1. History — Early Days

A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die out, and a new generation grows up that is familiar with it.
—Max Planck (1858–1947)

Use of mechanised ultrasonic inspection systems has now become a common occurrence in nondestructive testing (NDT). Any review of an NDT journal or NDT related Web page will quickly reveal a wide variety of scanners and data acquisition software systems available. Goldman[1] and McMaster[2] describe mechanised systems using motorised carriages that were used in the 1940s and 1950s for aircraft structures, plate scanning, and for rail testing on train-mounted systems. Data display and recording in early UT was first just the RF traces on a scope. A bit later, there were B-scan and C-scan scope displays using phosphorescent screen persistence and later still pen recorders using ink or hot wire elements on heat- or light-sensitive paper.

Today, we seem to take for granted the speed and accuracy associated with mechanised UT inspections. One of the main beneficiaries of mechanisation enhancements in ultrasonic testing is the pipeline industry. It has taken the best part of half a century but the traditional radiographic inspection of pipeline girth welds is now being replaced, in many locations, by mechanised UT.

In this chapter, we will identify the highlights of the progression of events that led from an idea to a major industry.

1.1 Early Ideas

In any discussion of pipeline girth weld inspection by mechanised ultrasonics, one must look to RTD b.v. in the Netherlands as a pioneer in the industry. Since 1959, they have been working on options for the pipeline industry. An example of one of the early efforts made by RTD is shown in Figure 1-1. This early version of the Rotoscan shows a split ring support on which the probe holder moves. A single probe was used with a single channel ultrasonic instrument. Three separate UT instruments were used for each of the three probes: two probes set opposite each other to detect longitudinal flaws and a third probe to detect transverse defects. The instruments were not multiplexed and so would have been subjected to the possibility of cross talk.

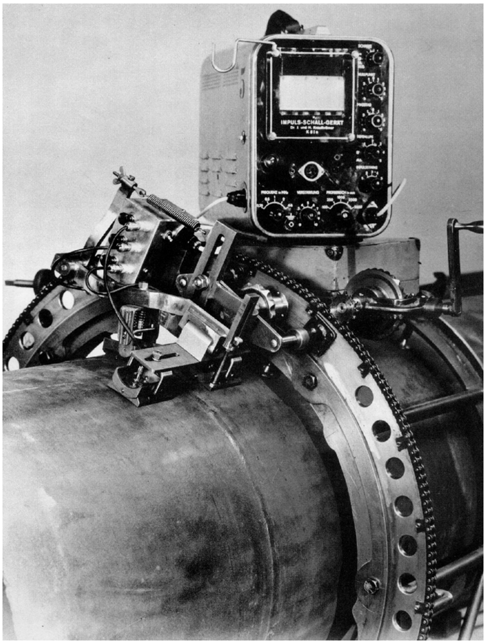


Photo courtesy of RTD b.v.

Figure 1-1 RTD three-probe Rotoscan (single-channel unit shown, around 1959)

Simple applications of ultrasonic testing in pipe mills on longitudinal or helical seams were about the extent of pipeline UT during the 1960s. During the 1970s there again seemed to be an increased interest in a faster, radiation-free option to inspect girth welds.

One of the early efforts in the 1970s came out of Japan. M. Nakayama et al.[3] at Nippon Steel Product Research and Development Laboratories, Sagamihara City described a prototype with two probes calibrated on through holes 3.2 mm in diameter (similar to the calibration technique for the submerged arc longitudinal seam welds). Scanning could be done from 100 mm/min to 1000 mm/min and coupling checks could be made using the opposing probe configuration, which used a pair of probes of 5 MHz, 10 × 10 mm, 70°. Recorded outputs were made on a polar graph plot that indicated amplitude with angular position around the circumference (see Figure 1-2).

Nakayama et al. noted that detection of flaws was closely related to test sensitivity, but if sensitivity was too great, the echoes from the weld bead geometry lowered the signal-to-noise ratio.

