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1.3 Current Industry NDE Requirements and AUT Procedures

This section is a review of following items:

- Standards
- Requirements for qualification of AUT systems
- AUT procedures
- Survey of operators to determine their general experience with AUT pipeline girth weld inspection

1.3.1 Review of Standards

AUT has been extensively used since last 15 years on cross country, onshore, and offshore projects. The most extensively used standards for UT procedure and acceptance criteria are:

- CSA Z662-99 Oil and Gas Pipeline Systems[1.3-1)]

- CSA Z663-03 Oil and Gas Pipeline Systems[1.3-2)]

- DNV OS F101:2000 Submarine Pipeline Systems[1.3-3)]

- API 1104, 18th Edition Welding of Pipelines and Related Facilities[1.3-4)]

- API 1104, 19th Edition Welding of Pipelines and Related Facilities[1.3-5)]

- ASTM E 1961-98 Mechanized Ultrasonic Examination of Girth Welds Using Zonal Discrimination with Focused Search Units[1.3-6)]

- EN 14163:2002 Petroleum and Natural Gas Industries – Pipeline Transportation Systems - Welding of Pipelines (ISO 13847:2000 modified)[1.3-7)]

This section consists of review of all above-mentioned standards into two main sections namely UT method and acceptance criteria.

1.3.1.1 CSA Z662-99 Oil and Gas Pipeline Systems

1.3.1.1.1 UT for Girth Welds

CSA Z662-99 describes the method to be employed for UT of pipeline girth welds. The standard describes the general requirement on MUT along with additional requirements for mechanized inspection systems. The inspection is required to be performed in accordance with a documented procedure approved by the company. The standard requires referring the applicable information in the testing procedure from ASME Boiler and Pressure Vessel Standard, Section V, Article 5 and a description of the methodology used to investigate indications, to the extent that they can be evaluated in the terms of the standards of acceptability. The standard does not require any mandatory qualification of the UT procedure/system used during production (per project) as required by API 1104, 19th edition and DN OS F101.

It also details the requirements on UT equipment and supplies used. The standard further lists the requirements for mechanized inspection systems such as:

- **Mode of Operation:** The standard requires the testing equipment to have capability of operating in pitch-catch transmission mode in addition to P/E mode. It does not refer any requirements for PA system requirements which have started gaining popularity and more usage in industry.

- **Recording/Imaging System:** System is required to include means of displaying the weld and the position of imperfections in the weld.

- **Acoustic Coupling:** Equipment is required to have means to monitor the effectiveness of the acoustic coupling. It does not specify the requirement in detail as far as usage of environmentally safe wetting agent usage is considered.

- **Operating Temperature:** The standard requires to examine the maximum temperature differential between the search units, calibration block, and pipe wall and establish within which accuracy and resolution are to be maintained.

- **Distance Measurement:** The equipment used for the project is required to be capable of measuring the position of indications with an accuracy of 10 mm in the circumferential direction and 2 mm in the axial direction, with a resolution of 2 mm in both directions. It is very important to note that the system is required to be capable of showing accuracy in circumferential and axial direction both and it needs to be validated by the equipment. In order to comply with the validation requirement, it is very important that system is capable to present the results in both the circumferential and axial directions.

- **Search Units:** All the search units used are required to have contact surfaces contoured to the pipe curvature. Dimension changes and performance changes requiring replacement or repair of the search unit is required to be established.

- **Qualification of Ultrasonic Inspectors:** The ultrasonic inspectors are required to be qualified in accordance with the requirements of Level II of CGSB standard CAN/CGSB-48.9712. The company has an option to require the inspectors to demonstrate their competence in operating, and evaluating the results of their inspection system.

- **Calibration:** The calibration block requirements per this standard is based on the method as weld assessment. The calibration blocks are required to be manufactured in accordance with ASME Boiler and Pressure Vessel Code, Section 5. If Appendix K of the standard is used which is primarily accepting welds based on fracture mechanics principles the calibration block is required to be made of pipe material, with specific reflectors designed to simulate the expected imperfections. The effect of variations in acoustic velocity in the pipe material is to be considered in the design of the calibration block when Appendix K is used.

- **Production Welds Inspection Procedure:** When the calibration block is not manufactured per Appendix K the standard requires block to consist of 1.5-mm-diameter SDH in the center of the weld as-reference reflector. It is required to mark circumferential distance references onto the pipe surface to allow the positioning of defects from the output of the inspection system. The inspection sensitivity is required to be measured using the calibration block at regular intervals not exceeding 1 hour or every 10 welds, and when any part of the inspection system is changed the result from the sensitivity measurements are required to be recorded. Any decrease of more than 3 dB from the sensitivity established in the calibration for any search unit shall require recalibration and a re-inspection of all welds inspected since the last acceptable sensitivity verification. It is also required to record the temperature differential between the search units, the calibration block, and the pipe wall to be examined at regular intervals. The circumferential position accuracy of the system output is required to be validated at regular intervals by comparing it to the actual distance traveled around the pipe. Any deviation from the requirements, as described above, needs to be recorded and corrected. It is also required to record any change in search unit position and if any are found, it will require a verification of recording gate positions and inspection sensitivity. It is required to examine the search units for wear at regular intervals not exceeding 500 welds or whenever wear is apparent. Coupling loss over a circumferential distance exceeding 12 mm requires a re-inspection of weld.

It is important to note that there are many requirements that are needed to be established and described in the procedure. The establishment of such requirements can be solely carried out by the contractor and described in the procedure. It, thus, becomes very important for the qualification of AUT system whereby all above required properties can be tested and verified to meet the requirements.

1.3.1.1.2 Acceptance Criteria for Girth Welds

The standard of acceptability for imperfections recorded by UT (i.e., weld conditions giving indications that exceed the recording level) is as follows:

1. Imperfections characterized as cracks shall be unacceptable regardless of length or location.

2. Individual imperfections (other than those characterized as cracks) that are determined not to extend into the weld beads closest to the surfaces of the pipe shall not exceed 50 mm (2 in.) in length, and the cumulative length of such imperfections in any 300-mm (12-in.) length of weld shall not exceed 50 mm (2 in.), except that for welds less than 300-mm (12-in.) long, the cumulative length of such imperfections shall not exceed 16% of the weld length.

3. Individual imperfections other than those covered by Items 1 and 2 shall not exceed 12 mm (0.5 in.) in length, and the cumulative length of such imperfections in any 300-mm (12-in.) length of weld shall not exceed 25 mm (1 in.), except that for welds less than 300-mm (12-in.) long, the cumulative length of such imperfections shall not exceed 8% of the weld length.

The standard also consists of Appendix K, “Standards of Acceptability for Circumferential Pipe Butt Welds Based on Fracture Mechanics Principles”. This appendix explains the fitness-for-purpose (FFP)-developed acceptance criteria. The standards of acceptability that are derived by this method are based on ECA and include consideration of the measured weld properties and the intended service conditions. This appendix explains requirements on various sections like weld procedure qualification, mechanical properties, etc., in order to achieve the FFP acceptance criteria. The determination method of maximum-acceptable sizes of imperfections is explained in this appendix along with interaction rules to be used during the results interpretation. The interaction rules described in this appendix is not as exhaustive as described in API 1104. Per CSA standard the imperfections shall be considered to interact if the distance between them is less than the length of the smaller imperfection. For such imperfections, the effective length will be the sum of the dimensions of the two imperfections

plus the distance between them. The description defect interactions are very well defined in API 1104 which defines not only circumferential interaction but does define the vertical interaction and interaction of defects with the surface.

The acceptance criteria based on Appendix K changes for each projects based on the variables changes for specific to a project.

1.3.1.1.3 UT for In-Service Welds

The NDT for fillet welds (including those in branch connections) are required to be nondestructively inspected for defects using magnetic particle inspection and, where practicable, ultrasonic techniques. There are no specific requirements imposed on the ultrasonic techniques for the in-service welds; the requirements of MUT defined for girth welds should be applicable for in-service welds. The standards requires for a time delay of not less than 48 hours to be included between the completion of a fillet weld and the commencement of its NDT.

1.3.1.1.4 Acceptance Criteria for In-Service Welds

The acceptance criteria for in-service welds stands the same as for the acceptance criteria of girth welds.

1.3.1.2 CSA Z662-03 Oil and Gas Pipeline Systems

1.3.1.2.1 UT for Girth Welds

There are no major changes to UT section of the standard from the 1999 to 2003 edition. The changes made in 2003 mainly consist of:

- The equipment needs to be capable of measuring the position of indications with an accuracy of 10 mm and a resolution of 2 mm in the circumferential direction. The 1999 edition stated for the equipment to be capable of measuring the position of indications with an accuracy of 10 mm in the circumferential direction and 2 mm in the axial direction.

- The 2003 edition states the reference levels to be set at 80% FSH, and recording to be set at 40% FSH (6 dB below the reference level).

- There is an addition of two clauses as the requirement for re-inspection of completed welds:

    - A coupling loss in a single channel over a circumferential distance not exceeding 12 mm, unless such loss is compensated by data from other inspection channels to maintain full volumetric inspection.

    - Concurrent coupling losses in two adjacent inspection channels.

1.3.1.2.2 Acceptance Criteria for Girth Welds

There are no major changes to UT acceptance criteria section of the standard from the 1999 to 2003 editions.

