Nondestructive Examination of PVRC Plate-Weld Specimen 201

Ultrasonic examination can indicate discontinuities not detectable by X-ray examination but this capability does not imply that ultrasonic examination should have precedence over radiography for acceptance or rejection of indications.

A PVRC SUBCOMMITTEE REPORT

Introduction

The PVRC Industry Cooperative Program* on heavy section steels for use in nuclear reactor pressure vessels has been planned to answer the question “What are the properties and how effective are inspection techniques for heavy section steels?” The goal therefore is to obtain by both destructive and nondestructive testing comprehensive data on variations in the mechanical properties and chemical composition of heavy-section steels and the extent of discontinuities in these steels.

Taking as a starting point the ASME Boiler and Pressure Vessel Code procedure for the ultrasonic examination of welds, the Task Group on Examination of Welds has prepared a series of heavy-section specimens containing intentional defects in the welds, and successively modified the nondestructive examination procedure to obtain acceptable agreement on discontinuity size measurements, position, and location of the flaws in the prepared specimens. Teams of nondestructive examination personnel compared the results of the examinations, followed by rewriting the procedure to correct for disparities in the results, until satisfactory results were obtained. Sectioning of the specimen and metallurgical examination confirmed the presence of the intentionally placed flaws.

A copy of the revised examination procedure is included with this report (see Appendix) although further modifications are anticipated from the results of examinations of the other test specimens.

Analysis of Test Results

Figures 1 and 2 show the locations of flaws placed intentionally in PVRC Weld Test Specimen No. 201. Figure 3 shows the actual locations of flaws in the portion of the weld which was removed from the specimen and sectioned. Each flaw from the removed portion was sectioned, photographed, and radiographed in a reduced section thickness of about 8/2 inch. The results are shown in Figs. 4 through 8. It is evident that the flaw positions very closely match the positions intended by the fabricator.

An ultrasonic examination was conducted by five industry teams according to the PVRC procedure in effect at that time. The flaw maps resulting from the last examination are included as Figs. 9 through 13. To evaluate these results, it was decided to accept plotting errors of up to 1 inch in any of the three perpendicular coordinate directions, but if any one coordinate exceeded this tolerance, the flaw was considered a false indication. However, if no indication was located within tolerance, the flaw was considered to have gone undetected. No team detected all of the flaws although the team results were markedly improved over previous examinations of this kind.

It was the opinion of the task group that the data without sufficient explanatory information might well be misinterpreted as a condemnation of ultrasonic weld testing. This would be far from the truth. To put the data in the proper context, it was decided to compare the ultrasonic test data to radiographic data on the same weld. Radiographs made with a 25-MeV betatron at a 103-inch focal-spot-to-film-distance in the usual direction (normal to the weld face) and at angles more or less perpendicular to the fusion surfaces (15 degrees to the left and to the right) are shown in Fig. 14. The radiographs would have been quite acceptable under ASME code limitations but they were not ideal in two respects:

- Single-film radiography was used so there was no second film to confirm film defects or subtle density differences.

- Film density was only slightly above 2.0. Penetrameters were quite clear and sharp, however, and the 1% hole was readily detected.

A quality rating was chosen which would correlate the two test methods. The number of correctly located flaws was divided by the sum of false indications plus the number of known flaws which were undetected:

\[
\text{Rating} = \frac{F}{f+u}
\]

where \(F\) = flaws detected correctly; \(u\) = undetected flaws; and \(f\) = false indications.

Radiography was only required to have two accurate coordinates (no depth) whereas ultrasonic examination was required to have three accurate coordinates. Only the interpretation of the perpendicular shot was used for the rating of the radiogr-
phy. Film graders whose results are presented here, included the normal film grader employed by a major fabricator (V), a quality supervisor with many years experience in radiography (W), two of the best film graders employed by another major fabricator (X and Y), and a resident inspector whose responsibility includes film reading (Z). This was considered a good cross section of film interpreters and probably well above average.

The ratings of the ultrasonic testing teams and the x-ray readers are given in Table 1.

Detailed Analysis

A detailed analysis is presented below.

Team A

The Team A results in Fig. 9 show that indication 3 and flaw E match. Indication 8 matches flaw A and indication 6 matches flaw D. Indication 2 matches flaw C and 1 matches flaw G. Indication 7 matches flaw F. The indication identified as 4 matches flaw H and both 9 and 12 match flaw 1. Indication 10 matches flaw B. Indications 5 and 11 are considered false and flaw 12 was not detected.