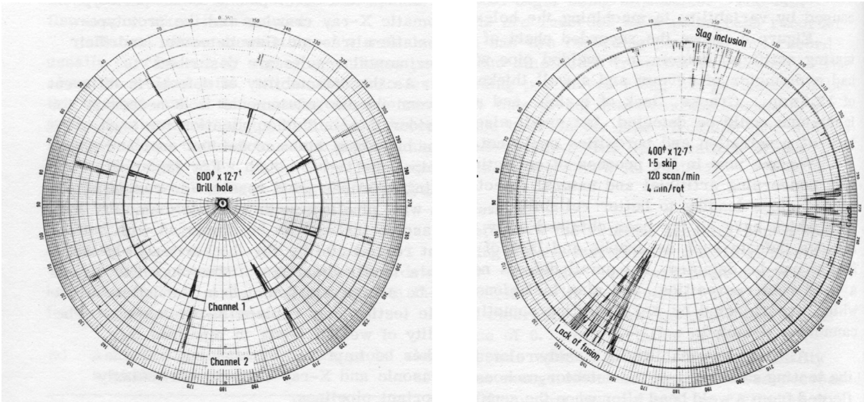


Figure 1-2 Polar plot from the Nippon Steel prototype system

On the left is a polar graph made with the eight through holes 3.2 mm in diameter used for calibration.

On the right is a weld scan showing: slag (1 o'clock), crack (3 o'clock), and lack of fusion (7 o'clock).

1.2 The Introduction of Mechanised Welding

One of the reasons for the slow advances in the application of ultrasonics to girth weld inspection was the variability in the weld cap and root bead geometry. As noted by the Japanese authors in the 1974 paper, the geometry signals were a cause of poor signal-to-noise ratio.

Around this time, work was being done to mechanise the welding process. Some early efforts had been made during the 1940s using an oxyacetylene heated upset-butt welding process. In 1958, Esso Research and Engineering Company funded a project at Battelle in Columbus, Ohio, USA. This used a then new process called gas metal arc welding (GMAW) with a CO_2 cover gas. Problems with the process were mostly due to fit-up as it had used the standard 60° included bevel angle.

In the mid 1960s Crutcher-Rolf-Cummings merged with M. J. Crose Manufacturing and operated as CRC-Crose International until sometime in the 1970s when they became Crutcher Resources Corp. In the mid 1960s Jerry Nelson (who had been the engineer working on the Battelle project) approached CRC with an idea for a new and improved system. He purposed to make a system that would be composed of a bevel facing machine, an internal line-up clamp/welding machine to deposit the root pass and external welders to run on bands clamped to the pipe outside surface. This was the foundation of the CRC Automatic Welding System and it remains essentially unchanged today.

The CRC welding system had some growing pains. Welding parameters were then poorly understood, the operators were not welders and needed to have extensive training and like most new technology, it was not readily accepted in the industry. Finally, some trial runs were made, welding parameters were improved, and the operators became proficient. In about 1983 CRC Pipeline International broke away from Crutcher Resources Corp. and became a privately held operation. In 1985, CRC Pipeline International merged with Evans Pipeline Equipment to form CRC-Evans Pipeline International.

Mechanised GMAW is now the preferred method of producing large diameter pipeline girth welds. CRC Automatic Welding System was one of the first systems developed but now others are also proving effective. Vermaat from the Netherlands, SERIMAR from France, and RMS from Canada, are but a few of the systems used today. Some use internal clamp and welding machines while others use just the internal clamp with a copper backing ring. When well tuned, all produce a narrow uniform cap and a smooth, nearly flat root profile.

