AIB-VINCOTTE

FOREST CENTRAL OFFICE
Avenue du Roi, 157 - B-1060 Brussels
Phone (2) 536 82 11 - Telex 22550 - Fax (2) 537 46 19

R&D n° : 47-3-0022-4 May, 90

DEVELOPING ULTRASONICS FOR PWR PUMP BOWL IN-SERVICE INSPECTION

Nuclear Engineering International

May 1990

P. RORIVE (SEMO), P. CAUSSIN, Ph. DOMBRET

Developing ultrasonics for PWR pump bowl in-service inspection

By P. Dombret, P. Caussin and P. Rorive

An effective solution to the problem of inspecting thick-section austenitic stainless steel in PWR pump bowls has been developed in Belgium, using ultrasonic beam focusing. The first application was at Tihange 1 using dedicated automated equipment. Wider applications are envisaged.

The frequency range commonly used in ultrasonic testing (UT) allows acoustic pulses to propagate in most low-alloy carbon steels, providing a suitable resolution in both axial and lateral directions. The metal grain is much smaller than the wavelength of the signal, and the examined material may be considered an isotropic lossless medium.

Basic limitations. However, the austenitic structure of most stainless steels rules out that comfortable trade-off. Indeed, the grain coarseness highlights the elastic anisotropy of the crystallographic lattice, inducing several strong disturbances in wave propagation, such as energy scattering and acoustic ray deviations.

With conventional UT on austenitic materials, there is commonly a low signal/noise ratio and therefore uncertainty about reflector location. This is often made worse by poor access conditions and a lack of prior information on the components to be tested, and leads to limited flaw detection and sizing capability. This is particularly evident when dealing with austenitic castings and welds, where large, often columnar, grains can develop during the solidification of the metal.

Despite this, the mechanical and chemical properties of stainless steel have led to it being widely used in critical industrial installations; in most nuclear power plants, the largest part of the piping system is made from stainless steel.

Most applicable regulations require that a volumetric in-service inspection be carried out on such components to detect possible service-induced flaws. As radiography is less practical and efficient than it can be during the erection of the plant, efforts have been made to enhance the capability and reliability of conventional UT techniques.

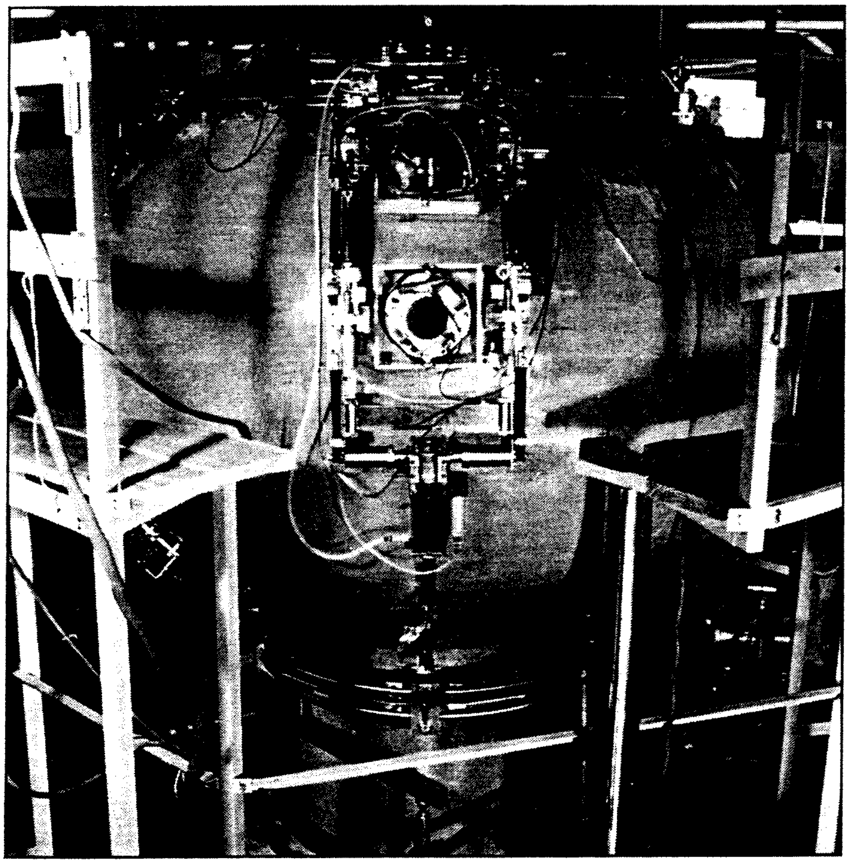
P. Dombret and P. Caussin are with AIB-Vinçotte, Avenue du Roi 157, B-1060, Bruxelles, Belgium. P. Rorive is with SEMO, Tihange, Belgium.