1.3.1.2.3 UT for In-Service Welds

The changes made in this section compared to the 1999 edition mainly consists of direct deposition welds are required to be subjected to full-volume NDT by ultrasonic methods and a surface inspection by magnetic particle methods. The procedures for magnetic particle inspection and UT are required to be in accordance with the requirements of the ASME Boiler and Pressure vessel Code, Section V, Articles 7 and 5, respectively. A time delay of not less than 48 hours is required to be included between the completion of a direct deposition weld and the commencement of its NDT.

1.3.1.2.4 Acceptance Criteria for In-Service Welds

The changes made in this section compared to the 1999 edition mainly consists of ultrasonic indications exceeding the reference level and greater than 10 mm (0.40 in.) in size in a any directions is treated to be a reject with an option of permitting to evaluate welds using alternative acceptance criteria, based upon accepted fracture mechanics principles.

1.3.1.3 DNV-OS-F101, 2000 Submarine Pipeline Systems

1.3.1.3.1 UT

This standard has two different appendices covering NDT; Appendix D that specifies the requirements for methods, equipment, procedures, acceptance criteria, and the qualification and certification of personnel for visual examination, NDT of C-Mn steels, duplex steels, other stainless steels and clad steel materials and weldments for use in pipeline systems, while Appendix E specifies the requirements pertaining to AUT of girth welds.

Appendix D covers various aspects of NDT like quality assurance, NDT methods, NDT procedures, personnel qualifications, reporting, and timing of NDT. It also describes the use of MUT which consists of requirement of UT procedures, MUT equipment, calibration block, calibration of ultrasonic equipment, UT contact surface area, and flaw detection.

The standard has clearly spelled out limits on timing of NDT; it requires, whenever possible, NDT of welds not to be performed until 24 hours has elapsed since completion of welding. If welding processes ensuring a diffusible hydrogen content of maximum 5 ml/100 g of weld metal are used, adequate handling of welding consumables is verified, shielding gas content of H_2 is controlled, or measures (such as post heating of the weldments) are taken to reduce the contents of hydrogen, the time stated above (24 hours) can be reduced.

The MUT equipment is required to:

- Be applicable for the P/E technique and for the double-probe technique.
- Cover as a minimum the frequency range from 2 to 6 MHz.
- Have a calibrated gain regulator with maximum 2 dB per step over a range of at least 60 dB.
- Have a flat screen accessible from the front for direct plotting of reference curves or be capable of displaying user-defined curves.
- Allow echoes with amplitudes of 5% of FSH to be clearly detectable under tests conditions.
- As a minimum, include straight-beam probes (0 degree) and angle-beam probes of 45, 60, and 70 degrees. Additional probes for TOFD and double-probe techniques are recommended. For testing of longitudinal welds in pipe probes with 35- and 55-degree angles may be required. Probes shall, if necessary, be suitable for use on hot surfaces (100 to 150°C).

The standard requires use of IIW/ISO calibration block (ISO 2400) for calibration of range and for angle determination. For testing of welds, the reference block is required to be manufactured from the actual material to be examined. The standard allows another material to be used for calibration block manufacture if can be proved that the material have acoustic properties similar to the actual material to be examined. The calibration block is required to consist of SDH. The thickness of the reference block, diameter, and position of the drilled holes is as shown in Figure 1.3-1 and Table 1.3-1.

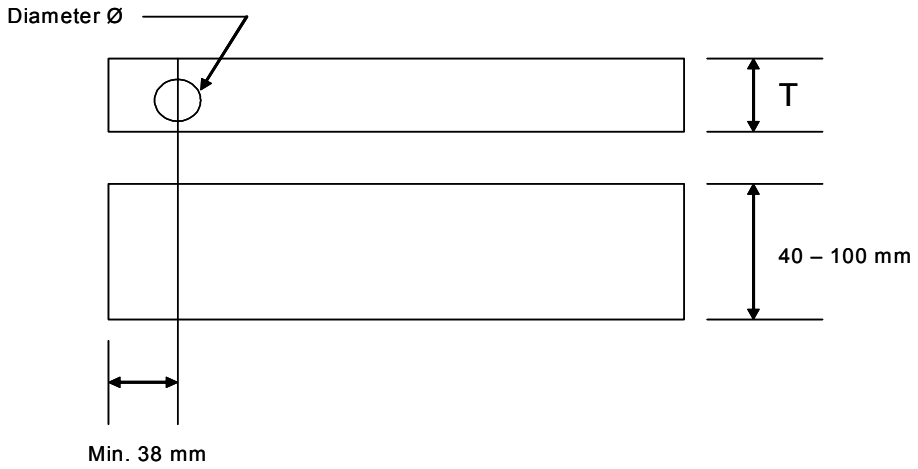


Figure 1.3-1. Reference Block Dimensions

Table 1.3-1. Reference Block Dimensions

Material Thickness (t) (mm)	Thickness of Reference Block (T) (mm)	Position of SDH	Diameter of SDH (mm)
T <25 mm	20 or t	¼ T and	3.0
25 mm ≤ t <50 mm	38 or t	½ T and	3.0
50 mm ≤ t < 100 mm	75 or t	¾ T	3.0
100 mm ≤ t < 150 mm	125 or t		3.0

It is required for the evaluation of indications to establish reference DAC using three points. The curve is required to be plotted on the instrument screen, unless the equipment is equipped with software capable of constructing user-defined DAC curves.

It is important to note that the standard requires testing welds from both sides when possible. If the testing is performed from one side, a refined testing technique is required to be performed to ensure detection of defects. This requirement is stated in DNV code only and is very useful as it helps in ensuring full coverage of the weld. The testing is required to include the area adjacent to the weld for laminations and scanning for transverse indications in the weld and base material. The probe movement velocity is required not to exceed 100 mm per second. For flaw detection the corrected primary gain is allowed to be increased by a maximum of 6 dB. Defect evaluation is not to be performed at this increased gain level.

The indications noted are to be investigated by maximizing the echoes by rotating the probes and by using different angle probes with DAC curves established. All indications exceeding 20% of the reference curve are required to be investigated with all indications exceeding 50% to be reported. The investigation is required to be performed to extent that the operator can

determine the shape and location of the indication. For dimensional evaluation, either the “6 dB-drop” method or TOF or maximum amplitude method can be employed.

This appendix describes manual NDT of base materials and weld overlay, automated NDT (other than AUT), and the acceptance criteria as described in the next section.

1.3.1.3.2 AUT Girth Weld Testing

Appendix E covers the AUT of girth welds and qualification of ultrasonic systems. The AUT system per this standard is accepted only through qualification. The standard describes in detail the requirement on documentation, ultrasonic system equipment and components, recorder setup, circumferential scanning velocity, gate settings, recording threshold, power supply, software, system logbook, spares, slave monitors, procedure, calibration, field inspection, re-examination, evaluation, and reporting.

For ultrasonic instruments using multiple channels, P/E, tandem, and/or through-transmission it is required to provide adequate number of inspection channels to ensure the examination of the complete weld through-thickness in one circumferential scan. Each inspection channel is required to provide:

- P/E or through-transmission modes
- One or more gates, each adjustable for start position and length
- Gain adjustment
- Recording threshold between 5 and 100% of FSH
- Recording of either the first or the largest signal in the gated region
- Signal delay to enable correlation to distance marker position
- Recordable signal outputs representing signal amplitude and sound travel distance.

The standard requires instrument to provide a linear A-scan presentation. It is learned through this project and many others that having more presentation like a C-scan, a sectorial scan provides a lot of help in interpreting the test results. It is thus recommended that with more options available the requirement on providing more presentation during testing is very important to analyze the results better.

For ultrasonic instruments using the TOFD technique, the instrument has to provide a TOFD B-scan image.

Calibration blocks to be used to qualify the inspection system for field inspection are required to be manufactured from a section of pipeline specific linepipe. It is required to measure the

acoustic velocity and attenuation measurements to be performed on material from all sources of pipe material supply to be used. If differences in acoustic velocity for the same nominal wall thickness from any source of supply results in a beam angle variation of more than 1.5 degrees, specific calibration blocks are to be made for material from each source of supply showing such variations. The above requirement is very important especially on forgings and on few more projects on thick pipes, it is being experienced that a drastic amount of difference in acoustic velocity noted before the UT of girth welds. There is a need for velocity checks to be performed at a pipe mill during pipe manufacturing and based on the results the calibration blocks are manufactured and used during inspection of girth welds and not having any big impact on production schedule.

The standard does not restrict for any specific usage of calibration reflectors, it prefers the use of principal reflectors which are normally 3-mm-diameter FBHs and 1-mm-deep surface notches. Other reflectors, if needed, are allowed to be used. The calibration blocks are required to be designed with sufficient area so that the complete transducer array will traverse the target areas in a single pass. The standard requires establishing a calibration block register. The register needs to include all calibration blocks to be used identified with unique serial number and include the dimensional verification records, ultrasound velocity, name of the plate/pipe manufacturer, and the heat number.

It is required with each transducer to position for the peak signal response from the calibration reflector and set the detection gates. The gate is required to start before the theoretical weld preparation and a suitable allowance to be included to allow for the width of the HAZ, so that complete coverage of the HAZ is achieved. It is very important to note that there is always a tolerance established to the bevels during production and that tolerances needs to be specified before the calibration block manufacturing and to ensure with the extreme ends of bevel tolerance the inspection will still be valid.

