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PERFORMANCE DEMONSTRATION EXPERIENCE FOR REACTOR PRESSURE VESSEL SHELL ULTRASONIC TESTING

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Abstract

The most ultrasonic testing techniques used by many vendors for pressurized water reactor (PWR) examinations were based on American Society of Mechanical Engineers "Boiler and Pressurized Vessel Code" (ASME B&PV Code) Sections XI and V. The Addenda of ASME B&PV Code Section XI, Edition 1989 introduced Appendix VIII - "Performance Demonstration for Ultrasonic Examination Systems". In an effort to increase confidence in performance of ultrasonic testing of the operating nuclear power plants in United States, the ultrasonic testing performance demonstration examination of reactor vessel welds is performed in accordance with Performance Demonstration Initiative (PDI) program which is based on ASME Code Section XI, Appendix VIII requirements. This article provides information regarding extensive qualification preparation works performed prior EPRI guided performance demonstration exam of reactor vessel shell welds accomplished in January 1997 for the scope of Appendix VIII, Supplements IV and VI. Additionally, an overview of the procedures based on requirements of ASME Code Section XI and V in comparison to procedure prepared for Appendix VIII examination is given and discussed. The samples of ultrasonic signals obtained from artificial flaws implanted in vessel material are presented and results of ultrasonic testing are compared to actual flaw sizes.

Introduction

The most ultrasonic testing (UT) techniques used by many vendors for Pressurized Water Reactor (PWR) examinations were based on the **American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Sections XI and V**. The ASME Code editions up to and including edition 1986 specified the following requirements for Ultrasonic Testing (UT):

- personnel qualifications, experience, visual acuity and ability to differentiate colors used in the method
- system calibration: calibration block, instrument performances, transducer's refracted angles (0, 45, 60 deg.)
- examination performance (4 directions if applicable)
- recording criteria (amplitude based)
- flaw sizing (amplitude based)
- flaw analysis criteria (acceptance standards)

In order to improve safety of the components by improving the UT technique's detection capabilities, the UT requirements have been modified by obligations of United States Nuclear Regulatory Commission **Regulatory Guide (RG) 1.150** Revision 1 issued in 1982.

The RG 1.150 introduced new, additional prerequisites to the ASME Code requirements:

- more conservative flaw sizing in the inner 25% of the vessel wall volume (amplitude based)
- scanning for near surface flaws (application of additional search units)

The 1989 Addenda of the ASME Section XI introduced Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems" in an effort to increase confidence in the performance of UT of the operating nuclear power plants. By the ASME Code, Appendix VIII the reactor vessel shell performance demonstration qualification is divided in two supplements: Supplement 4 which deals with inner 25% of the vessel wall, and Supplement 6 which deals with vessel wall thickness from 25% to full thickness of the component.
This appendix provides the requirements for satisfying of the following:

- qualification of personnel, equipment and examination procedures through the use of flawed test specimens and blind tests in order to demonstrate capability of flaw detection and sizing
- the acceptable false call rate
- tolerance of flaw under-sizing and over-sizing

Qualification Preparation Works

During the year 1992, the first Inetec-WesDyne (subsidiary of Westinghouse) works regarding the organization of the Appendix VIII qualification has been undertaken. Beside all other necessary activities to be performed, the qualification strategy has been directed to:

- determination of the equipment to be used
- developing of the examination procedure

The criteria of defining equipment to be used for qualification have been based on the following facts:

- acquired experience in RPV examinations
- quality of acquisition system regarding the data quality obtained
- system reliability
- proposed scanning speed (6 inch / sec. – 150 mm/sec)
- instrument possibilities to minimize noise level (data averaging)
- possibility of automated flaw detection and sizing

Beside challenging flaw detection and sizing criteria, the examination procedure introduced the following goals:

- minimizing the time needed for system calibration regardless of :
    - RPV material chemical composition
    - RPV material heat treatment
    - RPV wall thickness
- minimizing "on vessel" time
- simple and fast failed component substitution
- application of automated flaw sizing

