welds occurred in the middle 1/3 of the thickness, outside of the code required examination volume. As an additional level of assurance, we will perform essentially full volume ultrasonic examination of these welds during the Unit 2 preservice and inservice inspections. This expanded ultrasonic examination volume will cover the area of interest for inservice monitoring of the integrity of these welds.

In addition to the Section XI ultrasonic examination being performed on the nozzle to elbow welds, we are going to perform a second Section XI ultrasonic examination of all welds after hydrostatic and pre-operational testing. This subjects the welds to one pressure/temperature cycle, and the subsequent ultrasonic examination will serve as the official Section XI preservice baseline.

The inservice inspection program for the first 10 years following installation of the nozzle to elbow welds (second 10-year interval) will be front loaded to the maximum extent permitted by ASME Section XI code. Four steam generator nozzle to reactor coolant elbow welds will be examined during the first period of the interval (at the next scheduled refueling outage), two during the second period, and two during the third period.

The ultrasonic examinations described to this point will be conducted using a technique which has demonstrated sensitivity on an actual defect in a nozzle to elbow weld. On October 15, 1988, a very thin, 3/4" long radiographic indication was detected on steam generator 23 cold leg. Before the indication was removed, we characterized various ultrasonic transducers on this indication based on amplitude response, signal-to-noise ratio, and screen presentation. Superior performance was obtained using a 45°, 1 MHz, dual element (two 1/2" x 1" crystals), fixed roof angle, refracted longitudinal wave transducer. At code scanning levels, this indication produced a 50% DAC (Digital Amplitude Correction) peak amplitude response with a signal-to-noise ratio of better than 4:1. 50% DAC is a recordable indication by ASME Section XI criteria.

When ultrasonic transducer characterization was complete, the size of the indication was quantified by a cycle of grind/penetrant test/photograph/depth measurement. A layer of roughly 1/16" was removed by grinding during each cycle. Using this method, the indication was determined to have a through-wall dimension of 1/4", maximum length of 7/8", at a depth of 1-1/8" from the outside diameter. According to ASME Section XI, 1983 edition plus Summer 1983 Addendum, this indication is subsurface and has a through-wall dimension to component thickness ratio (a/t) of 4.5%. The allowable preservice inspection planar indication size in Table IWB-3514-2 is less than a/t = 7.8%. Therefore, the ultrasonic technique to be used on Cook Nuclear Plant steam generator nozzle to reactor coolant elbow welds has demonstrated capability to detect in-situ reflectors which are smaller than code allowable sizes. This gives a high level of confidence that the ultrasonic examination technique provides a valid assessment of the integrity of the installed welds for preservice and inservice inspections.

As an additional qualification of the ultrasonic examination technique, we have completed design of a steam generator nozzle to reactor coolant elbow mock-up block. We plan to have this block fabricated from the same cast carbon steel and stainless steel material specifications as the nozzle and elbow, and 308L buttering will be applied to the cast carbon steel. The block will have two sets of side-drilled holes at 1/4T, 1/2T, and 3/4T, and two 0.3" deep by 0.06" wide ID notches. Five ID cracks will be induced ranging from less than Section XI allowable sizes to greater than Section XI allowable sizes, and four flaws will be embedded in the middle-third of the weld joint ranging from less than Section XI allowable sizes to greater than Section XI allowable sizes.

F. Summary

1) On the nozzle side of Cook Nuclear Plant Unit 2 steam generator nozzle to reactor coolant elbow welds, cracking was caused by notches formed at the fusion line which propagated due to shrinkage stresses in the joint.

2) Metallurgical and chemical analysis has verified the integrity and mechanical properties of the installed welds.

3) All nozzle to elbow welds have been accepted by ASME Section III radiography and ASME Section XI ultrasonic testing is in progress.

4) Supplemental examinations have been completed or are planned to further demonstrate the integrity of the Unit 2 nozzle to elbow welds:

   A) Radiography angled along the weld joint prep has been completed;

   B) Full volume preservice and inservice ultrasonic examination;

   C) Section XI ultrasonic examination of all Unit 2 steam generator nozzle to reactor coolant elbow welds before and after pre-operational testing. The examination after pre-operational testing will constitute the Section XI preservice baseline.

5) The Unit 2 second interval ISI program will be revised to require the examination of four nozzle to elbow welds in the first period, two in the second period, and two in the third period.

6) Use of a preservice and inservice ultrasonic examination technique which has demonstrated capability to detect in-situ flaws smaller than allowable by Section XI criteria.

7) A nozzle to elbow mock-up block has been planned which will provide an additional reference for ultrasonic procedure qualification.

G. Conclusion

The items discussed above demonstrate the full acceptability of the installed welds, and with our committed actions for ultrasonic examination, we have satisfactorily resolved the issues on steam generator nozzle to reactor coolant elbow welds.