The standard specifies requirements on initial static calibration and dynamic calibration. The initial static calibration consists of optimizing for field inspection using the relevant calibration block. P/E and tandem transducers, in turn, have to be adjusted to provide a peak signal from its calibration reflector, and the signal needs to be adjusted to the specified percentage of FSH. The gain level required to produce this peak signal response is the primary reference level (PRE) which needs to be recorded along with S/N ratio and the transducers stand-off distance. With the system optimized, the calibration block is required to be scanned dynamically. The position accuracy of the recorded reflectors relative to each other needs to be within ±2 mm, and with respect to the zero start within ±10 mm. Gate settings should not deviate more than 0.25 mm from the reference positions.

Before the ultrasonic system is used for examination of production welds, the system is required to be tested. After calibration of the complete system, a weld is required to be scanned followed by re-calibration with the inspection band removed between each scan. If any of the echo amplitudes from the reflectors of the calibration block deviate more than 2 dB from the initial calibration, the system cannot be used until acceptable corrections have been made. For an acceptable test, three satisfactory scans and re-calibrations are required. In addition, a power failure is required to be simulated and operation of the system on the alternative power source with no loss of examination data is required to be verified. The verification of power source failure is considered to be very important, especially in the areas prone to power shortage or power surge as it has been found that in instances where the alternative power source does not work properly in time resulting in loss of data.

The standard requires transducer case height measurements to be provided for prior to the start of field weld examinations. An accurate (±0.1-mm) measurement is required to be made of the case height at each corner of each transducer. These measurements are required to be recorded and to provide a comparison for the periodic measurements taken throughout the examination period to assess for transducer wear.

For circumferential position accuracy as a minimum the position accuracy of the chart distance markers are to be validated twice during each shift. Chart accuracy is required to be ±1 cm or better and results to be recorded.

The transducers are required to be examined for wear against the baseline measurements performed, whenever a change in gain of more than 6 dB is necessary to maintain the required percentage of FBH. The transducers are required to be replaced or the contact face should be resurfaced to correct any of the following:

- Beam angle changes of ±1.0 degrees for angles less than 45 degrees or ±1.5 degrees for angles greater than 45 degrees.

- Squint angles exceeding 1.5 degrees for single-crystal transducers and 2 degrees for twin-crystal transducers.

- For all transducers except creeping-wave transducers the noise shall be at least 20 dB weaker than the signal from the reference reflector at the target distance.

- For creeping-wave transducers the noise shall be at least 16 dB weaker than the signal from the reference reflector at the target distance.

- Scores in the transducer wear face which may cause local loss of contact or which exceed 0.5 mm.

Re-examination of welds is required whenever any of the following occurs:

- Welds examined at sensitivity lower than 3 dB from the PRE should be re-examined.

- Welds exhibiting a loss of acoustic coupling, i.e., a drop in echo amplitude of more than 10 dB from the level through a clean weld for a circumferential distance which exceeds the minimum allowable defect length for the affected channel shall be re-examined.

- If a calibration scan shows that the system is any way “out of calibration”, all welds examined since the last successful calibration shall be re-examined.

1.3.1.3.3 Acceptance Criteria for Girth Welds

The acceptance criteria defined in the standard is in three sections.

- Pipeline girth welds were the accumulated strain resulting from the installation and operation will not exceed 0.3%, when all strain concentration factors (SNCF) are included. The acceptance criteria applicable for welds in C-Mn steel where the accumulated plastic strain resulting from installation and operation will not exceed 0.3% as stated in Table 1.3-2.

    - It is important to note that the acceptance criteria stated in Table 1.3-2 assumes that multi-pass welds are used and that the height of defects will not exceed the height of a welding pass or maximum 0.2 t. If the welding methods, e.g., shielded arc welding (SAW), “one-shot” welding, etc., resulting in weld passes higher than 0.2 t are used, defect indications equal to the length limits given in the tables shall be height determined with MUT. If the height exceeds 0.2 t or the height of a welding pass, whichever is smaller, the defect is not acceptable.

- Acceptance criteria for pipeline girth welds where the accumulated strain resulting from installation and operation is above 0.3% but will not exceed 2.0%, which is to be established by an ECA. The ECA shall determine the fracture toughness values required to tolerate the defects permitted as mentioned Table 1.3-2. Alternatively, FFP-type acceptance criteria can be established based on fracture toughness values actually achieved.

- Acceptance criteria for pipeline girth welds where the accumulated strain resulting from installation and operation is above 2.0%, shall be established on an ECA, and validated by testing.

Table 1.3-2 Acceptance Criteria for Ultrasonic Testing

Indication length, L	*Maximum echo amplitude permitted*
L ≤. t/2, maximum 12,5 mm	Reference level + 4 dB
t/2, maximum 12.5 mm < L < t, maximum 25 mm	Reference level - 2 dB
L ≥. t, maximum 25 mm (indications in both outer t/3)	Reference level - 6 dB Accumulated length in any 300 mm of weld: t, maximum 50 mm
L. ≥ t, maximum 50 mm (indications in middle t/3)	Reference level – 6dB Accumulated length in any 300 mm of weld: 2 t, maximum 50 mm
Cracks are not permitted.	
Transverse indications: Indications shall be considered as transverse if the echo amplitude transversely exceeds the echo amplitude from the same indication longitudinally with more than 2 dB. Transverse indications are unacceptable unless proven not to be planar, in which case the acceptance criteria for longitudinal indications apply.	
For indications approaching the maximum permitted length it shall be confirmed that the indication height is less than 0.2 t or maximum 3 mm (see 303).	
Total accumulation of discontinuities: The total length of acceptable indications with echo amplitude of reference level – 6 dB and above shall not exceed 3 t, maximum 100 mm in any weld length of 300 mm nor more than 12% of total weld length. Any accumulation of defects in any cross section of weld that may constitute a leak path or reduce the effective thickness of weld more than t/3 is not acceptable.	
If only one side of the weld is accessible for testing 6 dB shall be subtracted from the maximum echo permitted above.	
Notes: a) Reference level is defined as the echo amplitude corresponding to the echo from the side drilled hole in the reference block described in Fig. D-2 of this appendix, or equivalent reflector. b) All indications exceeding 20% of the reference level shall be investigated to the extent that the operator determines the shape, length and location of the imperfection. c) Indications that cannot be established with certainty shall whenever possible be tested with radiography. Indications that are type determined in this way shall meet the acceptance criteria of Table D-4. d) Longitudinal imperfections where the echo height intermittently is below and above the acceptance level, shall if possible be investigated with radiography. Indications that are determined in this way shall meet the acceptance criteria of Table D-4. If radiography cannot be performed, the length shall not exceed 3 t, maximum 100 mm in any weld length of 300 mm e) Length, height and depth shall be determined by an appropriate method, see B.315. f) Detectable imperfections are not permitted in any intersection of welds	

The standard describes the method and requirements for establishment of ECA. The UT uncertainty data used in the ECA has to be appropriate for the applied UT equipment and procedures used for the detection and assessment of flaws of concern in the material and weld geometries in question. The data used in the ECA needs to be derived from the qualification testing of the AUT system. The uncertainty data from the qualification testing needs to be statistically treated to establish the flaw sizing error that gives a 95% confidence level against undersizing of flaws. The maximum-allowable flaw sizes from the ECA needs to be increased in length and height with a flaw sizing error, that based on the data from the qualification testing will give a 99% confidence level against undersizing of flaws.

For MUT, the data used in the ECA for quantitative estimates of UT uncertainty, performance and reliability are preferable based on the “measured response versus actual flaw size” type. The estimate needs to be based on published results from comprehensive studies into the reliability of MUT.

1.3.1.4 API 1104th Edition, 18th Edition, May 1994 Welding of Pipelines and Related Facilities

1.3.1.4.1 UT

API 1104, 18th edition does not address any specific requirement for AUT and neither does it state a specific format for the AUT system qualification specific to a project. Operators have been noticed generating project specifications requiring the qualification of AUT systems before the use of system on project especially for pipeline for critical applications (steel Catenary risers or tendons). The UT method requirement per API 1104, 18th edition is as follows: “When ultrasonic testing is specified by the company, a detailed written procedure for ultrasonic testing shall be established that meets the requirements of ASTM E 164. The company and the NDT contractor should agree on the ultrasonic testing procedure or procedures before the performance of production testing. The company shall require the contractor to demonstrate that the proposed procedures will produce acceptable results and shall require the contractor to use such procedures for production testing.”

1.3.1.4.2 Acceptance Criteria

Section 6 of API 1104 states the acceptance criteria; this criterion does not state any restrictions as far as height of defect is considered. The acceptance criteria stated under this section is as follows:

- All indications that produce a response greater than 20% of the reference level shall, to the degree possible, be investigated to determine the location, shape, extent, and type of reflectors and shall be evaluated according to the following criteria:
    - Linear indications interpreted to be shallow crater cracks or star cracks, located at the weld surface, with a length less than 5/32 in. (3.96 mm) are acceptable. All other cracks are unacceptable, regardless of size or location in the weld.
    - Linear indications (other than cracks) interpreted to be open to the surface are unacceptable if they exceed 1 in. (25.4 mm) in total length in a continuous 12-in. (304.8 mm) length of weld or 8% of the weld length.

- Linear indications interpreted to be buried within the weld are unacceptable if they exceed 2 in. (50.8 mm) in total length in a continuous 12-in. length of weld or 8% of the weld length.