1.3 UT Adaptations to the Mechanised Welding

In 1971, just as the CRC Automatic Welding System was beginning to show promise, Vetco Offshore Inspection saw the CRC system in Houston, Texas and sent a welding “bug” and band along with some sample welds to their Canadian office. There, a young engineer named Tony Richardson designed the first UT inspection system for the CRC welding process (see Figure 1-3 and Figure 1-4). This consisted of a Branson SonoRay UT instrument, a multiplexer, a Clevite-Brush four-channel light beam chart recorder, and four immersion probes. The immersion probes had one pair directed at the root (one each side) and the other pair was directed at the fill. This system also included an odometer (encoder). The problems associated with the annoying signals from the weld cap and root were addressed by setting gate lengths on a special calibration block that limited the data collected to the weld volume.

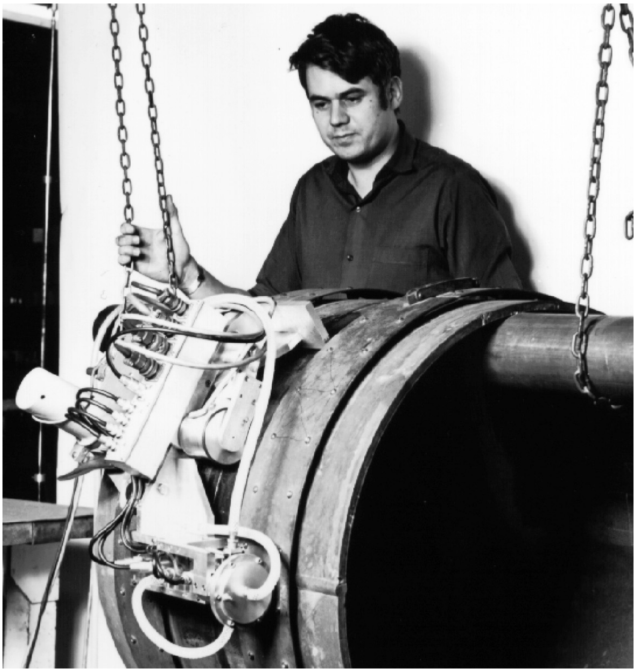


Figure 1-3 Tony Richardson with the first multiprobe scanner mounted on a CRC welding band

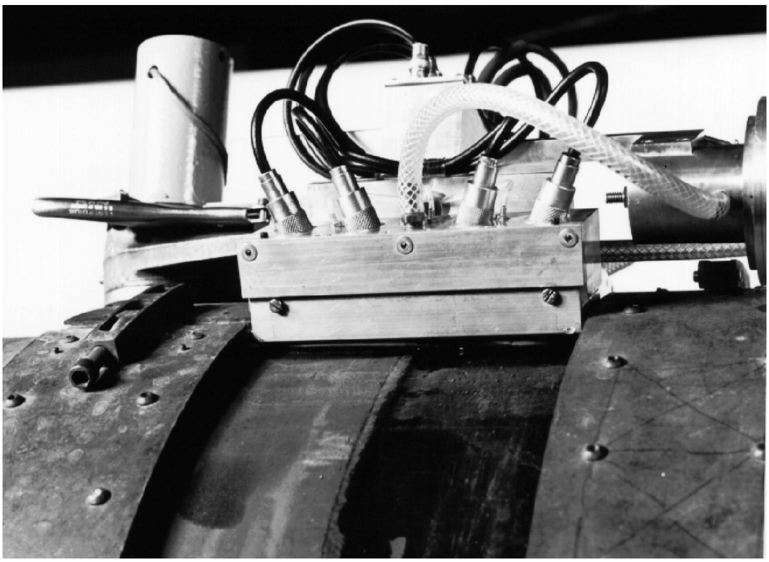


Figure 1-4 Tony Richardson's scanning head using four immersion probes (1972)

This system was ahead of its time. Attempts to get TransCanada Pipelines Ltd. (TCPL) interested failed as they saw no application for it in 1972. It was sent to the Vetco European office and had an evaluation by British Gas but nothing further developed with Vetco with that specific design.