SEARCHING FOR A COMPROMISE

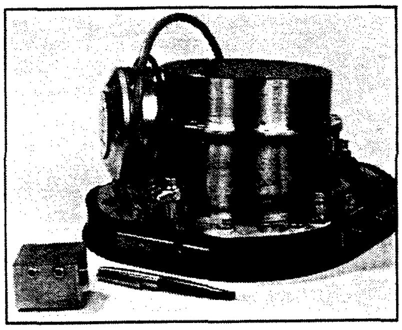
As a general rule, longer wavelengths must be used in coarse grain materials to facilitate wave propagation. The associated reduction in sensitivity and resolution can be countered using the methods that new technology has made available — transducers with heavily damped elements produce short pulses, providing depth resolution, whilst any beam width reduction technique takes care of the lateral resolution.

This explains the enhancement of the signal/noise ratio obtained by twin-crystal search units (commonly called TRL probes), the apparent beam of which results from the convolution of the sound fields of the separate transmitter and receiver. All such transducers designed for austenitic material inspection generate short compression wave pulses at fairly low frequencies. However, their efficiency is limited to a certain depth range, which depends on both the probe characteristics and the scattering encountered in the propagation medium.

Where a very high degree of scattering must be faced, or where the material



▲ **The inspection equipment was tested on a full-scale mock-up of a pump bowl in which windows were opened to insert the steel samples. Here the pitch—catch configuration is shown.**



▲ **Contact twin-crystal probe (left) and focused beam transducer (right) used to inspect depth range.**

is very thick, the TRL approach leads to very large piezoelectric elements and it becomes difficult to assure the acoustic coupling of these.

Acoustic beam focusing can however offer a more effective alternative —albeit with the penalty that implementation is more demanding. Either lenses or digital processing (SAFT) can provide high sensitivity and sound/noise ratio, and the degree of focusing can be customized to yield any required beam width (at the focal distance) between the ultrasonic wavelength and the standard transducer beam dimension. Experience also shows that the focal characteristics bear up satisfactorily against the disturbances induced by the austenitic macrostructure.

To summarise the approach adopted here, the key is always to find a compromise between two opposing requirements: good pulse propagation; and interaction of the pulse with the reflector. To determine the ideal compromise it is necessary to have access to the actual component to be examined or to a representative sample.

INSPECTING PWR COOLANT PUMPS.

Most PWR coolant pump bowls are made from cast austenitic steel. The typical thickness of the casing is about 200mm. Before the technology to fabricate such bowls in a single piece became available, electroslag welding was used to assemble three, and subsequently two parts.

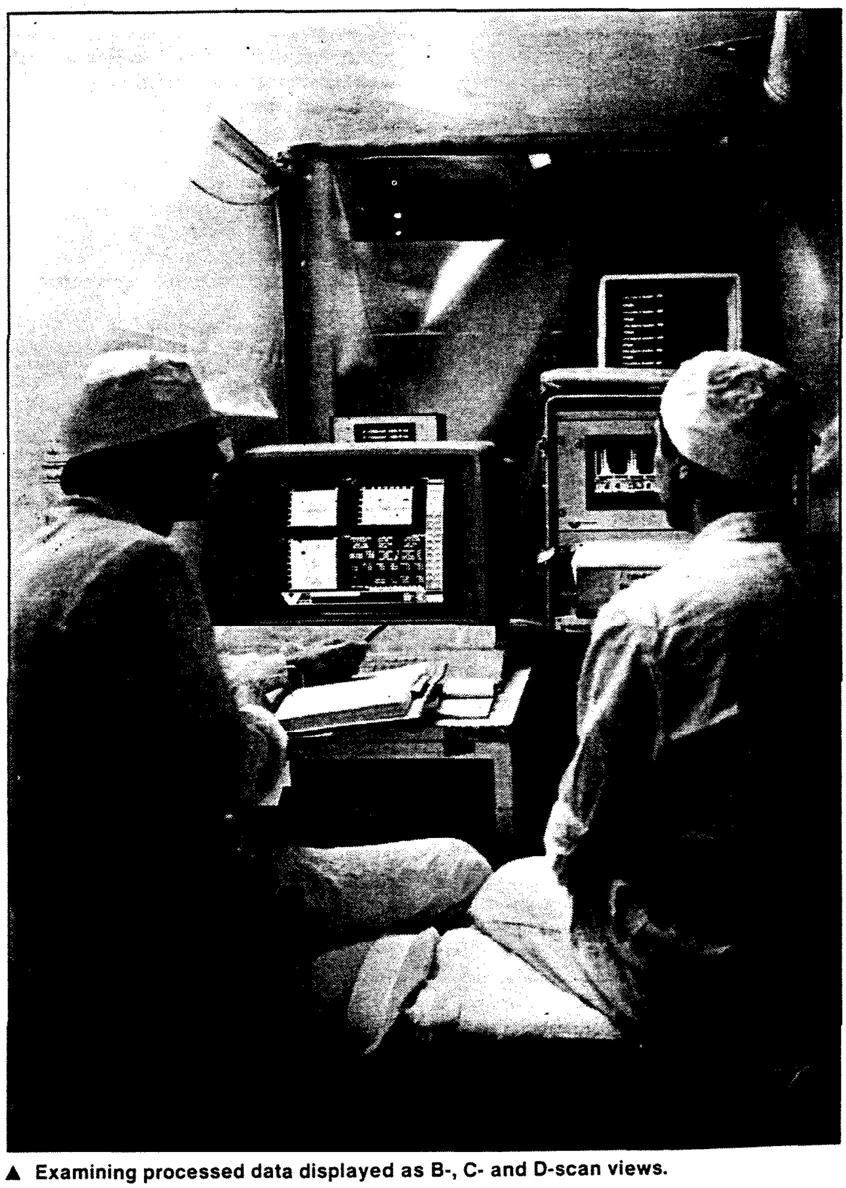
Section XI of the ASME code requires that a volumetric examination of the welds be carried out every ten years. In the case of Tihange 1 (900MWe PWR), it was recognized that the MINAC X-ray inspection system which had been used in two other Belgian units (Doel 1 and Doel 2, 400MWe PWRS) would not be satisfactory.