1.3.1.5 API 1104th Edition, 19th Edition, September 1999 Welding of Pipelines and Related Facilities

1.3.1.5.1 UT

API 1104, 19th edition consists of more information listed on UT compared to the 18th edition. This edition consists of sections on:

- Ultrasonic procedure
- UT
- Personnel requirements
- Qualification of the testing procedure
- API sensitivity standard (calibration block), parent material UT
- Scanning and evaluation level for parent material UT/manual ultrasonic weld testing/AUT
- Production UT
- Identification of reported indications.

This edition also states the requirement on AUT system qualification before use on production.

The standard requires an NDT Level III in the ultrasonic method to develop the application technique and prepare and approve the testing procedure. Only Level II or Level III certified personnel can calibrate equipment and interpret the test results. NDT Level II or III personnel in ultrasonics are required to perform the test and evaluate the results per the acceptance/rejection criteria. It is noted that many NDT company establishes their own standards for personnel qualification for some critical applications like SCR or tendon welds. It is very important that a global operator qualification system is established for qualified Level II or Level III qualification before they start work on critical welds applications. It is very important that this global qualification takes into account various aspects of welding, production, and critical application of welds and formats the qualification program. The global qualification program for operators' qualification is suggested to be an independent testing group.

The standard defines the requirements on reference standards into two sections:

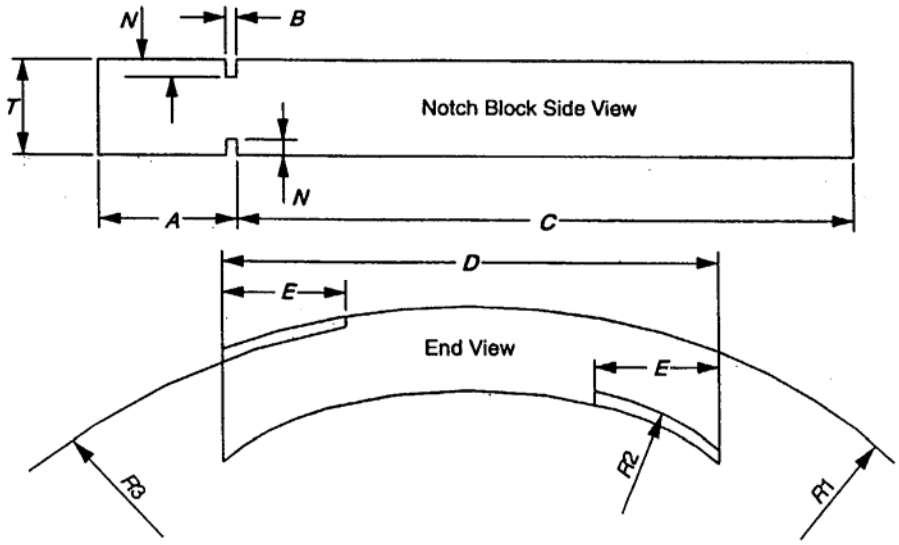
- MUT
- AUT

- **MUT:** The MUT sensitivity is required to be based on a two- or three-point reference level [i.e., DAC or time-corrected gain (TCG)] derived from an N10 notch introduced into a sample of the pipe to be inspected (Figures 1.3-2 and 1.3-3). The highest point of the DAC/TCG cannot be less than 80% of FSH. The reference standard is also required to be used to determine the actual sound beam velocity, refracted angle, and sound path distance in the pipe material to be inspected. Unknown velocity and refracted angle is required to be determined when welds in pipe of different chemistry specifications, wall thickness, and diameter or from more than one pipe and rolling or piercing manufacturer are to be inspected. This can be accomplished by using two probes of the same nominal angle and frequency with the probes directed toward one another (Figure 1.3-4). When difference is noted in velocity, angle, or sound path distance another reference standard is required to be made from the different material.

- **AUT:** For AUT and also in some instances if a company requires MUT, FBH will be required to be machined into a sample of the pipe to be inspected. This piece is required to be used as calibration reflectors in addition to the N10 notches at the inside and outside surfaces. The diameter of each FBH is required to be approximately equal to the thickness of one welding fill pass. The flat reflecting surface of each hole is required to be installed at the same angle and position as the weld joint preparation for each fill pass required by the welding procedure. Additionally, planar reflectors or FBH are required to be installed at the weld center-line position with their flat reflecting surfaces vertical to the weld. All reflectors are required to be spaced apart so that no two will be within the beam spread of one probe simultaneously.

This standard states for testing on an other than new construction, a pipe sample of the same grade, wall thickness, and diameter as the pipe to be inspected to be used to make the reference standard. A transfer technique using probes of the same nominal angles and frequencies are required to be used for inspection and to carry out to determine actual full skip distance, actual refracted angle, and attenuation in the material to be inspected (Figure 1.3-4).

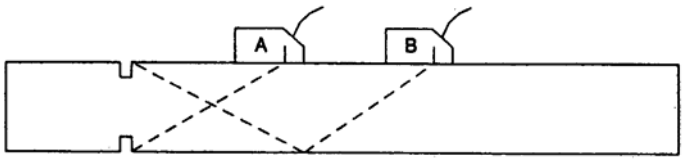
The standard requires parent material ultrasonic tests which consist of: after completion of the circumferential butt weld, but prior to its UT, a compression wave test of the parent material on both sides of the weld to be performed (minimum distance = 1.25 × the longest surface skip distance to be used). All interfering partial- and full-beam reflectors are required to be noted (datum location and distance from the weld edge) on the examination record.



Dimensions:

T	Nominal pipe wall thickness
N	Notch depth = 10% *T* plus or minus 10% of notch depth
A	2 in. (50 mm) minimum length
B	0.125 in. (3.2 mm) maximum notch width
C	11.35 T plus 2 in. (50 mm) minimum length
D	3.1 in. (80 mm) minimum width
E	1 in. (25 mm) minimum notch length
*R*1	Outside radius of pipe
*R*2	Radius of inside notch = *R*1 minus 0.9 *T*
*R*3	Radius of outside notch = *R*1 minus 0.10 *T*

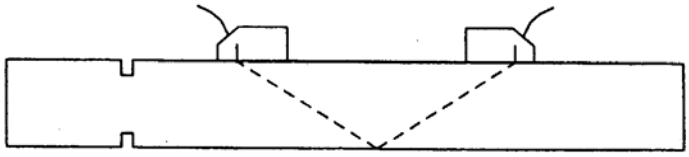
Figure 1.3-2. Reference Block for MUT



With the transducer in Position A, maximize (peak up) the echo from the inside notch and adjust amplitude to at least 80% of full screen height. Measure the surface distance from the inside notch to the transducer exit point. Surface distance divided by measured wall thickness equals refracted angle tangent.

Position the transducer in line with the outside notch at double the distance used to peak up the inside notch (Position B). Verify that the outside notch echo peak is at or near zero depth reading. This will establish that refracted angle and velocity settings are sufficiently accurate.

Figure 1.3-3. Establishing Distance, Refracted Angle, and Velocity



Using two transducers of equal angle and frequency, one transmitting and the other receiving, maximize (peak up) the echo received. Measure the surface distance between the transducer exit points. Half the surface distance divided by measured wall thickness equals the refracted angle tangent. Without changing instrument settings, repeat this process on pipe with unknown velocity, refracted angle, and attenuation to determine any differences.

Figure 1.3-4. Transfer Procedure

Under the scanning and evaluation level the standard has distinct sections to better explain parent material UT, MUT, and AUT.

- **Parent Material UT:** Under this section manual compression wave testing of parent material is required to be performed with the second backwall echo from the reference standard and adjusted to a least 80% of FSH. AUT of the parent material is to be performed using the same calibration method and evaluation level as that used for manual compression wave, or a different technique if demonstrated to be equal to or better than the manual method.

- **MUT:** MUT is required to be performed at a scanning sensitivity of DAC/TCG reference sensitivity plus 6 dB minimum. All indications that exceed 50% of DAC/TCG screen height needs to be evaluated. Evaluation sensitivity for MUT should be DAC/TCG reference sensitivity plus 6 dB with an evaluation level for all indications at 50% of DAC/TCG screen height. After the reference, scanning, and evaluation sensitivities and levels have been established, they need to be qualified, and then incorporated into the final procedure and in the final qualification report.

- **AUT:** AUT is required to be performed at a scanning sensitivity of 80% screen height reference sensitivity plus 4 dB when using the P/E technique. Evaluation sensitivity is stated to be the same as scanning sensitivity. Evaluation level screen height (recording threshold) is required to be 40% of FSH using the automated P/E technique. Other automated techniques, reference reflectors, reference sensitivities, scanning sensitivities, evaluation sensitivities, and evaluation levels can be used if demonstrated to be equivalent to the P/E technique for the detection and evaluation of weld imperfections.

1.3.1.5.2 Acceptance Criteria

Compared to the 18th edition, the 19th edition defines in detail definition and explanation on various types of indications with respect to UT. Various aspects of changes in weld geometry and its interpretation, explanations on linear indications, transverse indications, and volumetric indications are listed in detail as part of acceptance criteria.

The acceptance criteria for linear indications remain unchanged from the 18th edition. There is some explanation added to acceptance criteria of transverse and volumetric indications. The criteria listed for such indications are as follows:

- Transverse (T) indications (other than cracks) shall be considered volumetric and evaluated using the criteria for volumetric indications. The letter T shall be used to designate all reported transverse indications.

- Volumetric cluster (VC) indications shall be considered defects when the maximum dimension of VC indications exceeds ½ in. (13 mm).

