BEAM SPREAD CORRECTION

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Beam spread measurements have been a Section XI requirement since the 1973 Summer Addenda, Paragraph I-4460, became effective. Section XI 1977, paragraph IWA-2232(a) refers to Section V, Article 4 for ultrasonic examination rules. The latter Paragraph T-431.3 requires beam spread measurements at intervals no greater than 3 months. The beam spread measurement technique is in the nonmandatory appendix as Paragraph B-60, so other techniques may be used.

No use of beam spread measurements is specified in the Code. Unofficial but generally recognized justification for continuing the requirement include (a) identification of beam variables to assist in selection of a search unit for a reexamination at a later date, (b) to have the information available when it is determined how to perform beam spread correction of indication dimensions.

During the February 1979 Inservice Examination of the Rochester Gas and Electric Company's Robert E. Ginna plant, a complete mechanized examination of the reactor pressure vessel weld was accomplished. These examinations disclosed the presence of several ultrasonic reflectors due to imperfections in the weld or associated base metal. Most of these reflectors were readily determined to be within the ASME Code acceptance standards. Therefore, further evaluation of these reflectors was not necessary and they were recorded for future reference. One indication in the nozzle-to-shell weld of Nozzle N2A was of an amplitude requiring further evaluation of its significance. In order to perform a fracture mechanics evaluation of the significance of this reflector, the true size of the flaw was required. A process of evaluation of the examination data was undertaken in an attempt to determine the size and nature of this reflector. Also, controlled experiments were performed to confirm the accuracy of the theoretical calculations and considerations.

Recorded mechanized ultrasonic examinations permit reading indications 20% DAC and greater. The 0°, 45° and 60° examinations from the inside surface of the vessel as well as the 45° examination from the nozzle bore show no record of the indication detected with the 15° angle beam longitudinal wave from the nozzle bore. The plane of maximum sensitivity is the same for the 15° nozzle bore and the radiographic examinations. This is supported by the fact that no ultrasonic response from the imperfection was obtained with the 0°, 45° and 60° examinations performed on the vessel wall or from the 45° examination also performed from the nozzle bore. These observations indicate that the reflector is directional and is oriented essentially perpendicular to the 15° longitudinal wave sound beam. If the reflector was a rough and faceted crack, ultrasonic indications would have been obtained from the other examination beams which also interrogated this area. If the reflector were more globular, or rounded, responses to these other examination angles would also have been noted. Based on experience in vessel fabricator shops, this type of thin planar slag has been noted on other occasions. Furthermore, a review of the fabrication radiographs

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of this weld show the presence of entrapped planar slag. This was confirmed by several Level III reviewers of the radiographs.

Therefore, it was concluded that the reflector is thin, smooth, and in a plane perpendicular to the 15° beam. The writer has witnessed the excavation of a similar indication in a fabrication shop. The shop-excavated indication was not detected with the 0°, 45° and 60° ultrasonic examinations but was repaired due to a clear radiographic indication. Excavation revealed a 1/32-inch·thick, smooth slag inclusion measuring 1-inch throughwall by 3 inches long near midwall at the fusion line of a nozzle-to-vessel weld. Due to the similarity of the nondestructive examination responses, it is believed that the indication in the Ginna reactor pressure vessel (RPV) nozzle-to-vessel weld N2AY is a thin, smooth slag inclusion in a plane perpendicular to the beam of the 15° nozzle bore examination.

Heat affected zone (HAZ) cracks were detected in three nozzle-to-shell welds in the 1972 preservice of the Hatch Unit 1 RPV. These cracks were detected with 45° and 60° examinations from the outside surface of the vessel and subsequently excavated and repaired. These cracks were confirmed with 0°, 45° and 60° examinations from the inside surface of the vessel, 10° examination from the nozzle bore and by metallographic examination during excavation. Neither record radiographs nor radiographs taken on site revealed the HAZ cracks. The multifaceted nature of such cracks breaks up the reflection so that several small indications of multiple planes are observed. Sizing such reflectors to the 50% DAC limits of the indication works well without beam spread correction of indication dimensions. Indications having unknown orientation and identity should be sized to the 50% DAC limits without beam spread correction. However, based on Southwest Research Institute's (SwRI) experience with flaw indication sizing, beam spread correction should be used on some flaw indications.