SG NOZZLE TO REACTOR COOLANT ELBOW JOINT DETAIL

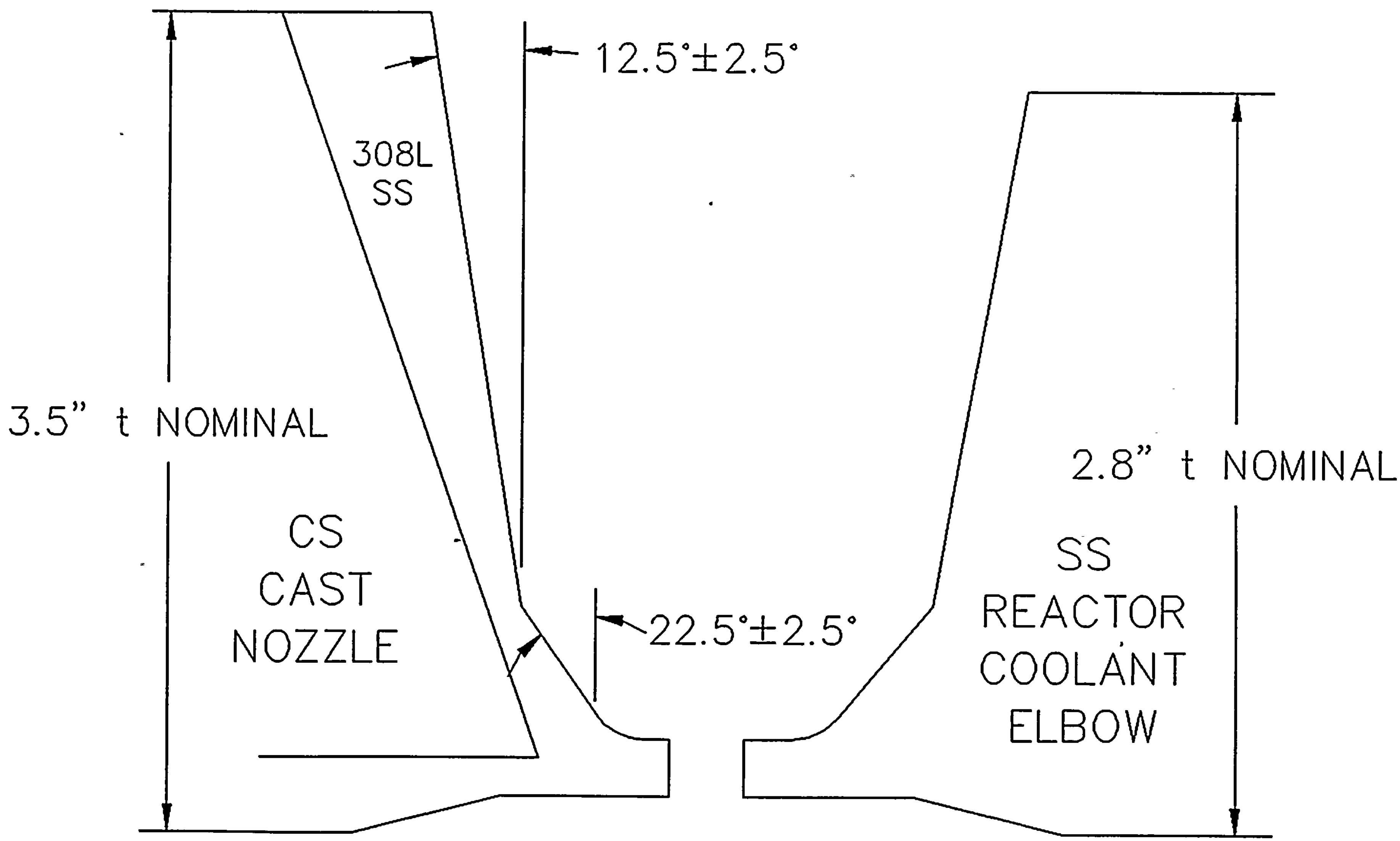

FIGURE 1

FIGURE 2

CHEMICAL ANALYSIS:

	C	Cr	Ni	Mo	Mn	Si	P	S	Cu
E308LT-1 Range	.04	18.0-21.0	9.0-12.0	0.5	0.5-2.5	1.0	.04	.03	0.5
Buttering Specimen (#21 Hot Leg)	.045	19.55	10.0	.04	1.3	0.58	.024	.012	.04

Trace amounts of Ti, Al, Sb, and Sn were also present, but insignificant. The slightly higher carbon of the deposit is the result of dilution from the type 308 filler metal used to weld the reactor coolant pipe to the nozzle.

E308 Range	.08	19.5-22.0	9.0-11.0	0.75	0.5-2.5	0.3-0.65	.03	.03	0.5
#23 Cold Leg	.06	20.87	9.11	0.10	1.69	0.49	.039	.012	0.09
#24 Hot Leg	.05	21.54	9.28	0.08	1.65	0.48	.036	.014	.07

Only one chemical analysis was performed on these specimens. Phosphorous heat analysis supplied with electrodes was within specification. Slightly higher phosphorous determined to be insignificant from standpoint of weldability and service integrity.