Determination of the Equipment to be Used for Appendix VIII Qualification

The equipment used for RPV examinations at that time has been evaluated for conformance with established requirements. It has been found that:

- no major equipment changes are needed to be performed for qualification purposes
- the number of cable connectors and cable length have to be changed due to later possibility of pulser/receiver board set up on the scanner in close proximity to transducer
- minor acquisition software changes need to be performed in order to speed up the system characterization

The above prerequisites have been easy to perform. The fast Fourier transformation included up to that time in the analysis software has been added to an acquisition part of the software so the system characterization is provided by a "click" of the button.

The Procedure Development

The procedure development process was much more complicated:

- while older procedures simply incorporates ASME Code examination rules and in accordance to them prescribe examination requirements, procedure to be prepared for Appendix VIII examinations does not have any prescribed guidance or directions.
- for Appendix VIII examinations ASME Code gives only the requirements regarding system tolerance and tolerance of obtained results.
- severe detection and sizing criteria required special attention and considerations during preparation of the procedure. The most parts of the procedure needed to be verified and experimentally proven. For that reason, procedure development process has been performed on a special way: the most steps written in the procedure have been verified by practical trials. Examples of artificial flaw and real crack tip diffracted signal measurements with and their actual dimensions are presented on figure 1 and figure 2.

After an extensive research and experimental works have been performed, the final version of the procedure has been produced. Generally, procedure define:

- type of material and minimal diameter of the vessel for which procedure is applicable
- applicable thickness range
- scanning requirements
- side from which examination has to be performed
- couplant
- essential equipment together with required instrument performance documentation and replacement equipment (system characterization - transducers, pulser/receivers, cables)
- requirements for personnel (level of previous qualification regarding to SNT-TC-1A and ASME Code Section XI)
- examination sensitivity adjustment
- examination requirements - determination of the essential variables: sampling frequency, Peak Detect and Hold (PDH), system delay, buffer length, A-scan data averaging, Pulse Repetition Frequency (PRF), increment value, scanning speed, pulser and receiver settings, channel triggering sequence, criteria for accepting of acquired data, etc.
- analysis requirements:

- verifying of the sensitivity level,
- resolution of flaw signals and non relevant signals such as geometry reflections, beam redirected signals, mode converted signals,
- criteria for flaw length measurements (for each type of transducer),
- criteria for flaw through-wall size measurements (tip diffraction),
- recording requirements: data file name, software revision, weld ID, flaw length, through-wall extent of the flaw, flaw ligament, name and signature of examiner

> examination records:

- examination procedure,
- system characterization,
- sensitivity calibration,
- identification of examined areas and area restricted from examination due *to the access limitations*
- indications recorded,
- personnel certifications,
- dates and times of examination,
- reference block drawing,
- equipment identification and performance documentation

Conclusion

Based on knowledge acquired during preparation of qualification, successful Appendix VIII qualification exam passed in January 1997 and in comparison with experience acquired during extensive examinations of the reactor pressure vessels by use of ASME Code based procedures, the following issues may be noted:

- the ASME Code based procedures, which includes requirements of RG 1.150 would not be capable of passing the qualification test. This may be explained as follows:
  - sensitivity of the ASME based procedures may be assumed as adequate
  - the detection part of qualification might be passed only if skilled analyst would perform data analysis
  - ASME Code amplitude based sizing criteria have shown inconsistent measurements (in some cases flaws are undersized and in other cases flaws are oversized)
- automated flaw sizing (length and through-wall) did not show acceptable results for qualification
- increasing of a scanning speed to more than 6 inch per second does not influence the quality of ultrasonic data
- identification of TIP DIFFRACTED signals provide enough precise measuring technique for flaw length and through-wall sizing for both, Supplement 4 and Supplement 6 examinations
- system qualified in accordance with Appendix VIII provides application of less conservative approach to analytical flaw evaluation