Under most conditions, a reflector can be sized by using the rules contained in Appendix 1 of the 1974 Edition of Section XI of the ASME Boiler and Pressure Vessel Code. In this case, these rules are not appropriate. Appendix 1 sizing rules are based on using 45° and/or 60° angle beam (or other angle beams separated by at least 15°) examination techniques. Such examinations were applied to the vessel inside surface but did not detect the subject reflector and the weld in effect passed the Code-required UT examinations. Even though it was not a Code requirement, an angle beam longitudinal wave was applied to the bore of the nozzle and directed perpendicular to the axis of the weld. This additional examination was performed in the interest of maximizing the effectiveness of the weld interrogation. Directing a beam perpendicular to the major reflecting plane of a weld-related defect results in a high degree of reflectivity from an imperfection. This technique, which is more sensitive to planar reflectors at the weld interface than the typical technique described in Appendix 1, can be applied only because of the unique geometry surrounding the nozzle-to-shell weld. Because the search unit movement during the nozzle bore scan is essentially parallel to the plane of the flaw, some of the examination parameters which enter into the flaw-size calculations described in Appendix 1 are not available. Since reflection amplitude and parallel search unit movement are the only parameters available to be used in determining flaw size, supplemental considerations must be effected.

Recognizing that the difference between the measured and the true reflector size can only be determined by considering the basic sound beam properties, a brief summary of the physics of ultrasonic beam propagation which defines the beam spread and sound pressure amplitude distribution within that beam are as follows:

The beam spread angle ϕ from the beam axis to the edge of the total beam is calculated from the equation, $\phi_{total} = \arcsin 1.22\ \lambda/D$

Where λ = wavelength= V/f

V = velocity in the material in millimeters per microsecond

f = examination frequency in cycles per microsecond

D = dimension of the transducer in millimeters

The beam spread angle to the 50% point is calculated using the equation,

$$\phi_{50\%} = \arcsin .56\ V/fD$$

and to the 20% point

$$\phi_{20\%} = \arcsin .92\ V/fD$$

A 2.25 MHz, 3/4-in. dia. search unit producing a straight beam longitudinal wave in steel has a

$$V/fD = 5.89/2.25(.75)25.4 = .1374, \text{ therefore}$$

$$\phi_{50\%} = 4.4° \text{ and } _{20\%} = 7.3°.$$

Since these angles are computed for the beam axis to the 50% and the 20% levels, the 50 to 50% and 20 to 20% angles double. That is, half of the energy is outside the 8.8° cone and 20% of the energy is outside the 14.6° cone.

In order to obtain beam measurements on the same basis as the computed beam spread angles, we would need to use various sizes of disc reflectors (such as flat-bottom holes) to reflect the 50 to 50% portion of the beam. Side-drilled holes are a better geometric simulation of suspect reflectors and are more convenient reflectors for angle beam calibration since they are equally reflective to various beam angles and modes of wave motion. The nonmandatory Code technique for beam spread measurement uses the 50 to 50% DAC response from the side-drilled hole. (This is different from the 50% of total beam computation and the measured angles are different from the computed angles.) In this case the investigation metal path is greater than 3T/4 metal path, so the responses from the T/2 and 3T/4 calibration reflector were used for beam spread measurement. Figure 2 shows 5-1/2° beam spread for the 50 to 50% DAC points, while similar plotting gave an 11° beam spread for the 20 to 20% DAC points as measured on side-drilled holes. Such a beam detected and 50% DAC sized the Figure 1 indication which gave 117% DAC maximum amplitude from a reflector in nozzle-to-shell weld N2 in the Ginna RPV during the March 1979 inservice examination.