However, in the same year, NOVA (then Alberta Gas Trunk Ltd.) began development of the GMAW process using the CRC Automatic Welding System and by 1977 decided that UT was the best option for the 37.5° root bevel and 45° hot pass bevel angles. Not being aware of the Canadian development already established five years previously using the CRC equipment, NOVA opted to have RTD develop a system based on the CRC Automatic Welding System. RTD adapted their existing yoke version Rotoscan used on offshore applications and put it on a CRC welding band. This land-based version was dubbed the *Bandscan* to differentiate it from the offshore version that was called *Rotoscan*. Soon the name *Bandscan* was dropped and reverted to "Rotoscan."

In the late 1970s there were several other companies developing mechanised systems but when demonstrating their abilities on the girth welds, all wanted to show how much information could be collected and how it duplicated manual style scanning. To do this, they used a raster scan. Scanning with a raster movement can provide useful information and the relationship of signal-to-position (echo dynamics) using raster motion could be helpful in sorting out defects from geometries; but the scan process is extremely slow. When demonstrated on typical welds 42 in. (1067 mm) in diameter the scanning time was on the order of 10–15 minutes and interpretations would require even more time. The linear scan showed the best hope for production rates typically achieved by welding (80–100 welds per day at that time).

The Rotoscan used standard contact probes (just as the Nippon Steel system had) but used several probes on each side trying to optimise for the weld bevel (just as the Vetco scanner had). With the combined interest of a potential pipeline user (NOVA) and the manufacturer/service company (RTD), the development moved faster. However, standard contact probes and simple amplitude gating still resulted in many false calls. It became apparent that probe design had to be reconsidered.

1.4 Probe Design Changes

The obvious solution to annoying signals caused by off-axis components of the beam was to limit the divergence of the beam. This led to the development of focused transducers designed for the application. The well-known pseudo-focus effect using a transmit-receive pair of elements did not provide an adequately small focal area and suffered from skew effects on longer path lengths. Focused transducers, even contact focused transducers, are not new. Back to the earliest editions in *Ultrasonic Testing of Materials* by the Krautkramer brothers, they described the principles involved in this application. The options in the 1970s were based on one of three principles:

- a flat element with a curved lens,
- a curved element with a matching lens insert,
- a mosaic element array on a curved wedge surface.

Although the principles were well documented, the previous uses for this technology had not demanded the sort of precision required by this application.

Improved techniques for the relatively thin pipeline girth weld applications were possible only with focused probes. The first of these applied to the girth weld inspections used internal lenses and was developed by BAM in Germany. Later, others experimented with shaped elements. By the mid 1980s spot sizes were consistently held to around 2 mm in diameter at the area of interest and false calls that were caused by beam edges interacting with weld surface geometries were virtually eliminated.

This improved signal-to-noise ratio allowed a new philosophy to be considered: engineering critical assessment (ECA). The ECA concept uses the principles of fracture mechanics to assess the severity of a defect based on its vertical extent. The small spot sizes now achieved allowed the weld to be divided into several zones. This linking of ultrasonic results to fracture mechanics was probably the single most important aspect in the development of mechanised UT on girth welds.

Although the concept of dividing the weld into zones was popularised in the pipeline industry by Glover et al.[4] in the late 1980s, the concept was used in a much earlier report (work done in 1981/82) by Moles and Allen[5]. Not only did they utilise the concept of zones to size flaws but they used a computer display to indicate the zones. They also used the tandem pitch-catch arrangement of elements, which was later re-developed by Canmet in the study reported by Glover as the recommended option for the inspection of the 5° vertical bevel of GMAW. The application of the tandem probe arrangement has long been popular in Europe for heavy-wall vessel inspections. Krautkramer references A. de Sterke[6] regarding this technique, who described the practice that had been used in Europe for some time by then.

