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SAFETY INJECTION NOZZLE WELDS

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Sizing Small Defects in PWR Vessel

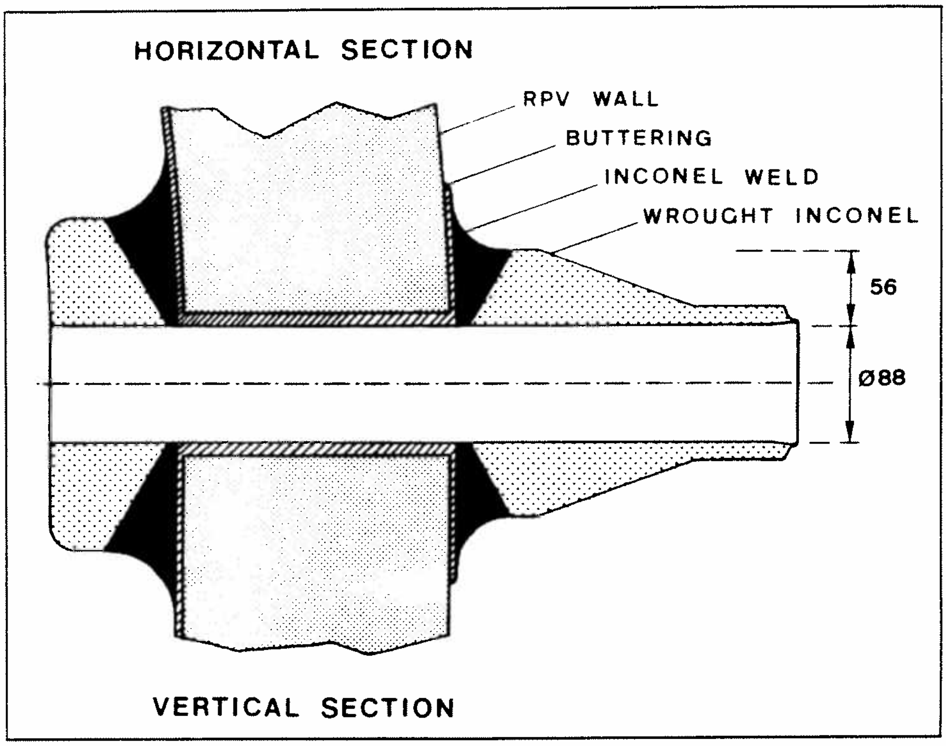
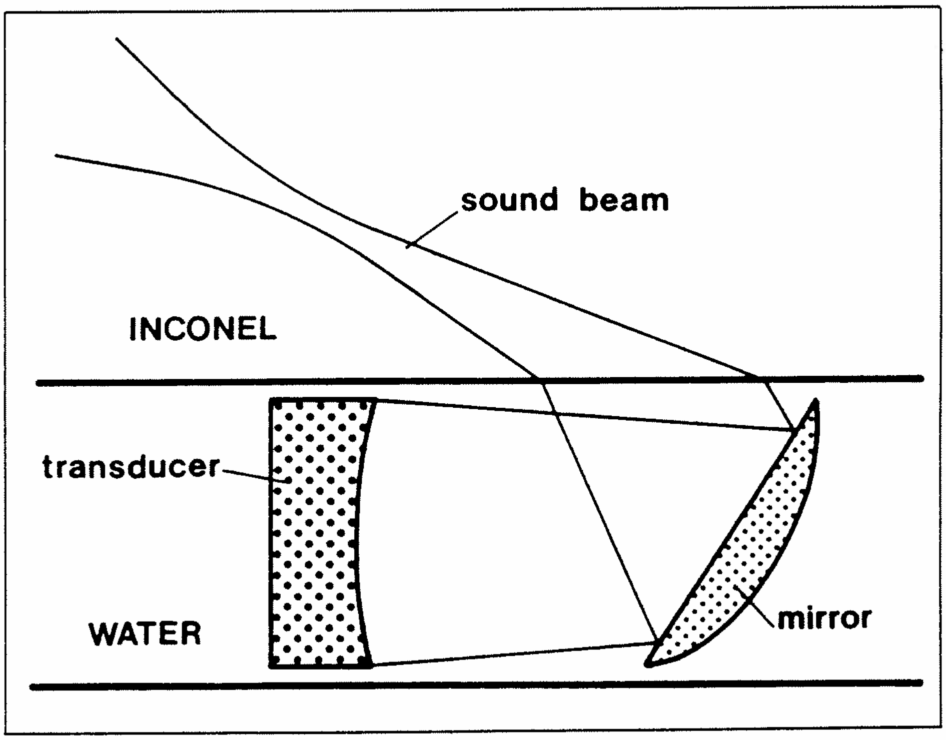