As shown in the top frame of Figure 1, the indication was recorded on a circumferential scan of the nozzle-to-vessel weld from the nozzle bore with the 15° angle beam longitudinal wave at 7.64-inch metal path in reference position 19.14 inches and on successive circumferential scans at reference positions 19.40, 19.62, and 19.87 inches. These scan increments increase the metal path to a reflector perpendicular to the 15° beam by the relationship:

$\Delta MP = \text{Sin } 15°$ (scan increments): that is,

$\Delta MP = \text{Sin } 15° \text{ (.26 in.)} = .0673 \text{ in.}$

$= \text{Sin } 15° \text{ (.22 in.)} = .0569 \text{ in.}$

$= \text{Sin } 15° \text{ (.25 in.)} = .0647 \text{ in.}$

Adding these MPs and comparing the computed MPs for a planar reflector to average maximum amplitude metal paths for each of the three successive scans gives the following:

Computed MP	Maximum Amplitude Average Metal Path	No. of Areas	Range of Deviation from Avg.	Computed Minus Avg.
7.64 in.	7.64 in. (Base Reading)	(1)	-	-
7.71 in.	7.73 in.	(4)	±.01	-.02 in.
7.76 in.	7.75 in.	(3)	±.01	+.01 in.
7.83 in.	7.83 in.	(4)	±.01	.00 in.

The ±.01-inch range of deviation from average calculates to a range of reflector plane angles of 15° ±3° for the eleven maximum amplitude metal path readings. This substantiates our conclusion that the slag inclusion is located at the weld-to-base metal interface in a plane perpendicular to the 15° angle beam longitudinal wave.

A study was conducted to demonstrate the appropriateness of beam spread corrected reflector sizing. Essentially this study consisted of placing a flat-bottom hole reflector in the calibration block and comparing the measured size with the known reflector size. In this test, the geometry of the nozzle examination area was simulated, the same or similar search unit and wedges were used, and similar records were taken. Other controls exercised in the study to assure appropriateness of the comparison are as follows:

1. A flat-bottom hole was drilled at an angle so that the search unit-wedge combination used in measurement of the flaw indication produces a beam perpendicular to the flat-bottom hole at a metal path within ±10% of the flaw indication metal path.

2. The flat-bottom hole was located in a calibration block so it does not interfere with subsequent calibrations.

3. The selected calibration block had ultrasonic coupling conditions similar to the examination and had the same diameter side-drilled holes as used in calibration for the examination.

4. Calibration was performed on the block for comparing the flat-bottomed hole response to the maximum response of the flaw indication.

5. The flat-bottom hole amplitude response did not deviate from the flaw indication response by more than 2 dB.

6. 50% to 50% DAC measurements were made on the flat-bottom hole in the through-wall and length directions as the search unit was moved toward and across the reflector.

7. The 50% to 50% DAC through-wall dimension of the flat-bottom hole minus the flat-bottom hole diameter was demonstrated to be the through-wall spread correction.

8. The 50% to 50% DAC length dimension of the flat-bottom hole minus the flat-bottom hole diameter was demonstrated to be the length beam spread correction.

9. The flaw indication through-wall dimension 2a minus the through-wall beam spread correction was shown to be the beam corrected flaw indication dimension 2ac.

10. The flaw indication length dimension ℓ minus the length beam spread correction was shown to be the beam spread corrected flaw indication ℓc.

11. The beam spread corrected flaw indication dimensions ac and ℓc as shown in Figure 3 were used in computing a/ℓ ratio and the a % of t of the indication for comparison with the allowable indication limits applicable to the indication location.

In this instance, it was possible to simulate the examination condition and vessel component geometry and demonstrate the effects of ultrasonic beam spread on determining the size of a reflector. This particular reflector was well suited for this exercise because its orientation was established with an unusually high level of confidence by interrogating it in more ways than is usually possible. All of the information accumulated relative to this reflector gives a high level of confidence that its true size, orientation, and character are as reported and that the practice of basing its size on the projected 50% DAC limits corrected for beam spread is appropriate.

Also, Paragraph IWA-2240 allows for alternate techniques to be used in lieu of the Code specified techniques if it can be demonstrated to the satisfaction of the inspection specialist that the alternate techniques provide results which are equal or superior to the Code specified techniques. This was done and the alternate sizing techniques used are therefore in compliance with the requirements of Section XI of the ASME Code.