Team B

The Team B results in Fig. 10 show that indication 3 and flaw E match. Indication 8 matches flaw A and indication 6 matches flaw D. Indication 2 matches flaw C and 1 matches flaw G. Indication 7 matches flaw F. The indication identified as 4 matches flaw H and both 9 and 12 match flaw 1. Indication 10 matches flaw B. Indications 5 and 11 are considered false and flaw 12 was not detected.

Team C

Indications recorded in Fig. 11 identified as 4 and 12 match flaw A. Indication 3 matches flaw F. Indication 2 matches flaw B. Indications 9, 1, and 8 match flaw H. Indications 5 and 6 both match flaw 1.

Six indications must be considered false although it seems obvious that errors in plotting depth have caused most of these discrepancies. Apparently some of the flaws detected from the reverse side of the plate were plotted as though detected from the top. Without correcting for this error, there are five undetected flaws and the rating is $5(6+5) = 0.45$.

Team D

As in the case of team C, team D, whose results are plotted in Fig. 12, seems also to have made a plotting error in a number of instances. Apparently they neglected the 2-inch inset of the reference point causing many flaws to appear about 2 inches to the left of their correct locations.

Uncorrected, indications identified as 2 and 3 match flaw A. Indication 5 matches flaw E. Indication 5 matches flaw C. Indication 7 matches 1 although this is apparently not a true match. Indication 8 matches H and this is genuine. Thus six flaws were undetected under this plot and there were six false indications. The rating would thus be $4/(6+6) = 0.33$. When the 2-inch correction is made, the rating increases to $7/(3+2) = 1.4$.

Team E

The plot of team E's results is found in Fig. 13. Indication 7 corresponds to flaw D. Indication 4 corresponds to flaw F. Indication 6 matches flaw A. Indication 3 matches flaw H. Indication 8 corresponds to flaw C. Indication 2 matches flaw B. Indication 1 matches either G or 1 but fits 1 closer. There is only one false indication—5—and three flaws went undetected.

General Comments

Observations that seem evident are as follows:

1. One team plotted depths in error, evidently due to neglect in calculating the depth from the appropriate side.
2. One team apparently neglected to allow a 2-inch inset for the index point.
3. One team (team A) appears to have used a sensitivity which was lower than the rest.
4. One team (team B) appears to have overestimated flaw lengths.
5. Occasionally most teams failed to recognize that two indications at similar depth are often indicative of the same flaw.
6. If these errors could be corrected (and realizing that flaw 12 is likely beneath the flaw size threshold that we want to report) the results would be very good indeed.
Sectioning

After the ultrasonic examination and radiography took place, a portion of the weld area containing about half of the flaws was removed and sectioned as shown in Fig. 15. The location and identity of the flaws were measured and plotted.

The remainder of the weld was clad by weld deposit in a manner and with material similar to that used in cladding a reactor vessel except that this specimen had to be clad flat whereas reactor vessels are clad after they are in cylindrical form. The cladding was not ground nor otherwise treated to surface it for the examinations.

The industry teams of ultrasonic examiners were again assembled and the cladding portion of the weld was examined. No change in procedure or sensitivity was employed for this examination. Teams A, D, and E reported that no flaws were detected at a reportable level in the cladding portion of the weld.

Team B reported six indications (Fig. 22). Indications S and T both correspond to flaw 1. Indications R and I both match flaw H. Indications Q and U both correspond to flaw B. There were no false indications and two flaws were undetected.

Team C reported two indications (Fig. 23). Indication 1 corresponds to flaw B. Indication 2 corresponds to flaw H. There were no false indications and three flaws were undetected.

Conclusions

From the results of the examination conducted on the half of the specimen with the weld overly cladding, it is obvious that some method, multiplication factor, or correction factor will be required to increase the sensitivity for the examination of cladding welds. This project has been undertaken by the task group.

Even though several flaws were falsely reported, or failed to be reported by the ultrasonic teams, it is obvious that ultrasonic examination has the capability of indicating discontinuities not detectable by X-ray examination. This capability does not imply, however, that ultrasonic examination should have precedence over radiography for acceptance or rejection of indications. Rather the two methods should be thought of as being complementary, especially in view of the fact that the report compares results of an ultrasonic procedure which was recognized to be at a sensitivity level beyond ordinary radiographic capability to the results of a radiographic examination conducted with practices below the normal standard used by the manufacturers.