Consequently, work was begun on the development of an ultrasonic technique, funded by SEMO (a joint venture between Electricité de France and the Belgian utilities, which operates Tihange 1). Functions required of the UT method were the fulfilment of the ASME code requirements and the ability to conduct the examination from the pump outer surface during a refuelling shutdown.

Acoustic propagation experiments demonstrated that only low frequency (0.5MHz), longitudinally polarized waves can overcome the very high scattering caused by the coarse grain texture of the cast material. Contact TRL search units were developed to inspect the depth range from 10 to 60mm, while large diameter (140mm) focused beam probes, fitted with local immersion devices, were implemented to examine down to a depth of 200mm. Measurements of beam cross-sections in steel showed a focal diameter of about 15mm.

The total wall thickness is insonified in pulse-echo mode, under five orientations: one straight beam, and four 30° angled beams (parallel and perpendicular to the weld axis, each in both directions). In addition, the large focusing probes can be arranged in a pitch—catch configuration to provide further characterization data on indications found near the inner surface. This means that embedded defects can be differentiated from flaws connected with the surface.

The development work used several blocks. Most interesting was a flat SA-351 CF8A steel specimen, representative of a typical ASME pump casting. The acoustic representativeness of the sample was duly validated through amplitude, time and spectrum measurements of backwall



▲ **Examining processed data displayed as B-, C- and D-scan views.**

echoes and backscattered noise.

With the equipment described below, a signal/noise ratio of about 15dB was obtained from 9.5 and 4mm diameter holes side-drilled in this block, whereas a 4mm deep notch machined at the opposite surface produced a value better than 10dB.

EXPERIENCE AT TIHANGE

The huge weight (14kg) of the focusing transducers clearly requires mechanized inspection. Two dedicated manipulators (one for each weld) were used, capable of scanning a probe parallel and perpendicular to the weld axis; they could also accommodate the pitch—catch operation. Care paid to the design resulted in a minimal need for clearance (150mm) from the pump surface to perform the examination.

The control unit was a single-channel fully programmable data acquisition and processing system, which could be installed at any distance from the manipulators, thanks to pulser-preamplifiers directly attached to the transducers. On-line processing features included signal digitization, noise spike elimination, spatial averaging and some original peak-detection software which can extract a virtually unlimited number of peak amplitudes and associated times-of-flight. The processed data are displayed as B-, C- and D-scan views on a colour graphic screen. Data review and analysis are carried out off-line on a graphic workstation.

The equipment was tested and qualified on a full-scale polyester mock-up of a pump bowl, in which windows were opened to insert the available steel samples. The installation permits dynamic calibration to be achieved in the laboratory, and field calibration may be conveniently conducted on a dedicated plastic sample.

It took about two weeks to carry out the inspection on two welds at Tihange 1, including system installation and removal, and penetrant testing on the pump casing outer surface. TRL probe examination was carried out manually at the same time. Driving the automatic equipment requires two operators with dedicated training, some additional manpower being necessary to carry out the off-line analysis of the inspection data.

The pump outlet nozzle and supporting feet prevented about 30 per cent of the weld from being scanned. It is intended that the manipulators be modified slightly before the next examination so as to reduce this figure.

The Tihange 1 examination revealed no reportable indication in the weld zone. However, some small indications were detected well below the ASME reporting level.

FURTHER USES

The equipment is well suited to the most common two-weld pump bowl geometry in 900MWe three-loop PWRs of Westinghouse or Framatome design, and adapting it to single-weld casings requires only slight modifications to the manipulator.

The pump need not be disassembled to carry out the examination; only the thermal insulation has to be removed. This drastically reduces the time needed to achieve the inspection, the costs incurred and the radiation doses to personnel.

In addition, it is clear that the ultrasonic beam focusing technique developed for pump casing welds could be adapted to other thick-section austenitic components and welds — such as those in the primary piping system of PWRs —provided that sufficient access is available. This would obviously improve examination capability over current TRL technology.