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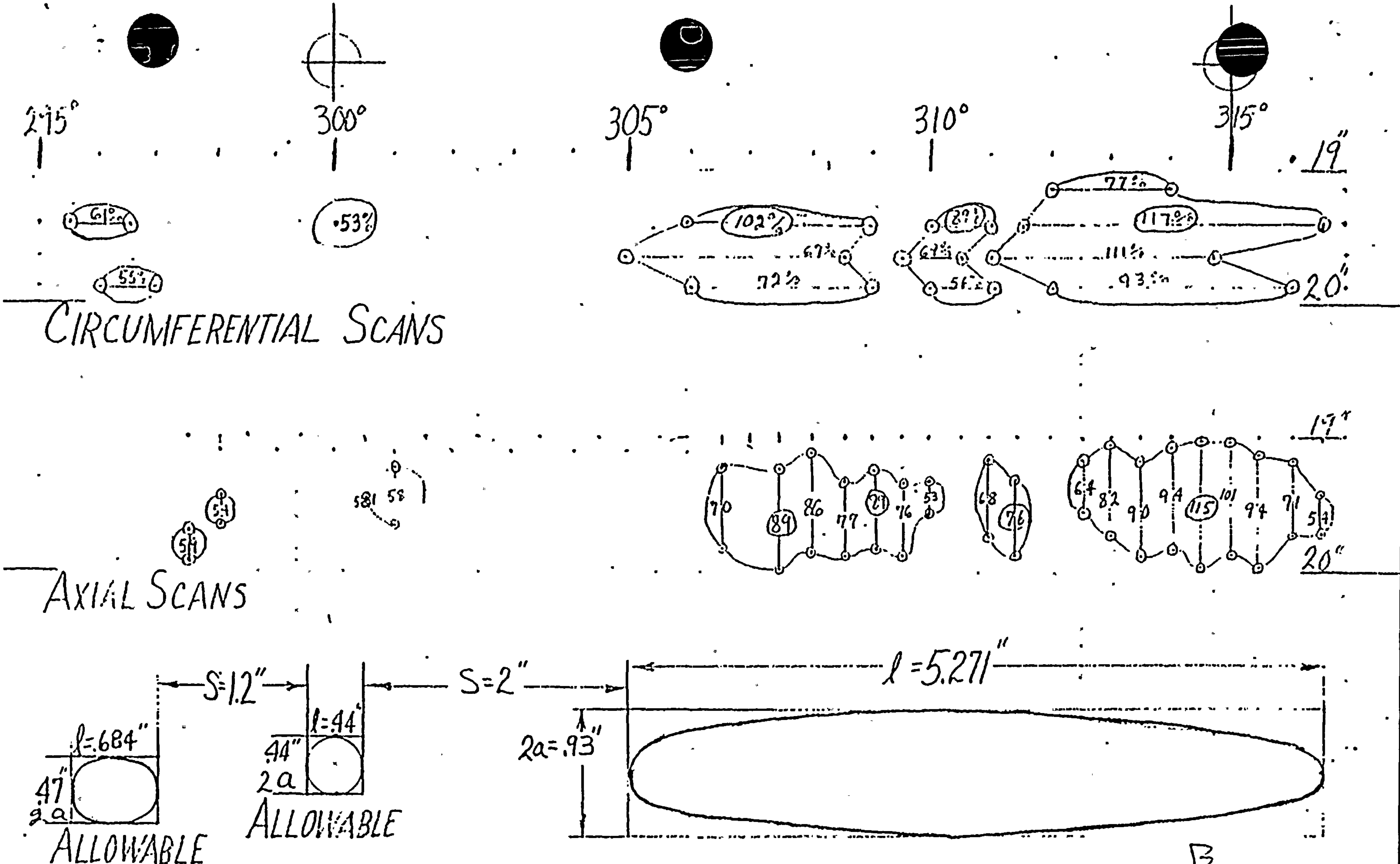
Attachments (3)



COMPOSITE OF INDICATIONS FROM 15°L. EXAM OF INLET NOZZLE N2~~A~~B (B-INLET)