- Volumetric individual (VI) indications shall be considered defects when the maximum dimension of VI indications exceeds ¼ in. (6 mm) in both width and length.

- Volumetric root (VR) indications interpreted to be open to the ID surface shall be considered defects should any of following conditions exist:

    - The maximum dimension of VR indications exceeds ¼ in. (6 mm).

    - The total length of VR indications exceeds ½ in. (13 mm) in any continuous 12-in. (300-mm) length.

- Any accumulation of relevant indications (ARI) shall be considered a defect when any of the following conditions exist:

    - The aggregate length of indications above evaluation level exceeds 2 in. (50 mm) in any 12-in. (300-mm) length of weld.

    - The aggregate length of indications above evaluation level exceeds 8% of the weld length.

The above-stated acceptance criteria is based on empirical criteria for workmanship and places primary importance on flaw length. The use of fracture mechanics analysis and FFP criteria is an alternative method of determining acceptance criteria and incorporates evaluation of the significance of both flaw depth and flaw length which is explained in detail as the appendix to API 1104.

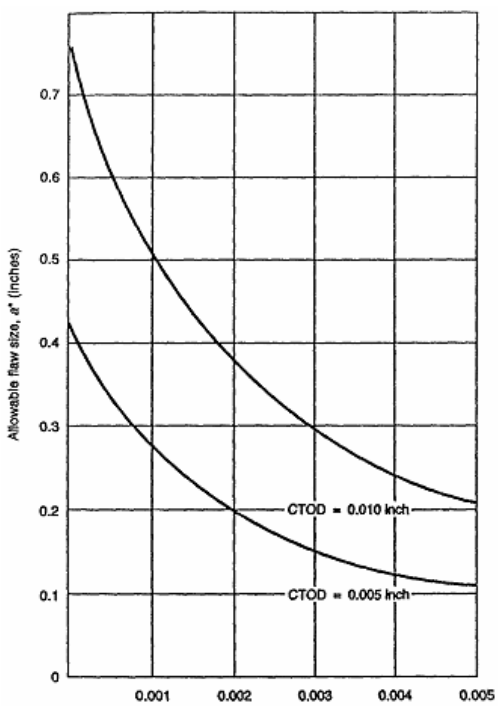
The FFP criteria provide more generous allowable flaw sizes, but only when additional procedure qualification tests, stress analyses, and inspections are performed. The appendix presents the minimum requirements to permit use of the alternative acceptance standards. The appendix does not prevent the use of workmanship acceptance criteria for determining imperfection acceptance limits for any weld, nor does it impose any restriction on allowable strain. Use of this appendix for the evaluation of any or all flaws, including circumferential cracks, is completely at the company's option.

Only circumferential welds between pipes of equal nominal wall thickness are covered by this appendix. Welds in pump or compressor stations are excluded, as are fittings (forgings) and valves in the mainline. Welds subjected to applied axial strain of more than 0.5% (steel Catenary riser welds) are not covered by this appendix. The primary purpose of this appendix is to define, on the basis of a technical analysis, the effect of various types, sizes, and shapes of these anomalies on the suitability of the whole weld for a specific service.

It is to be noted that the controls of the variables necessary to ensure an acceptable level of fracture toughness in a welding procedure are more stringent than those controlling welding procedures without minimum toughness requirements. The appendix describes the additional requirements and exceptions for the qualification of welding procedures. The appendix also describes the fracture toughness testing - the applicable fracture toughness test method is the crack-tip opening displacement (CTOD) method, the CTOD testing for testing procedure qualification is described in detail in this appendix.

The inspection and acceptable limits defined by the standard is as follows:

- **Planar Imperfections:** The use of ultrasonic techniques, acoustic imaging, radiographic techniques that employ densitometers or comparative visual reference standards, inherent imperfection-size limitation due to weld-pass geometry, or any other technique for determining imperfection height is acceptable per standard, provided the technique's accuracy has been established and any potential inaccuracy is included in the measurement, i.e., the determination of imperfection height shall be conservative. The use of conventional radiography to identify imperfections that require height measurement by other means is acceptable. The acceptable limits for circumferential planar imperfections are as shown in Figure 1.3-5. Planar imperfections that are transverse cracks are required to be repaired or removed.



Notes:

- In addition to the absolute flaw-size limit, the initial height shall not exceed ½ the wall thickness.
- For Interacting flaws, the length and height of the flaw shall be determined by Figure 2.
- For surface flaws, the allowable flaw height, a*, is subject to the restriction of Note 1.
- For buried flaws, die allowable flaw height, 2a* is subject to the restriction of Note 1. The status of a buried flaw is determined by Figure 2, Caw 4.
- Limits on flaw length are given in Table A-3.
- The maximum allowable applied axial strain may be limited by other standards and regulations.
- A residual strain of 0.002 in. per inch is included in each of the curves.

Figure 1.3-5. Alternative Acceptance Criteria for Circumferential Planar Flaws

- **Arc Burns:** The acceptable limits for un-repaired arc burns are as per Table 1.3-3 and are based on the premise that the HAZ has zero toughness but that any planar imperfections originating within the HAZ is blunted at the edge of zone.

- **Imperfections Interaction:** The standard describes the interaction rules. If adjacent imperfections are close enough, they may behave as single larger imperfections. Figure 1.3-6 is required to be used to determine whether interaction exists. If it does, the effective imperfection sizes is as shown in Figure 1.3-6 and needs to be computed and the acceptability of the effective imperfection needs to be evaluated by the applicable acceptance criteria.

- **Volumetric Imperfections:** Buried volumetric (three-dimensional) imperfections, such as slag and porosity, contained in material with high fracture toughness are much less likely to cause failure than planar imperfections and can be evaluated either by the same method used for planar imperfections or by the simplified method shown in Table 1.3-4. Surface-connected volumetric imperfections are required to be treated as planar imperfections and evaluated according to the criteria of Figure 1.3-6.

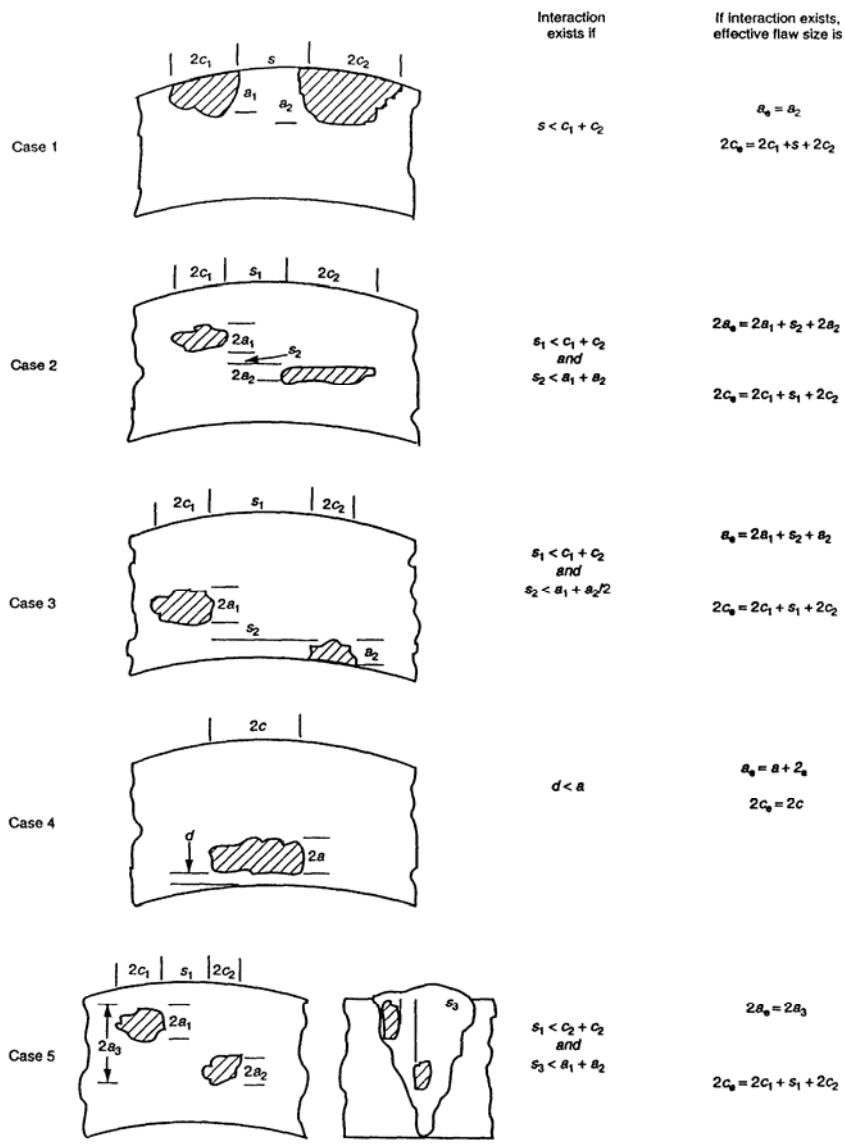


Figure 1.3-6. Criteria for Evaluation of Flaw Interaction

Table 1.3-3. Acceptance Limits for Un-Repaired Arc Burns

Measured Dimension	Acceptance Limit
Width	Lesser of t or 5/16 inch
Length (any direction)	Lesser of t or 5/16 inch
Depth (to bottom of crater)	1/16 inch

Note: The limits given in this table apply for minimum CTOD levels of either 0.005 inch or 0.010 inch, but only within the scope of this appendix.