Figure 1: Safety Injection Nozzle Design

Figure 2: Principle of Acoustic Beam Generation



Unlike in most PWRs, Belgian Doel-1 and -2's emergency cooling water is injected straight into the reactor pressure vessel through two set-on nozzles located at the level of the main coolant nozzles. The safe-end is made from wrought inconel, the same material is used for the reactor pressure vessel (RPV) wall buttering and for the manual metal arc welding. Figure 1 illustrates the assembly design.

Regulatory in-service inspection conducted during the first 10 years of operation was based on an ultrasonic examination procedure, using 2-MHz 45° refracted compression waves with a twin-crystal search unit. It evidenced the presence, near to the safe-end fusion line of both nozzles in Doel-1, of some borderline indications, with regard to the applicable ASME XI acceptance standards.

The resulting concern led to enhancement of the flaw sizing capability and to development of an automatic system to implement in the field the technique selected.

Ultrasonic Technique

Laboratory trials were carried out on a representative sample containing a number of 4.75 mm diameter holes side-drilled at various depths, as well as artificial flat reflectors, presumably similar to the actual defects. The same block was used subsequently for calibrating the equipment.

Flaw tip diffraction was experimented with in a pitch/catch configuration, but produced poor signal/noise ratios as a result of the material coarse-grained metallurgical structure and of the flaw misorientation.

Ultrasonic beam focussing provided better performances, with large 4-MHz piezoelectric crystals. As shown by Figure 2, a convex acoustic mirror placed in front of the transducer deflects the sound pulse and propagates compression waves at 45° toward the weld. Its curvature compensates for the focussing effect induced by the cylindrical water-inconel interface.

Beam diameters ranging from 3 to 8 mm as a function of depth can be achieved in this way, enabling one to detect edge diffraction signals from planar defects a few millimeters high. Volumetric indications, which do not produce clear diffraction patterns, can be sized by the conventional −6 dB drop method.

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Safety Injection Nozzle Welds

A 60° transducer, taking advantage of the specular reflection on defects oriented along the weld chamfer, was added to differentiate between small flaws and tip echoes. The eventual probe design is illustrated in Figure 3.

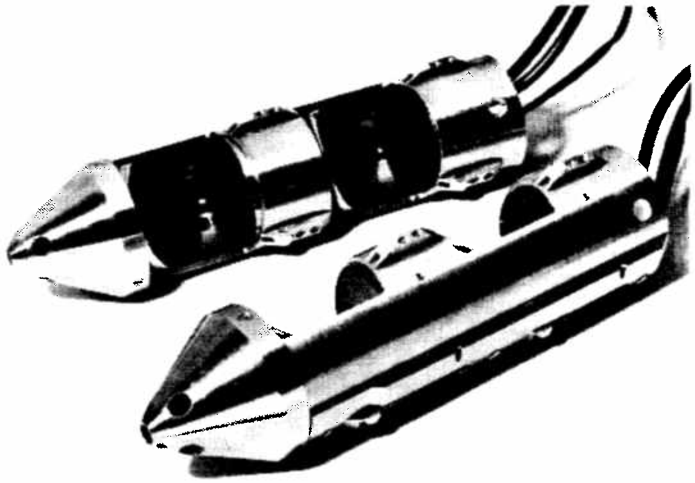

Figure 3: Twin-Transducer Probes

Inspection System

The stringent requirements regarding examination accuracy led to disregarding of the existing ISI scanning rig. A specially dedicated manipulator was developed, allowing for six independent motions powered pneumatically or by stepper motors. The insertion of the probe-bearing shaft into the nozzle borehole is controlled manually, with the help of numerous ultrasonic eyes fitted on the manipulator and on the main probe. In Figure 4, the mechanism can be seen installed on the Doel-1 pressure vessel.