Appendix

PVBC Procedure for Ultrasonic Examination of Welds in Plates 201 and 202 for Pressure Vessel Research Committee Program

Scope

1.1 Pulse-echo ultrasonic methods as described herein shall be employed when ultrasonic examination of welds is required in the PVRC evaluation program. The basic examinations required to establish the reliability, validity, and reproducibility of this procedure shall be conducted in strict conformance with the test requirements detailed herein. Any supplementary tests may be performed and reported separately. The supplementary data shall be presented with concise and sufficiently comprehensive descriptions of the modifications made to this procedure to enable duplication of the data by other committee members.

Application

2.1 The principal objective of the methods given herein is the reproducible detection, location and evaluation of indications within the welds and heat affected zone. The welds shall be examined by the angle beam method where practical. In the examination of welds where geometry or the condition described in Section 4.3 does not allow
angle beam examination from both sides of the weld from a single surface or a combination of surfaces, straight beam in two (2) directions at 90 degrees to each other shall be used.

**Basic Calibration Reflectors**

3.1 Side drilled holes in the PVRC block shall be used as basic calibration reflectors to establish a primary reference response of the equipment and to construct a distance-amplitude curve.

3.2 Other calibration reflectors

3.2.1 (In lieu of 3.1) Other calibration reflectors are permitted, provided relationship to PVRC standard is documented and reported, and equivalent response is demonstrated.

**Surface Preparation and Couplant**

4.1 Contact Surfaces

4.1.1 The finished contact surfaces shall be free from weld splatter and any roughness that would interfere with free movement of the search unit or impair the energy exchange through the couplant.

4.1.2 Glycerine shall be used as couplant.

4.2 Weld Surfaces

4.2.1 The finished weld surfaces shall be of adequate smoothness to prevent interference with the interpretation of the examination results. The weld surface shall merge smoothly into the surfaces of the adjacent base materials.

4.3 Base Material

4.3.1 After the weld is completed but before the angle beam examination, the area of the base material through which the sound will travel in angle beam examination shall be completely scanned with a straight beam search unit to detect reflectors which might affect the interpretation of angle beam results. In accordance with procedures contained in ASTM A435, consideration must be given to these reflectors and corrective measures taken to examine the adjacent weld.

**Angle Beam Method**

5.1 Calibration of Equipment

5.1.1 Frequency—The nominal frequency shall be 2.25 MHz and 1 MHz unless variables such as production material grain structure necessitate the use of other frequencies in order to assure adequate penetration.

5.1.1.1 A 1 in. by ½ in. Lead Metaniobate transducer shall be used.

5.1.2 Beam Angle—The beam angle in the material shall be 45 degrees ±1 degree inclusive with respect to the perpendicular to the contact surface. The precise angle shall be determined and recorded.

5.1.3 Distance-Amplitude Correction—Correction for the actual distance traversed by the ultrasonic beam as it passed through the material shall be provided by the use of curves or electronically. Such corrections shall be based on equivalent sound path distances on the PVRC block.

5.1.3.1 Determination of Curves—Distance-amplitude correction curves shall be constructed by utilizing the responses from the basic calibration holes in the PVRC block. The side drilled holes giving the maximum amplitude response shall be considered the primary reference point which shall establish the vertical gain level for the distance-amplitude curve. The gain control shall be set so that the response from the primary reference point is at its peak response and is 75% of full screen. Without changing the gain, the search unit shall be similarly placed to pick up all the other calibration holes. Interpreting the contemplated examination distance range and each response shall be recorded. From the recorded data, the applicable distance-amplitude curve shall be marked on the CTR screen and on the data sheet. The amplitude peaks shall be joined by a smooth line, the length of which shall be such as to cover the examination range.

5.1.3.2 Electronic Distance-Amplitude Correction—If the instrument is equipped with electronic distance-amplitude correction device or attenuator, the primary reference response shall be equalized at 75% of full screen. Lateral scans over the distance range to be employed in the examination.

5.1.3.3 Transfer Method—A transfer ratio of 1:1 shall be used for weld test plates 201 and 202.

5.2 Examination Procedure

5.2.1 Coverage—Where possible, welds shall be examined from both sides of the beam and from both sides of the plate.

5.2.2 Scanning Motion—The weld shall be examined by moving the search unit progressively along and across a sufficient contact area so that the entire weld, angulating approximately 10 degrees to each side in an oscillating motion.

5.2.3 Sensitivity Level—The reference level for monitoring discontinuities is the chosen primary reference response corrected for distance by the distance-amplitude curve or electronically.

When possible, scanning shall be performed at a minimum gain setting of ten times the reference level sensitivity.