1.5 Mechanised UT Enters the Computer Age

By persistence and support from a few believers like NOVA, TransCanada Pipelines and GasUnie, RTD managed to push on with the development of the concept of mechanised UT on pipelines. In about 1991, Guardian-Hyalog (now Shaw Pipeline Services Ltd., or SPSL), after encouragement and specific direction from NOVA, undertook to construct their own girth weld inspection system. But RTD had set the standards for what was expected, even down to the presentation format using multichannel strip charts and symmetry of output display to simulate the weld opened along the centreline. SPSL's first unit consisted of a bank of portable UT instruments, one for each probe. This bank of units was multiplexed and the outputs from the various UT instruments were fed to an analogue-to-digital conversion (ADC) card where the signals were processed and stored to a 286-PC style computer. The chart that was printed from the computer was made to look almost exactly like the strip chart output that RTD had been using since the mid 1980s. The SPSL system utilised the system encoder to space information equally on the strip chart hard copy, thereby making the information more precisely located. Prior to this the position was marked on the charts by a timing marker that estimated speed. Scanner speed variations were shown on the chart recording as different length intervals between the nominal 10-mm markers.

Now the speed of development was accelerated even more. RTD developed a MS-DOS®-based computerised system and developed a mapping display in 1993 to improve the discrimination between flaws and surface geometry, and it had the serendipitous advantage of characterising porosity. *Mapping* was just the modern equivalent of the B-scan. RTD collected stacked A-scans and assigned colours to the various signal amplitudes thereby making porosity appear like porosity on the computer monitor.

Examples of the earliest versions of the strip charts used in Canada are illustrated in Figure 1-5 and Figure 1-6.

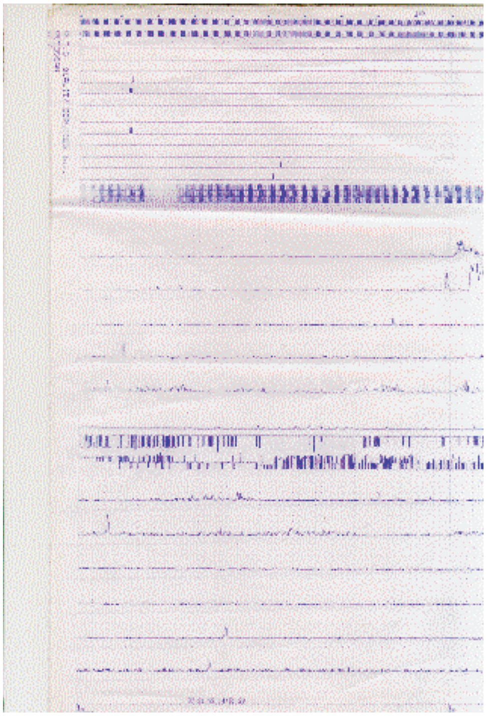


Figure 1-5 Original RTD strip chart format printed on a RMS recorder and light-sensitive paper