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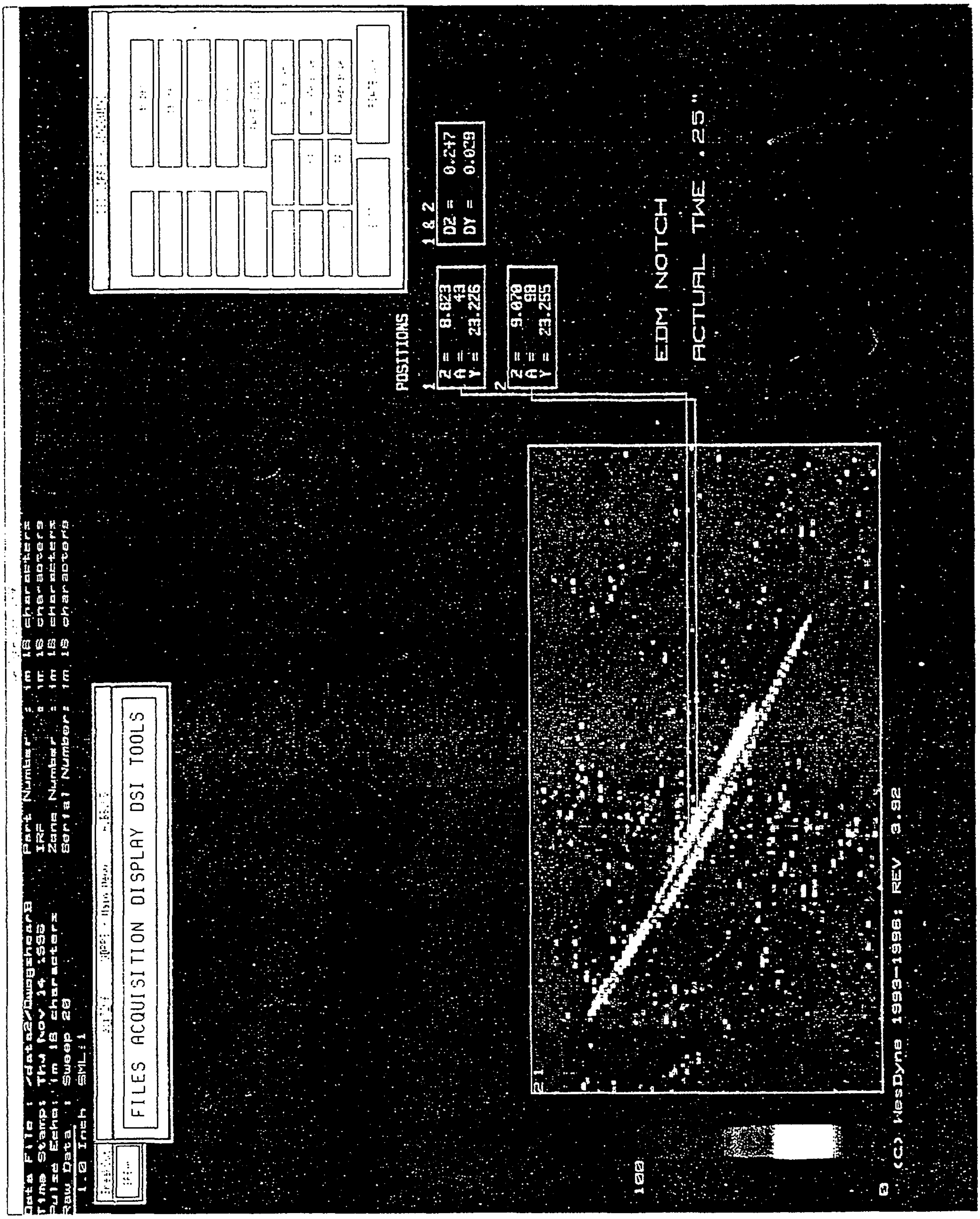

Figure 1. EDM notch response, tip diffraction measurement and actual through-wall dimension