5.2.4 Detection of Indications Parallel to the Weld—The search unit shall be placed on the contact surface with the beam aimed about 90 degrees to the weld and manipulated horizontally and longitudinally so that the ultrasonic beam passes through all the weld metal in two different approaches of the beam. Technique employing two search units may be used to detect lack of penetration in double welded butt joints.

5.2.5 Detection of Indications Transverse to the Weld—Two search units shall be placed on the contact surfaces adjacent to the weld, one on each side, making an angle of 45 degrees or less with the axis of the weld. Alternatively, if the weld surface is suitable, one search unit may be placed on the outside of the weld with the beam directed along the weld in such a manner that the entire depth and width of the weld is scanned.

**Straight Beam Method**

This is to be used as required in paragraph 5.1.

6.1 Calibration of Equipment

6.1.1 Transducer—The nominal frequency shall be 2.25 MHz unless variables, such as product material grain structure necessitate the use of other frequencies in order to assure adequate penetration. The transducer shall be 1½ in. Lead Metaniobate.

6.1.2 Distance-Amplitude Correction—Distance-amplitude correction curves shall be constructed by utilizing the responses from the basic calibration holes in the PVRC block. The side drilled holes giving the maximum amplitude response shall be considered the primary reference point which shall be to establish the gain level for the distance-amplitude curve. The gain control shall be set so that the response from the primary reference point is at its peak response and is 75% of full screen. Without changing the gain, the search unit shall be similarly placed to pick up all the other calibration holes. Interpreting the contemplated examination distance range and each response shall be recorded. From the recorded data, the applicable distance-amplitude curve shall be marked on the CTR screen and on the data sheet. The amplitude peaks shall be joined by a smooth line, the length of which shall be such as to cover the examination range.
6.1.3 Electronic Distance-Amplitude Correction—If the instrument is equipped with an electronic distance-amplitude correction device or attenuator, the primary reference response shall be equalized over the distance range to be employed in the examination.

6.1.4 Reference Level—The reference level for monitoring discontinuities is the primary reference response corrected for distance by the distance-amplitude curve or electronically.

6.2 Examination Procedure
6.2.1 Scanning Motion—The weld shall be examined by moving the search unit progressively along and across a sufficient contact area so as to scan the entire weld.

6.2.2 Sensitivity Level—When possible, scanning shall be performed at a minimum gain setting of ten times the primary reference level. Evaluation of discontinuities shall be carried out with the gain control set at this sensitivity level.

6.2.3 Verification of Penetration—Penetration shall be verified by (a) obtaining a reflection from an opposite parallel surface, or (b) obtaining the back reflection on similar material while using approximately the same length of sound and travel.

Evaluation of Indications
7.1 All indications which produce a response greater than the noise level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such reflectors and evaluate them.

Report
8.1 A report of the ultrasonic examination shall be prepared and shall contain the following information.
8.1.1 All procedures and equipment shall be identified sufficiently to permit duplication of the examination(s) at a later date. This shall include initial calibration data for the equipment and any significant changes.
8.1.2 A marked-up drawing or sketch indicating the weld(s) examined, the item or piece number and identification of the operator who carried out each inspection or part thereof.
8.1.2.1 The drawing shall be dimensioned in inches along X and Y axes starting from the bench mark. The depth from the test surface shall be recorded as the Z dimension.

8.1.2.2 The location of the defects shall be numerically identifiable.

8.1.3 A record shall be made of all investigated indications exceeding the 1/10 DAC. Maintained signals with travel movement more than 1 in. (measured 10% signal height through peak to 10%), shall be recorded as to size. Maximum amplitude, physical reflector dimensions, and locations shall be recorded.

8.1.3.1 Transducer travel less transducer length shall be the measured length of an indication as described above.

8.1.3.2 The extent in the Z direction shall be measured 10% signal height through the peak to 10% less the width of the transducer.

8.1.3.3 For indications having extent in the Z direction as measured above, there will be two recorded Z dimensions; minimum and maximum depths.

8.1.3.4 Transducer analysis will be made of all transducers used for the future examination of Plate 202. Frequency spectrum analysis, Schlieren analysis, beam profile, scanning sensitivity, beam exit, and beam angle will be recorded.

Each team should bring transducers to be used on test plate 202 and expect to leave them to be shipped to Dexter Olsson at Bethlehem Steel for this analysis. Transducers will be returned to the owners after the analysis is made and reports are filed. Approximately thirty (30) days from time of receipt will be required for the analysis.