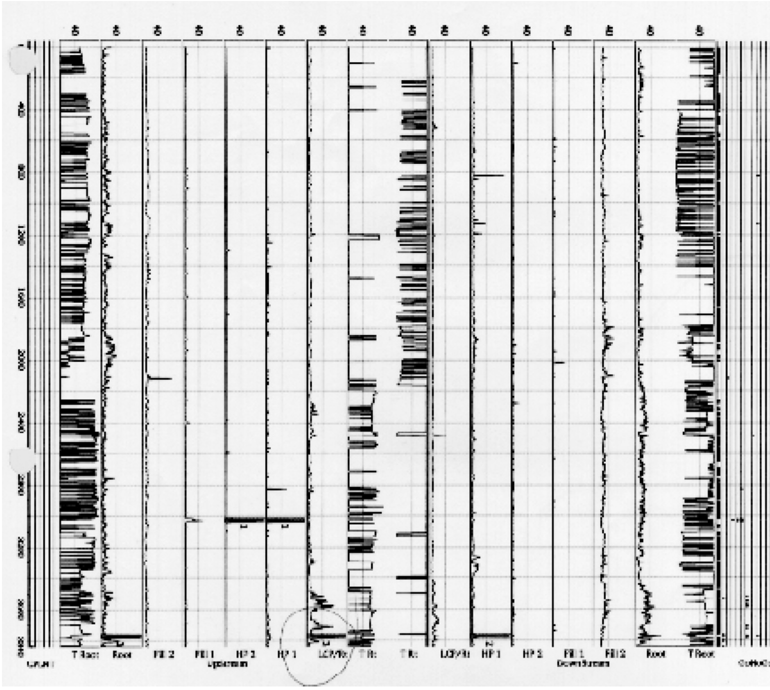
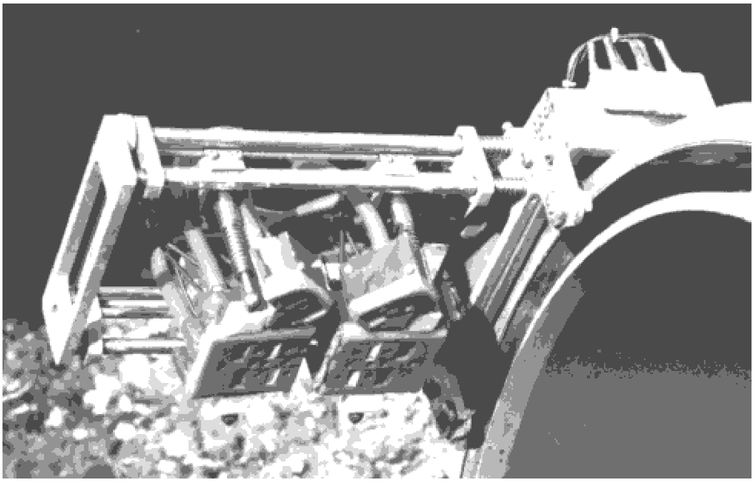


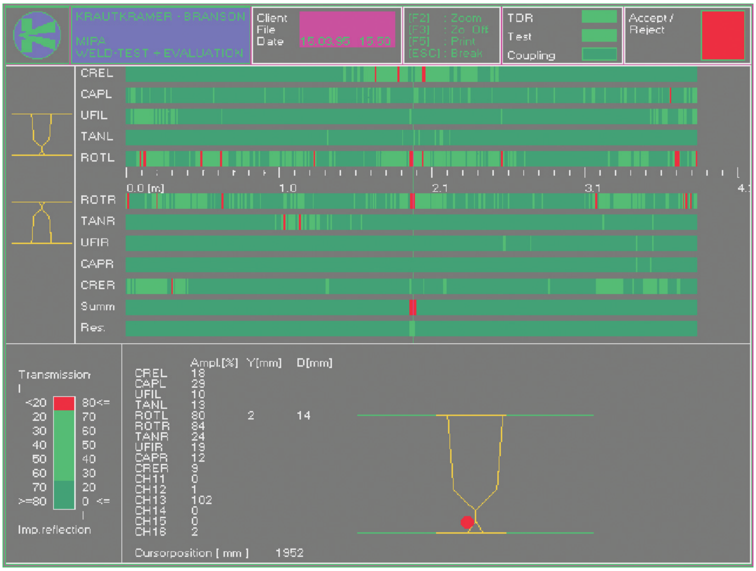
Figure 1-6 SPSL computerised strip chart format printed on a laser printer

In the early 1990s parallel development was being done by two other companies. SGS Gottfeld in Germany had designed its MIPA system and R/D Tech in Canada had developed its initial system subsequently used by AIB Vinçotte in Belgium. The SGS Gottfeld system seemed to be a flashback to the Vetco system of the 1970s but now modernised with computer technology. It too used immersion probes and a skirt to hold the water. The monitor display consisted of a series of bands for each channel with amplitude represented as a colour (a single line C-scan). Figure 1-7 and Figure 1-8 are courtesy of Rolf Diederichs and www.NDT.net, which can be found at http://www.ndt.net/article/schulz/.