NOTE: Single Values are Maximum

FERRITE READINGS: (Severn Gage)

Nozzle Buttering	5 - 7 FN
308 Weld	10 - 12 FN

Stainless steel weld metal is within 5 to 15 FN.

FIGURE 3
METALLURGICAL ANALYSIS

Performed by the Edison Welding Institute

SCANNING ELECTRON MICROSCOPE ANALYSIS:

Evidence of ductile rupture found on entire fracture surface.

HARDNESS TESTS:

84-96 Rb (#21 HL)

Correponds to acceptable tensile strength for 308L deposit (buttering).

94.5 Rb (#24HL) and 94.2 Rb (#23 CL) averages

Corresponds to acceptable tensile strength for 308 deposit (weld).

MICROSTRUCTURE:

1. Weld metal is normal. No sign of degradation.
2. Heating during repair will not degrade microstructure.

All evidence supports conclusion that crack initiated at tie-in region, and propagated due to overload.

ASME SECTION XI ULTRASONIC EXAMINATION VOLUME
SG NOZZLE TO REACTOR COOLANT ELBOW

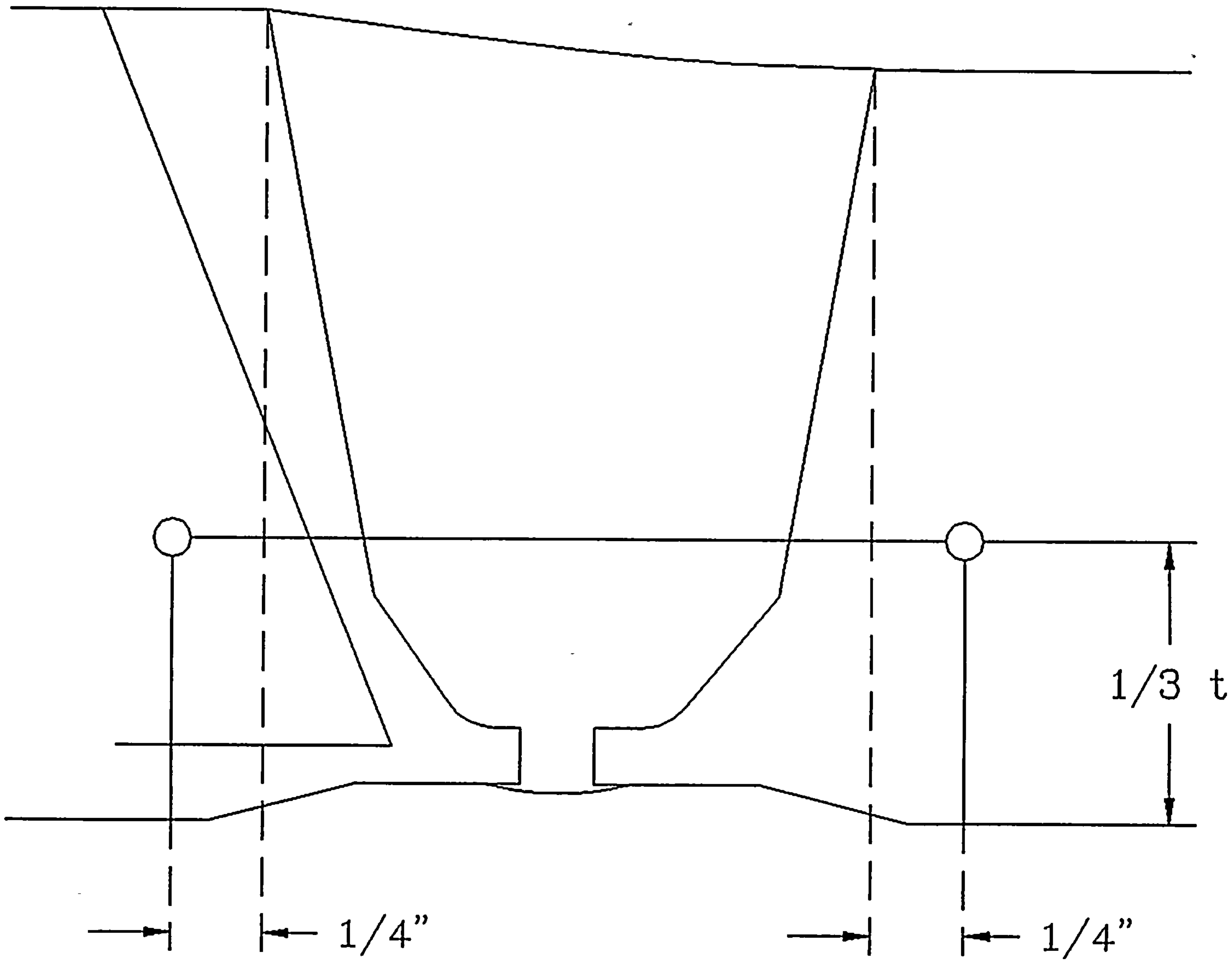

FIGURE 4