Procedure Requirements

9.1 Ultrasonic examination of welds shall be performed in accordance with the procedure given. Supplementary data shall be submitted with a written description of the procedure used. The minimum requirements of such a description shall be the following information:

9.1.1 Weld types and configuration to be tested including thickness dimensions.

9.1.2 Automatic defect alarm and recording equipment or both, if used.

9.1.3 Special search units, wedges, shoes or saddles, if used.

9.1.4 Rotating, revolving scanning mechanisms, if used.

9.1.5 Stage or manufacture when test will be made.

9.1.6 The surface or surfaces from which the test shall be performed.

9.1.7 Surface finish.

9.1.8 Couplant.

9.1.9 Method used.

9.1.10 Technique used.

| NATURE: INTENDED LACK OF FUSION |
| SIZE: 1 INCH LONG |
| LOCATION: |
| (SAMPLE) X: 2-1/8 – 3-1/8; Y: 11/16; Z: 5-1/16 |
| (PLATE) X: 15-5/8 – 16-5/8; Y: 15-3/16; Z: 5-7/16 |

Fig. 7—Flaw "F"
NATURE: SPONGY AREA
SIZE: 0.43 INCH DIAGONAL
LOCATION: (SAMPLE) X: 7-1/2; Y: 1/4; Z: 2-15/32
(PLATE) X: 21; Y: 14-3/4; Z: 2-15/32

X-RAY
(REDUCED THICKNESS)

MACRO

63633 3.5X STEEL 7-2
53966 3.5X STEEL (UNPOLISHED 7-2)

Fig. 8—Flaw 12

Fig. 9—UT flaw map, Team “A”

Fig. 10—UT flaw map, Team “B”
Fig. 11—UT flaw map, Team “C” (top left)
Fig. 12—UT flaw map, Team “D” (top right)
Fig. 13—UT flaw map, Team “E” (left)
Fig. 14—X-ray sketch (right)

Fig. 15—Plan view of sectioned weld 201 (left)
Fig. 16—X-ray report plotted by Reader “V” (right)
Fig. 17—X-ray report plotted by Reader “W” (bottom left)
Fig. 18—X-ray report plotted by Reader “X” (bottom right)
"The Fabrication and Welding of High-Strength Line-Pipe Steels"
by H. Thomasson

This report covers the fabrication and welding of line-pipe steels whose specified minimum yield strengths are in excess of 52,000 psi. It outlines the relationship between hardness, strength and weldability, pointing out that the first two are interrelated because in both cases we are essentially measuring resistance to deformation when we measure either hardness or yield strength. The interrelationships between weldability and hardenability are pointed out with the fact that we cannot make a weld without heat effects and the fact that the material surrounding the weld is for practical purposes heat treated. The essential property in high-strength line-pipe steel is therefore high strength with good weldability. This requires the lowest degree of hardenability consistent with the specified strength.

This condition is currently being met by the addition of small amounts of columbium combined with controlled rolling and controlled cooling. These ensure the fine grain size which in turn contributes to low hardenability.

The price of WRC Bulletin 161 is $1.50 per copy. Orders for single copies should be sent to the American Welding Society, 2501 N.W. 7th St., Miami, Fla. 33125. Orders for bulk lots, 10 or more copies, should be sent to the Welding Research Council, 345 East 47th St., New York, N. Y. 10017.
New Welding Research Council Bulletin Available

"Derivation of Code Formulas for Part B Flanges"

By E. O. Waters

New rules for bolted flanged connections appeared in the 1968 and 1970 Winter Addenda of the ASME Boiler and Pressure Vessel Code, and more recently in the 1971 edition of Section VIII, Division 1, providing for flanges with metal-to-metal contact outside the bolt circle. The development of this material came from recent work of the PVRC Design Division subcommittee that was assigned this topic.

There is considerable novelty in the formulas and charts in these rules, and it was the belief of the subcommittee members that their acceptance and understanding by Code users would be greatly aided if a concise account of their derivation were given. The paper was written with this in mind, and with the added purpose of providing a source to which reference could be made in the future, when specific inquiries have to be answered or revisions are contemplated.

Publication of this paper was sponsored by the Pressure Vessel Research Committee of the Welding Research Council. The price of Bulletin 166 is $3.50 per copy. Orders for single copies should be sent to the American Welding Society, 2501 N.W. 7th St., Miami, Fla. 33125. Orders for bulk lots, 10 or more copies, should be sent to the Welding Research Council, 345 East 47th Street, New York, N. Y. 10017.
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