FIGURE 1

SwRI 17-5581 GINNA 10 MAR79

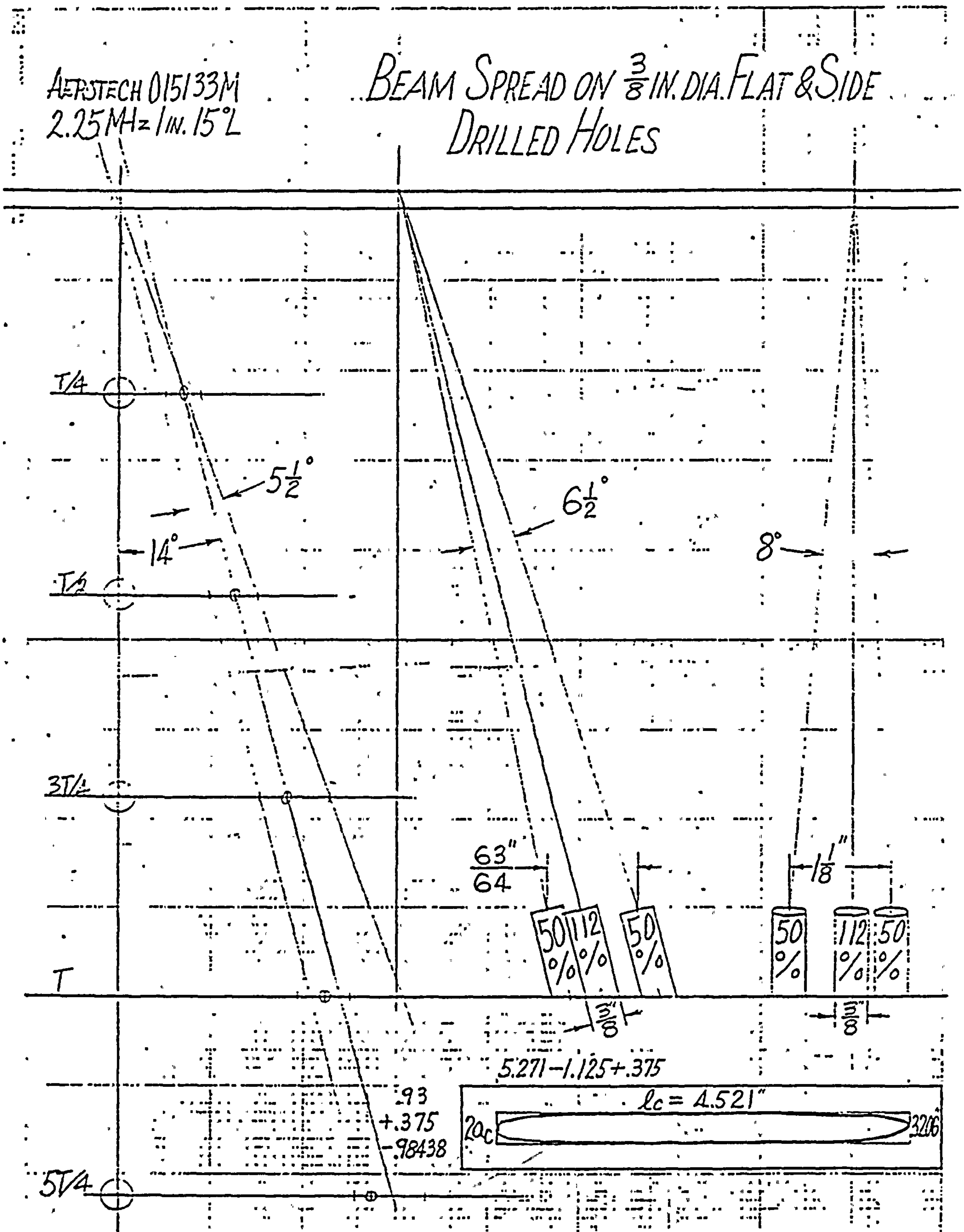


FIGURE 2 BEAM SPREAD REDUCTION OF COMPOSITE INDICATION DIMENSIONS

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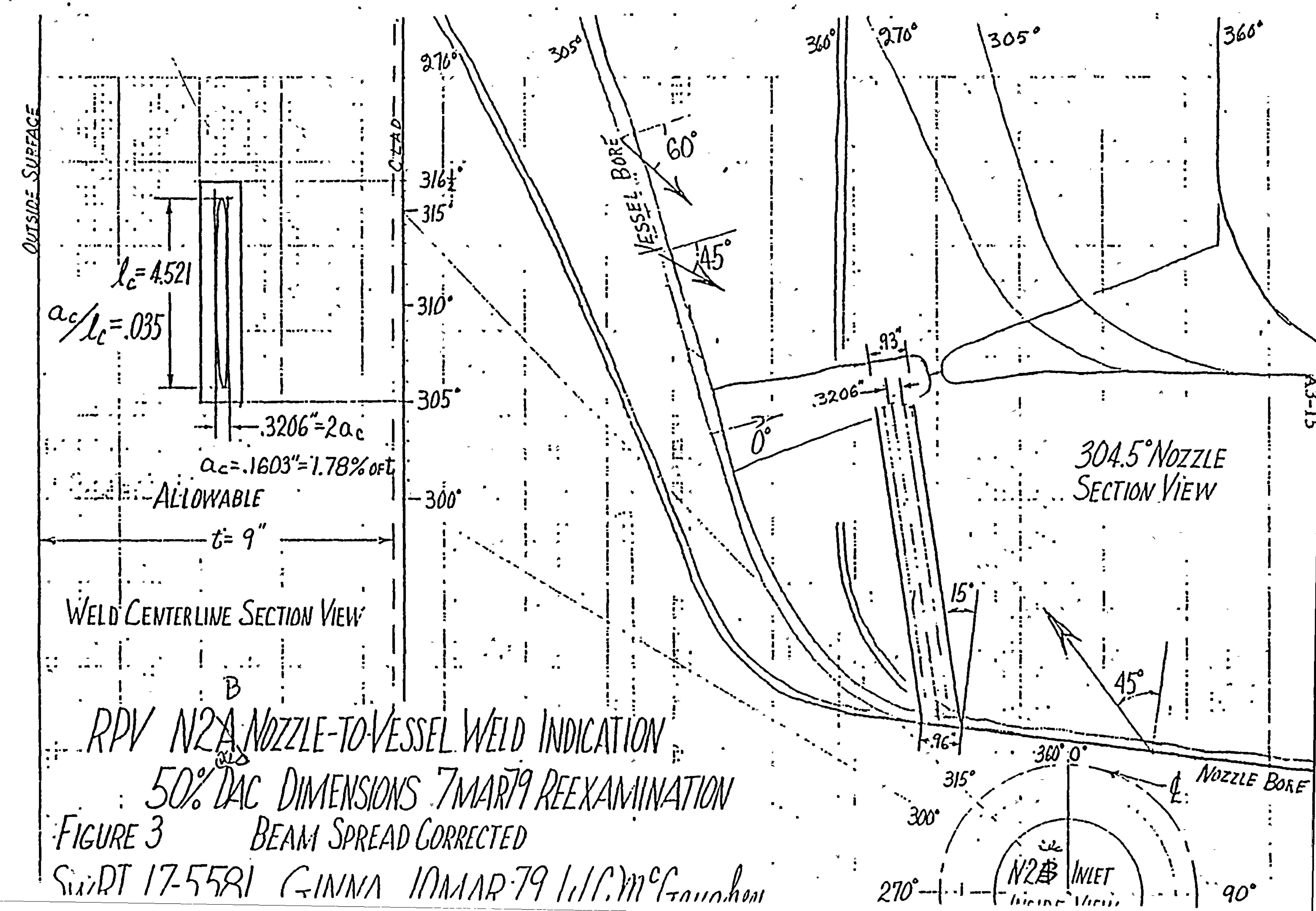

RPV N2A (B) NOZZLE-TO-VESSEL WELD INDICATION
50% DAC DIMENSIONS 7MAR79 REEXAMINATION
FIGURE 3 BEAM SPREAD CORRECTED
SwRT 17-5581 GINNA 10MAR79 W.C. McGaughey

ATTACHMENT 4

FRACTURE MECHANICS EVALUATION OF INLET NOZZLE INSERVICE INSPECTION INDICATION