Courtesy of Rolf Diederichs and www.NDT.net

Figure 1-7 SGS scanner



Courtesy of Rolf Diederichs and www.NDT.net

Figure 1-8 SGS chart display

The R/D Tech® system used a probe array with contact probes similar to that used in Canadian projects but their system also had a single line colour per channel C-scan display as the hard copy Figure 1-10.

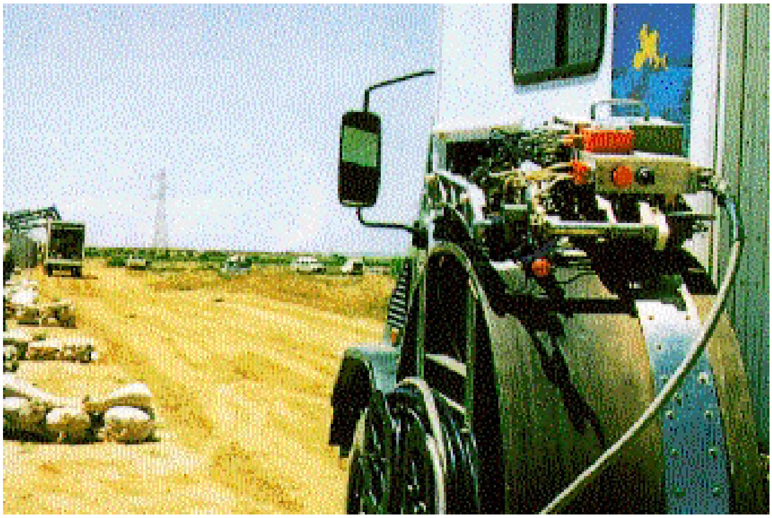


Figure 1-9 AIB scanner

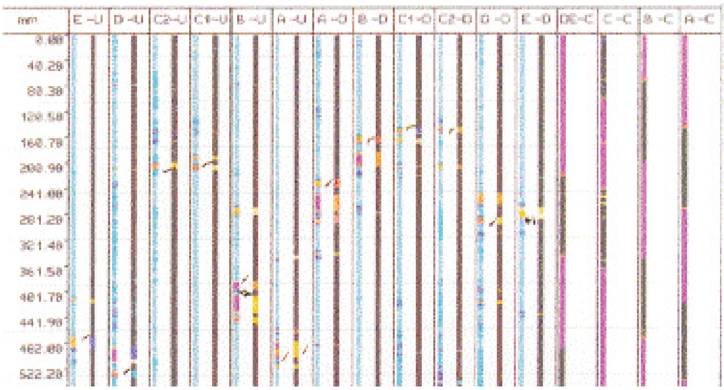


Figure 1-10 R/D Tech chart display used by AIB around 1992

Both the R/D Tech and SGS systems were used on a project in North Africa but failed to get accepted in Canada. By then the ease with which the RTD strip chart format using time and amplitude information combined on the same chart could be read by the operators made it the preferred presentation method.

An interesting side note: in 1992 a Canadian company, Canspec, used a prototype version of the AIB system and experimented with the B-scan display available in the R/D Tech software package. They found that root geometry and porosity were more easily identified using the B-scan information. This was over a year before RTD officially came out with their Roto-map which was designed for the same purpose (another example of parallel thinking).

In 1996 WeldSonix introduced their system. This system came up with a smaller scanning head (Figure 1-11) and full waveform data collection for all channels but also used the industry-accepted strip chart format.