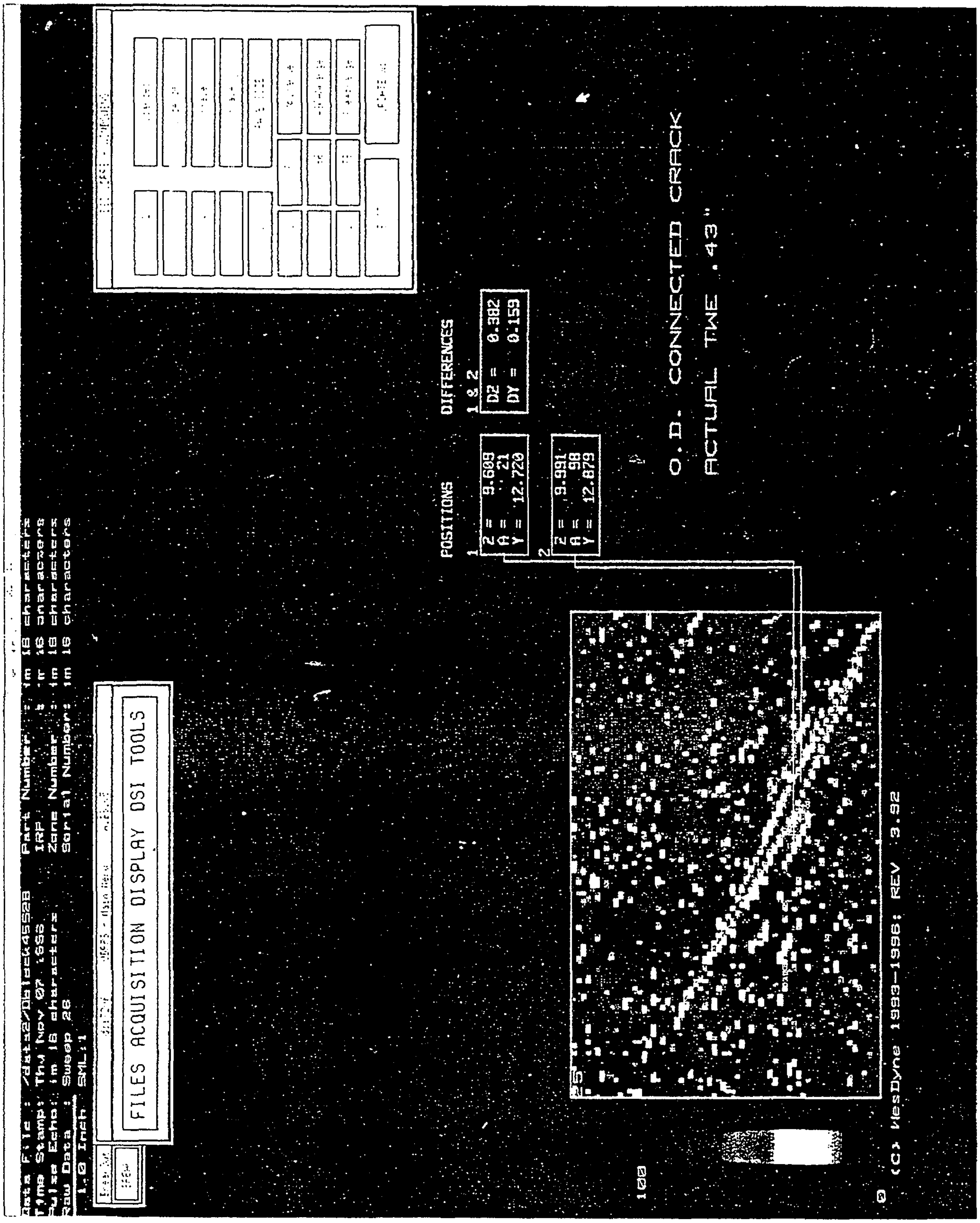

Figure 2. Crack response, tip diffraction measurement and actual through-wall dimension