Table 1.3-4. Acceptance Limits for Buried Volumetric Flaws

Flaw Type	Height or Width	Length
Porosity[a]	Lesser of $t/4$ or 0.25 inch	Lesser of $t/4$ or 0.25 inch
Slag	Lesser of $t/4$ or 0.25 inch	$4t$
Unrepaired burn-through	$t/4$	$2t$

Note: The simplified limits given in this table may be applied for minimum CTOD levels of either 0.005 or 0.010 inch, but only within the scope of this appendix. Alternatively, the company may elect to treat these flaws as planar flaws and employ Figure A-5. This table shall not be used with the surface-connected volumetric flaws (Figure A-6, Case 1) and surface-interacting flaws (Figure A-6, Cases 3 and 4), which shall be evaluated by Figure A-5.
[a] Limited to 3 percent of the projected area.

The appendix further details an example to derive the acceptable height and length based on the results achieved from mechanical testing during procedure qualification.

The alternative acceptance stated as part of Appendix A remains unchanged from the 18th edition.

1.3.1.5.3 UT for In-Service Welds

The Appendix B added to API 1104, 19th edition now consists of in-service welding. This appendix covers recommended welding practices for making repairs to or installing appurtenances on pipelines and piping systems that are in service. This section refers to the use UT the same as specified for girth welds. Since in-service welds that contact the carrier pipe are particularly susceptible to underbead or delayed hydrogen cracking, an inspection method that is capable of detecting theses cracks, particularly at the carrier pipe weld toe, is advised to be used. The specification further specifies the use of magnetic particle testing, UT

or a combination of both as the NDT method. The use of NDT is required to be properly developed, qualified, and approved procedures, to be effective at detecting hydrogen cracks at the toe of the sleeve, saddle, and branch to carrier pipe welds. The specification leaves at the option of the company to select the right NDT method for the application. It is very important to note that there is no restriction on inspection hold time, i.e., the time lapsed after welding and before inspection as stated by this standard as required by the CSA standard. This is a very important clause for the confirmation of detection of hydrogen cracking which has a general characteristic to develop with elapsed time.

1.3.1.5.4 Acceptance Criteria for In-Service Welds

The acceptance criteria for the imperfections detected in in-service welds by NDT is similar to the girth welds as stated above.

1.3.1.6 ASTM E 1961-98 Mechanized Ultrasonic Examination of Girth Welds Using Zonal Discrimination with Focused Search Units

This standard describes the practice to cover the requirements for mechanized UT of girth welds. The techniques used in the standard is based on zonal discrimination whereby the weld is divided into approximately equal vertical examination sections (zones) each being assessed by a pair of ultrasonic search units. Typical applicable zones are shown in Figure 1.2-1 and calibration block layout in Figure 1.3-7.

Thicknesses of material examined covered in the standard are normally from 7- to 25-mm (0.28- to 1.00-in.) and 15-cm (6.0-in.) pipe diameters and greater but also may be applied to other thicknesses and diameters if the techniques can be proven to provide the required zonal discrimination.

Examination zones typically described in the standard is of 2 to 3 mm in height. For most applications it will require the use of contact focused search units to avoid interfering signals originating from off-axis geometric reflectors and to avoid excessive overlap with adjacent zones. Application of this standard becomes limited with advanced UT like a PA technique that is gaining more usage due to advantages like electronically sweeping (changing angles) and skewing the ultrasonic waves.

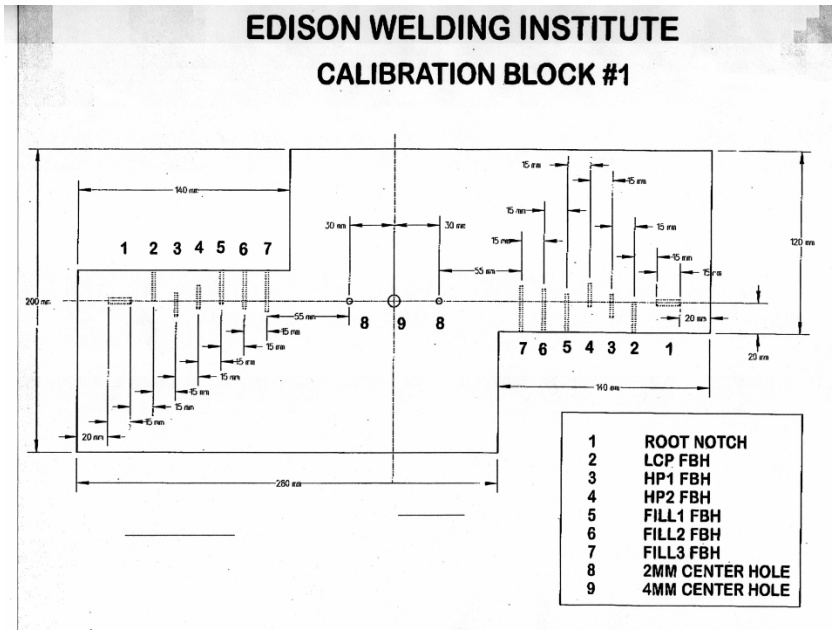


Figure 1.3-7. Typical Calibration Block Layout

The standard describes the requirements on various sections of AUT which is briefly described hereinafter:

- **Ultrasonic Equipment:** This section describes ultrasonic system, recording system, coupling, search units, reference standards, and personnel qualifications.

  The instrument should be able to provide a linear “A” scan presentation for each channel selected. The instrument linearity is required to be determined within 6 months of the intended end use date. Instrument linearity should be such that the accuracy of any indicated amplitude is within 5% of the actual full-scale amplitude. The recording or marking system should be able to clearly indicate the location of discontinuities relative to the marked starting position of the scan, with a ±10-mm (0.4-in.) accuracy. B-scan or other form of “mapping” displays is required to be used for volumetric flaw detection and characterizations and TOFD techniques may be added to improve characterization and sizing. An environmentally safe wetting agent can be used to enhance acoustic coupling. The search units are to be marked with a method to identify the manufacturer’s name, search unit type, exit point, incident beam angle, or refracted beam angle for a specific wedge-to-steel velocity ratio, frequency, and crystal size. The reference standard used is required to be used from the unflawed project-specific line pipe supplied. The personnel performing examinations to this practice is required to be qualified in accordance with nationally recognized NDT personnel qualification practice

or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, MIL-STD-410, or a similar document and certified by the employer or certifying agency.

- **UT Setup:** This section describes search unit positioning and primary reference sensitivity, gate settings, porosity detection search units (fill region), porosity detection search units (root region), evaluation threshold, recording setup, and circumferential scanning velocity.

  The search unit is required to be positioned at its operating distance from the simulated weld centerline on the reference standard and adjusted to provide a peak signal from its target reference reflector in the search unit's examination zone. The peak signal response is to be adjusted to 80% FSH for each channel. Using the reference standard, each detection gate shall be set to cover a sound path distance that starts at least 3 mm before the weld preparation and ends at least 1 mm past the weld centerline. Dedicated channels using B-scan or mapping-type presentations are recommended for detecting and characterizing porosity and other volumetric defects. The evaluation threshold for each detection channel is required to be typically 20% of FSH or greater for fusion zones. Channel output signals is required to be arranged on the recording display in a manner that allows the weld to be presented symmetrically either side of the weld centerline.
- **Dynamic Standardization:** This section describes detection channels and coupling monitor channels.

  With the system optimized the reference standard shall be scanned at the same speed at which the examination will be performed. The analog or digital recording shall indicate signals, 80% FSH, from each reference reflector recorded in their correct position assigned on the display. The circumferential positional accuracy of the recorded reflectors relative to each other should be within typically ±2 mm (0.08 in.), and with respect to the zero start they should be within typically ±10 mm (0.40 in.). A method is required to be employed to determine that constant coupling is achieved during examinations.

- **Field Examination:** This section describes weld identification, surface condition, reference line, system performance (sensitivity verification, circumferential position accuracy verification, temperature differentials and control, weld zone identification, and scanning sensitivity.

  Each weld is required to be identified by a unique number, a "0" mark and arrow, designating start point and direction of travel. A 100-mm (4-in.)-wide scanning area on each side of the weld should be clear of weld spatter and other conditions which may interfere with the movement of the search units, the coupling liquid, or the transmission

of acoustic energy into the material. Scribing a reference line on the pipe surface at a distance of 40 ±0.5 mm (1.60 ±0.020 in.) from the centerline of the weld preparation, on the examination band side is required. The reference standard should be used to verify scanning sensitivity at the start of each shift and thereafter at intervals not exceeding 2 hr or 10 welds, whichever comes first. The positional accuracy of the chart distance markers should be verified prior to commencement of the project and verified monthly. The chart should then be compared to circumferential distance measured with a tape measure placed on the outer surface of the pipe; chart accuracy should typically be ±10 mm (0.40 in.) or better, over the circumference. Scanning should be at least at primary reference sensitivity for fusion-zone channels and at the added gain setting for porosity detection channels. If standardization during production weld examination indicates one or more channels with values outside the range defined, the data from the welds scanned since the last acceptable standardization shall be evaluated to determine if the examination was acceptable or if the weld must be re-examined. An area with lack of coupling as indicated by the absence of a coupling monitor signal over a circumferential distance exceeding the minimum allowable flaw length, needs to be re-examined.