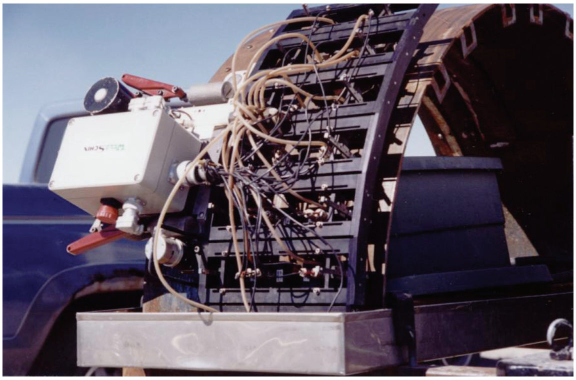


Figure 1-11 WeldSonix scan head

In 1997 R/D Tech decided to conform to the data presentation initiated by RTD nearly 20 years earlier and developed a newer version of both hardware and software based on their Tomoscan™ technology. In 1998/99 R/D Tech used this display (see Figure 1-12) for the data collected by the new phased array system they had developed.

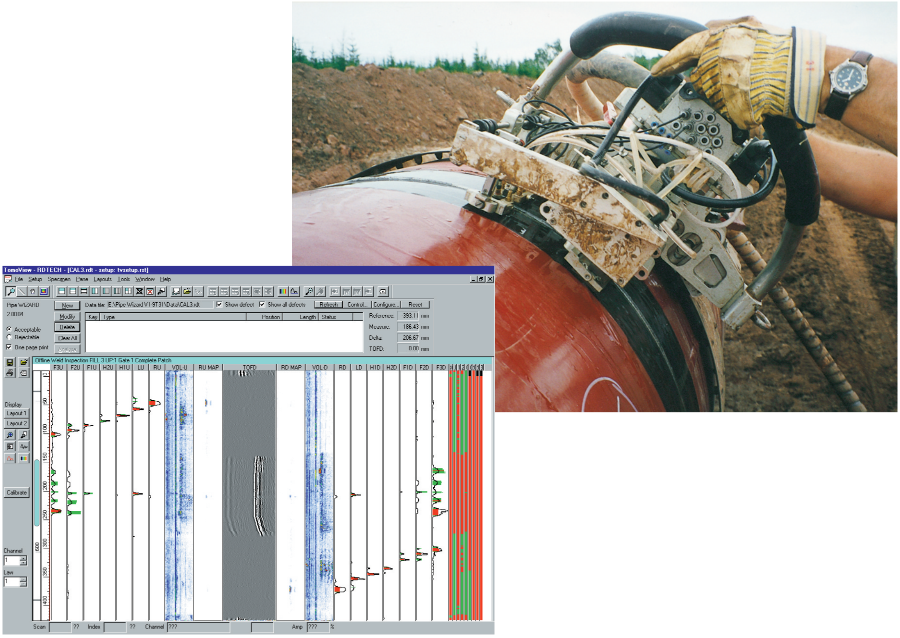


Figure 1-12 R/D Tech display 1997

1.6 Standardising Concepts

Until 1998 all mechanised UT on pipeline girth welds was done using company specifications specially worded to allow mechanised UT. This was required because existing codes and standards were worded as though ultrasonic inspections would be by manual techniques only. In 1998 ASTM E-1961 was published describing the various aspects involved in pipeline inspection using mechanised UT and zonal discrimination. In the 19th edition of API 1104 they revised its description of UT requirements to include mechanised systems. It does not specify the zonal techniques but if one is to use the Alternative Acceptance Criteria in the appendix of API 1104 there is no practical option other than the zonal technique.

Much of the acceptance of systems by the pipeline industry has been dictated by presentation. QA 9000 Ltd. introduced their Acuscan in the mid 1990s. Mechanically this looked very similar to the WeldSonix scanner but the report presentation had reverted to the top, side, and end views. This made it difficult to use with the ECA analysis by then common with the other systems.

References to Chapter 1

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Robert van Agthoven, RTD Rotterdam, The Netherlands, provided the image of the earliest Rotoscan and commented extensively on its early development years B.C. (before computers).

Rolf Diederichs has allowed use of his online collection of technical papers relating to the girth weld inspections (www.NDT.net).

Olympus NDT Canada provided copies of their early brochures (www.rd-tech.com).

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