Transducer scanning is driven by a 32-bits controller, which also stores the raw data delivered by the programmable ultrasonic instrument and by the position encoders, and displays views of the inspected volume on a color terminal D-scan and B-scan.

Data analysis and defect sizing are carried out by the inspector on an identical computer. Software offers powerful built-in aids such as amplitude weighting as a function of the distance-amplitude correction curve, windowing, amplitude locus curve plotting and distance calculations.

Examination Results

Field application in Doel-1 revealed many small defects in the examined region of both safety injection nozzles. In particular, the large indications revealed by the previous in-service inspection appeared to be clusters of such small flaws, obviously integrated into single records as a consequence of the sound beam dimensions.

On the contrary, the high resolution of the focussing transducers enabled very accurate estimation of the height of each individual defect and of the ligament that remains, thereby dispelling all doubts as regards weld acceptability in accordance with ASME criteria.

The developed system found a second application during the 10-year revision of Doel-2 where no significant indication was recorded. ■

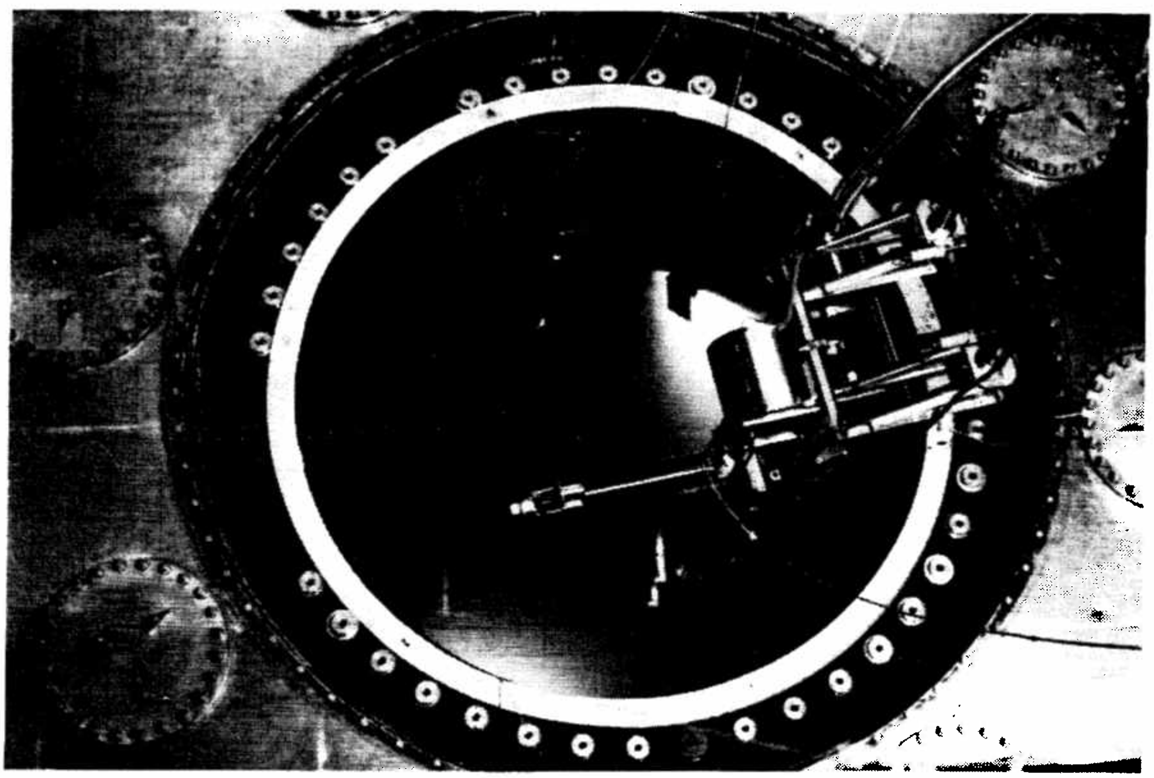

Figure 4: Manipulator Installed on the Doel-1 Pressure Vessel