- **Report:** The examination data produced as a permanent record should consist of a complete strip-chart-type hardcopy showing the reference point, the direction of scanning, date and time of examination, and the name of the operator. For B-scan data, depending on noise level, colors for mapping can be selected down to 3 to 5% FSH to aid in characterizing flaws.

- **Standards of Acceptability:** Standards of acceptability are to be established based on workmanship or ECA calculations.

The standard further explains as a part of annexure the following:

- Determining acoustic velocity in pipe steels
- Typical search unit configuration
- Minimum requirements for reference standards.

1.3.1.7 EN 14163:2002 Petroleum and Natural Gas Industries- Pipeline Transportation Systems- Welding of Pipelines (ISO 13847:2000 Modified)

1.3.1.7.1 UT

This standard refers briefly to manual and mechanized NDT along with acceptance criteria.

The standard allows to consider the possible need to delay NDT for a certain time after completion of welding, as any delayed hydrogen cracking may not occur immediately upon cooling. The standard leaves the consideration of the time delay to the company it does not state any mandatory requirements for the inspection. There are many standards that implies such time delay restrictions in case of Canadian standards the time delay is more for in-service welds while per DNV it is for every weld. This standard though identifies the cracking risk to be potentially higher in welds made with cellulose-coated electrodes and also increasing with pipe strength or wall thickness.

The ultrasonic equipment to be used is required to meet the requirements of ASME Section V, Article 5. For offshore applications, probes required to be used shall be suitable for use on surfaces with elevated temperatures.

The reference DAC curves are required to be used in accordance with ASME Section V, Article 5. Calibration Block No. 2 in accordance with ISO 7963 can be used for calibration of range but not for determining sensitivity.

The standard notes that whenever material, bevel geometry, welding method or other factors call for additional considerations in flaw detection, preparation of special calibration test pieces is required. The sound path length from the transducer to the reflector cannot be less than 0.6 N where N is the near-field length of the probe. For examination of welds with surfaces at elevated temperatures, calibration are required to be made at the same surface temperatures and with the same couplant as during the examination of production welds or by using a correction table constructed by practical experiments.

MUT is not allowed to be performed on surfaces with roughness or irregularities which cause the transfer measurement to vary by more than 3 dB. The total value of transfer correction is not allowed to exceed 6 dB. Tandem techniques are required to be used for girth welds with a bevel angle between 0 and 10 degrees if specified by the company. When using straight-beam probes for weld examination, the DAC curve is required to be drawn similarly to that for angle probes. The length of indications is defined as the circumferential distance over which the echo height exceeds the reporting level.

Under mechanized examination the standard states to use the equipment that is capable of providing reproducible examinations and permanent records, and be capable of identifying defects. The standard does not address the requirement on setup, qualification in detail for the use of equipment on the project.

All indications exceeding the DAC curve by more than 20% are required to be investigated and reported. Indications exceeding DAC either by more than 50% or 6 dB are required to be reported and evaluated. Length, position, and amount by which the DAC is exceeded together with echo characteristics are required to be documented for indications.

1.3.1.7.2 Acceptance Criteria

All linear indications that produce a response greater than 20% of the reference level are required to be investigated to determine the location, shape, extent, and type of reflector, and evaluated according to:

- All cracks are unacceptable, regardless of size or location in the weld.
- Linear indications (other than cracks) interpreted to be open to the surface are unacceptable if they exceed 25 mm in total length in a continuous 300 mm of weld or 8% of the weld length.
- Linear indications interpreted to be buried within the weld are unacceptable if they exceed 50 mm in total length in a continuous 300 mm of weld or 15% of the weld.

1.3.1.8 Qualifications of AUT Systems

AUT systems are now more commonly used for the FFP control of pipe girth welds replacing the traditional radiography workmanship control.

Defect acceptance criteria are often based on an ECA. The ECA gives allowable defect sizes depending on material properties and loading conditions during installation and operation. It is required that non-allowable defects are detected with a sufficiently high POD and that the probability of undersizing of defects is sufficiently low. Thereby, a sufficiently high combined probability that non-allowable defects are not accepted (i.e., rejected), may be reached.

In order to establish AUT performance data, AUT systems are subject to qualification by many operators and also per standards like API 1104 19th edition and DNV OS F101.

Following section is a review of various AUT qualification specifications.

1.3.1.8.1 API 1104th Edition, 19th Edition, September 1999 Welding of Pipelines and Related Facilities

This edition requires a mandatory qualification of the UT procedure; the qualification process mentioned is as follows:

- Welds (minimum of two per welding procedure) containing defects and acceptable imperfections shall be prepared from actual production pipe material samples using the approved welding procedure specification. Welder qualification welds may be used.

- Radiographs shall be made of the welds and the results documented.

- The UT procedure shall be applied, within the detailed temperature ranges, and the results documented and compared with the radiographs.

- Differences in detection results shall be documented. (Differences in detectability and resolution between ultrasonics and radiography may be noted.) If required by the company, destructive testing of the weld sample shall be made to discover or confirm the results.

- Use of the UT procedure on production welding shall be based on the capability of the implemented UT method/technique systems to: (1) circumferentially locate, (2) size for length, (3) determine depth from OD surface, and (4) axially (weld cross section) locate required imperfections/defects in the test samples.

As listed above, the standard does not specify a mandatory destructive testing for analyzing the results it leaves an option of comparing the AUT results with radiography if opted for. The standard does not specify any minimum requirements on the sizing or on the POD. It has been noted that the use of method employing sectioning of weld samples with induced defects for ultrasonic system is very useful. The mechanical sectioning serves as a very good tool for the accurate sizing of length and height of defect and compare it to AUT qualification results to better understand AUT system's capability.

1.3.1.8.2 DNV OS-F 101 Qualification of Ultrasonic System

The approach taken by this standard is similar to API 1104, 19th edition. The qualification of AUT system is weld method and groove geometry specific. Qualification done for one type of welds or an earlier version of the AUT system will not automatically qualify the system for a new application.

The scope of the qualification program consists of fulfillment of the requirements of specification, ability of the AUT system to detect defects of relevant types and sizes in relevant locations, accuracy in sizing, and locating defects.

- **Detection Requirements:** The detection ability of an AUT system is deemed sufficient if the probability of detecting a defect of the smallest allowable height determined during and ECA is 90% at a 95% confidence level. This requirement in most cases be regarded fulfilled, when the smallest allowable defect height is 3 mm or more and the AUT sensitivity level is set at 80% of the echo from a 3-mm-diameter FBH.

  An alternative route showing sufficient sensitivity and detection ability is to show that detection rates are higher, with 95% confidence, than those for an accepted workmanship NDT technique.

- **Sizing Accuracy Requirement:** The specification does not state any specific requirements on defect sizing accuracy. The sizing accuracy plays a very important role when used for determination of acceptable defect sizes calculated by ECA. High inaccuracy especially undersizing can create problems in defining the acceptance criteria. Thus, the sizing accuracy requirement is indirectly set.

- **Qualification Program:** The standard describes various stages of a qualification program such as collection of available background material, evaluation, planning, and execution of the program concluding with evaluation of results from capability and reliability trials. As a minimum per the standard a qualification will involve an assessment of the AUT system technical documentation, including the quality assurance system, and available information on detection abilities and defect sizing accuracy. A limited practical test, must, however, in many cases be executed.

- **Variables:** The variables must be taken into accounted are listed in the specification that consists of welding method, groove geometry, root and cap probe setup, probe setup for other channels, reference reflectors, system, data acquisition, data treatment, and software version.

- **Test Welds:** The standard describes the use of welds containing intentionally induced defects typical of those expected to be present in production welds for the qualification program. The welding method, material, and weld geometry to be used for preparation of these welds must be same as to be used during production. The welds made are required to consist of minimum ten defects per welding method/joint geometry to be

used during production. The presence and sizes of induced defects in the test welds are required to be confirmed by subjecting the welds to radiography, MUT, and magnetic particle or eddy current testing. The interpretation of radiographs and other test result should at least be performed by two individuals, initially working independently of each other and later reporting their findings jointly.

- **Qualification Testing:** The test welds are subjected to testing by the AUT system undergoing the qualification. For the testing purpose a low-echo amplitude recording threshold is required to be used. This threshold should be selected somewhat above the noise level and the recording of echo amplitudes may be used for possible later determination of the examination threshold setting to achieve sufficient detectability. The standard requires performing repeatability tests with several scans with guiding band removed and re-attached between scans. The qualification also requires performing at least one test performed at the elevated temperature expected during field work. The AUT test results needs to be report and the report should give identified defects in test welds with respect to circumferential position, length, height, and depth. In addition, the report should consist of the defect height and amplitude around the highest and lowest part of the defects for each 2-mm circumferential length over a length of 15 to 20 mm.

- **Validation Testing:** The validation testing is required to be performed by cross sectioning (“salami method”). Based on the locations marked as defects on the reports the cross sectioning plan is to be made. The extent of cross sectioning should be sufficient to ensure that the defect height sizing accuracy determination will be based on a minimum of 29 measurements made on different defects and/or "ultrasonically independent" parts of defects for each welding method and joint configuration. For determination of defect height sizing accuracy two parts of each defect, 10- to 20-mm long and corresponding to the highest and lowest part of the defect recorded on the AUT report is to be selected sectioning to determine defect height and location. The weld sections containing defects are required to be machined in increments of 2.0 mm, followed by etching and measure the height and depth measured with accuracy better than ±0.1 mm. Each cross section is required to be documented by photography with 5-10× magnification. For determination of detection abilities and adjustment of required threshold levels additional cross sectioning, or detailed ultrasonic mapping of specimens cut out from the test weld pipes is required. These cross sections are required to be selected randomly, at locations where one or more of the applied NDT techniques have found indications.

- **Analysis:** The analysis consists of accuracy in height sizing, length sizing, circumferential positioning/location, AUT defect characterization abilities compared to the results of the destructive tests and other NDT performed, repeatability when repositioning guide band and at elevated temperature. Whenever relevant, the analysis needs to consist of POD values or curves for different assumed echo amplitude threshold setting to determine the threshold to be used during examination, or an analysis of the relationship between echo amplitude and defect height.

- **Reporting:** A qualification report is finally to be generated describing the outcome of technical evaluation of the AUT system and qualification testing along with conclusions.

1.3.1.8.3 EN 14163:2002 Petroleum and Natural Gas Industries – Pipeline Transportation Systems - Welding of Pipelines (ISO 13847:2000 Modified)

The standard briefly describes the NDT (not specific to UT only) procedure qualification by means of practical demonstration on welds similar to the production welds for which the procedure is used. The NDT required for qualification are required to be conducted under anticipated field conditions and with weld temperatures foreseen during the examination of production welds. The standard does not explains any further means of verification of the results achieved during procedure qualification.

1.3.1.8.4 Typical AUT Qualification Practices

The majority of pipeline and offshore companies has generated typical specifications (global practices) that define the minimum requirements for qualification of AUT inspection systems for the inspection of girth welds. Typically, AUT qualifications are performed on project-by-project base. The requirements of the qualification programs for critical weld are quite extensive and descriptive that helps in ensuring the use of right system for the project application. The documents are usually confidential, very detailed, and broken into sections like production requirements, execution requirements, qualification testing, qualification criteria, validation testing, AUT scan documentation, data analysis, data reporting, comparisons, and statistical analysis. It is also very important and as noted in the specification to survey the capability of AUT contractor with respect to spares inventory, qualified operators in the team, engineering support available, in-house training conducted, and quality assurance. It is very important to understand the capabilities of various AUT systems available and the effect of changes in variable like pipe wall, pipe grade, and pipe OD on various AUT system capabilities.

The documents state for production jobs that use different bevel designs or acceptance criteria than those addressed in the qualification program, the contractor may be required to

demonstrate acceptable performance with these new variables. Unlike to DNV OS F101 the qualification described above does not require a qualification with change on variable. It is left at an option of the company to decide if the qualification program performed once is valid with any change in variable or a re-qualification program is required.

It is thus considered to execute a global AUT system qualification to cover various wall thickness, bevels, and pipe grade effects on system capabilities and accuracy to better help in directing the industry in selecting the right system for project specific application.

The weld samples fabrication method is same in majority of documents; the defects are required to be created by degradation of the welding process, welding parameters, welding conditions, and/or welding technique instead of machined or manually induced defects. It has been noted that welds made by degrading, as described above, tends to leave indications that are generally larger than achieved during production which is due to the chances of degrading the welding during production similar to the extent achieved during AUT system qualification is generally not observed. Thus, to determine the AUT inspection system capability to detect defects with the size less than 0.5 mm is very difficult. It is thus considered to better use a combination of: welds made by degrading the welding process to create defect and also use welds with machined or manually induced defects in order to assure the AUT inspection system's capability of detecting and sizing indications of various sizes.

Some documents state that the qualification is required before the system is used on the project but also states that at the discretion of the company the requirement can be waived in lieu of an alternative approach.

As a part of qualification it is required to prepare test welds representative of the welding process to be selected for scanning. The test welds are required to be scanned in sequence and then the sequence to be repeated again. The initial scans are required to be interpreted according to the acceptance criteria and the repeat scans are to be used to verify speed and reliability. In some documents it requires allotting maximum of 5 minutes per weld for the test to include scanning, evaluating, and recording the results. The elements of the system to be evaluated are compliance with technical requirement of the specification, completeness of required equipment, repeatability, speed, reliability, durability, and flexibility of operation. The details related to independent NDT and sectioning that generally helps in concluding the AUT qualification are defined in the majority of the documents.

The requirements of the procedures are to scan the welds supplied by the company and report any flaws that are outside the project acceptance criteria. The results from the qualification

scan is required to be further analyzed by the company to confirm the acceptance of the system and operators.

It is to be noted that there are various approaches that different companies follow for qualification of the AUT system; the requirements of each company changes based on the project requirement. AUT is playing a very critical part of the pipeline construction seems to demand for a global AUT qualification standard that can be used; this standard needs to be referred by standards like API 1104. This global document should take into account various AUT systems available and describe the in depth requirements of system qualification that can be referred and used for system qualifications.

As stated before, it would be a better proposition to qualify AUT systems at certain duration periodically and publish the results of the qualification which would afford to keep all the companies and contractors aware of the system capabilities and selecting the right system for the project application.

1.3.1.9 AUT Procedures Developed by Inspection Companies

The procedures developed by AUT companies are to describe in detail the AUT inspection system, inspection personnel qualification, inspection setup, inspection, and documentation generated for a project. Usually, AUT procedures are confidential.

The procedures generated by all AUT companies defines the transducers used including their:

- Selection
- Design and performance
- Calibration standards
- Ultrasonic scanning heat
- Gate settings
- Transducer positioning and primary reference sensitivity
- Field inspection method to include the surface condition of material
- Calibration
- Identification of material
- Interpretation of daily defects
- Acceptance criteria used.

Typical inspection parameters and search units for a particular pipe size is shown in Table 1.3-5. This table helps in better understanding the setup of the ultrasonic system that various

companies are taking to inspect welds. The above table shows various kinds of AUT techniques that can be used on a project. With the so many options available in the market and with different setup for inspecting a particular weld it becomes very necessary for comprehensive AUT system qualification and an comprehensive requirements produced that can be used to cover all systems and perform right checks to ensure that all different setups can give 100% weld coverage.

Table 1.3-5. Typical Inspection Parameters and Search Units

Zone Name	Assumed Height (in.)	Target (mm)	Technique	Angle (degrees)	Frequency (MHz)
Root	1.3	0.5-1.0 notch	P/E	50-70	4.5-7.5
LCP	1.3	2 FBH	P/E	55-70	5-7.5
Hot Pass 1	1.65	2-3 FBH	P/E	45-55	4.5-7.5
Hot Pass 2	1.65	2 FBH	P/E	45-55	4.5-7.5
Fill 1	3	2-3 FBH	Pitch/catch	40/50-45/55	4.5-7.5
Fill 2	3	2-3FBH	Pitch/catch	40/50-45/55	4.5-7.5
Fill 3	3	2 FBH 0.8-1.0 notch	P/E	55-65	4.5-7.5

1.3.1.10 General Operators Experience with AUT Pipeline Girth Weld Inspection

As part of this survey, various pipeline operators and contractors were contacted and visited in order to receive feedback on general experience with AUT girth weld inspection using multi-probe and linear PA systems only with focusing capabilities.

There were few concerns also shared by operators which follow:

- **Operators:** It has been experienced that operators plays a very important role in inspection. It has been noticed that even change in operators plays an important role in AUT system qualification. With change in operators the results of qualification with same system on similar pipe size and grade makes a big difference. Another concern is the availability of good operators is less. There are few operators trained and experienced for critical applications like risers and tendons available which make the execution of project very difficult.

- **Qualifications:** The results from qualification of AUT systems have shown varying results for same system with a minor change in pipe size or change in operators.

Also, a common feedback received from almost all operators was that they were informed about new advanced PA system's capabilities and accuracies. The advantage linked with PA AUT like electronic sweeping and skewing was of most interest by the operators as it helps not to leave any zone of weld un-inspected. In addition, it is assumed that due to the ability of sweeping and skewing of ultrasonic waves as part of PA AUT discontinuities with any orientation stands more chance to be detected.

The idea of generating global AUT qualifications was shared and found to be generally acceptable by all operators that will give a detailed explanation on all the AUT system capabilities and their performance which will help to select the right system for the right application. The above-mentioned qualification, as advised, should also cover the operator qualification as it plays a very important role in the inspection.

In all, the operators feeling toward AUT of pipeline girth welds was encouraging as it is seen to go in the right direction. However, with increased accuracy levels, requirements along with the deep-sea applications of pipeline and efficiency requirements the views shared can be summarized to have a better combined approach to streamline the requirements and qualification of AUT systems. It is also understood to expand the expertise in this field thus provide better support to the project management and fabrication group, to better understand the welding problems, and have high satisfaction and reliability ratings.

1.3.1.11 References

1.3.1-1. CSA Z662-99 Oil and Gas Pipeline Systems.

1.3.1-2. CSA Z663-03 Oil and Gas Pipeline Systems.

1.3.1-3. DNV OS F101:2000 Submarine Pipeline Systems.

1.3.1-4. API 1104, 18th Edition Welding of Pipelines and Related Facilities.

1.3.1-5. API 1104, 19th Edition Welding of Pipelines and Related Facilities.

1.3.1-6. ASTM E 1961-98 Mechanized Ultrasonic Examination of Girth Welds Using Zonal Discrimination with Focused Search Units.

1.3.1-7. EN 14163:2002 Petroleum and Natural Gas Industries - Pipeline Transportation Systems - Welding of Pipelines (ISO 13847:2000 modified).