#510326 (21)

ADVANCED FLAW SIZING IN PRACTICE

by

C.V. Sevenhoven, Royal Netherlands Navy, The Hague, The Netherlands
W.H. van Leeuwen, Röntgen Technische Dienst B.V., Rotterdam, The Netherlands

ABSTRACT

One of the activities of the Dutch Welding Institute (NIL) is to initiate and coordinate research projects, among which projects in the field of non-destructive testing (NDT). The most recent of these was the project "Advanced Flaw Sizing under Practical Conditions," which will be reported. The aim of this project was to evaluate the practical applicability of various non-destructive flaw sizing techniques on a series of weld samples with many different geometries, wall thicknesses and defect types. Apart from the accuracy of the sizing results, attention was paid to the ease and level of confidence of the signal interpretation, the necessity to use advanced systems under various conditions and the requirements with respect to the inspection personnel. An additional point of interest was to assess in which cases the TOFD (time-of-flight diffraction) technique would be useful for flaw detection as well as for sizing.

The flaw sizing techniques considered in this project were:

- the ultrasonic flaw tip reflection (FTR) technique,
- the ultrasonic time-of-flight diffraction (TOFD) technique,
- supersaft, which is an ultrasonic focused imaging technique,
- the alternating current potential drop (ACPD) technique, and
- the direct current potential drop (DCPD) technique.

The results and conclusions will be summarized.

Summary and Conclusions

One of the activities of the Dutch Welding Institute (NIL) is to initiate and coordinate research projects, among which projects in the field of non-destructive testing (NDT). The most recent of these was the project "Advanced Flaw Sizing under Practical Conditions", on which this document is the final report. The aim of this project was to evaluate the practical applicability of various non-destructive flaw sizing techniques on a series of weld samples with many different geometries, wall thicknesses and defect types. Apart from the accuracy of the sizing results, attention was paid to the ease and level of confidence of the signal interpretation, the necessity to use advanced systems under various conditions and the requirements with respect to the inspection personnel. An additional point of interest was to assess in which cases the TOFD (time-of-flight diffraction) technique would be useful for flaw <u>detection</u> as well as for sizing.

The flaw sizing techniques considered in this project were

- the ultrasonic flaw tip reflection (FTR) technique
- the ultrasonic time-of-flight diffraction (TOFD) technique [see fig 2 and fig 4]
- supersaft, which is an ultrasonic focussed imaging technique
- the alternating current potential drop (ACPD) technique
- the direct current potential drop (DCPD) technique.

Both ultrasonic tip diffraction based techniques (FTR and TOFD) were applied in several different ways. First, they were applied manually, i.e. with manual probe handling and conventional screen reading and data recording by the operator. Second, manual probe handling was combined with a simple go/no-go version of automatic data recording and B-scan display, using the Multiple Display Unit (MDU). Third, three different computerized systems involving mechanized scanning, advanced data handling and display were used. These three systems were:

- a system developed by RTD Rotterdam, based on existing laboratory instruments. This TOFD system was designed to be user friendly, applicable on a wide variety of inspection geometries and reasonably suitable for field applications.
- the Nerason system of Nucon IPS, Amsterdam. This is an existing advanced multi-purpose ultrasonic system, for which recently TOFD software has been developed. The Nerason system has proven its suitability to work under field conditions for many years. In this project it has been used in combination with an immersion scanning system.
- the Zipscan system of the british research institute AEA Harwell. Zipscan was the only system with which at the beginning of the project field experience in TOFD application existed. Since the system is not

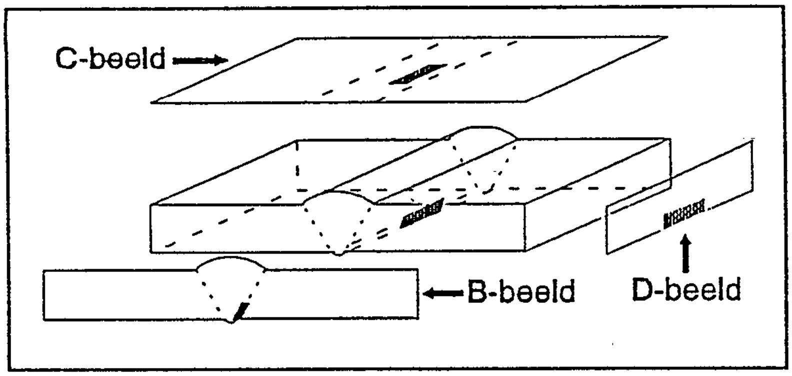


fig. 1: projectie van lasindicatie in B-, C- en D-beeld

[P. SCAN]

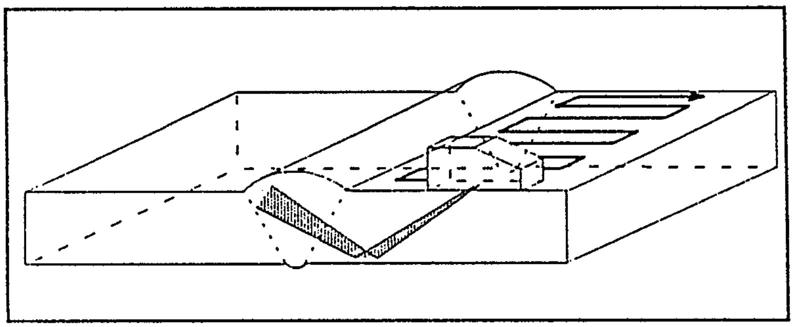


fig. 3: pulsecho meanderscanning

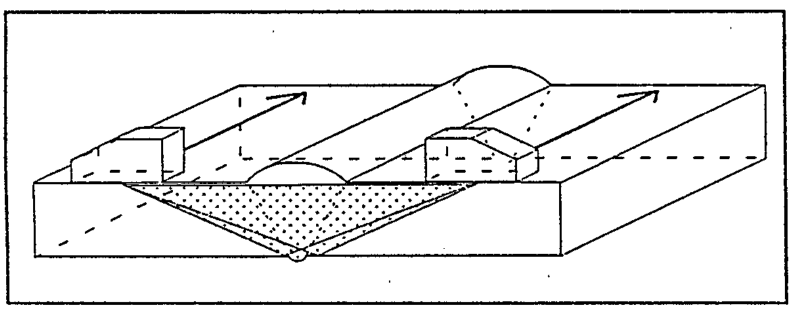


fig. 4: TOFD scanning

suitable to operate high frequency probes necessary for TOFD on small wall thickness samples, in addition a newer system called Flaw Monitoring System was applied.

The supersaft technique is developed by the Danish Welding Institute (now part of Force Institutes). It is a computer data processing routine to be applied on data collected with the P-scan system.

Test samples used in the project comprised (see figure 4.1):

- flat butt welded plates with wall thicknesses between 10 and 30 mm. The plates contained single side welded U- and V-welds with intentionally made weld defects of different kinds.
- T-shaped samples with K-welds containing fatigue cracks; wall thickness 38 mm.
- three tubular joint samples, two containing fatigue cracks and one containing a notch simulating a weld root defect. Tube diameters between 200 and 460 mm; wall thickness 8 to 16 mm.
- a split-tee type pipe repair sample containing notches in the weld toe. Wall thickness 9 mm (main pipe) and 27 mm (repair shell).

The ultrasonic measurements within the project were carried out by Röntgen Technische Dienst bv, Rotterdam and Nucon IPS, Amsterdam with contributions from AEA Harwell (England), the Danish Welding Institute and Shell/Billiton Research, Arnhem. The potential drop techniques were carried out by the Foundation for Advanced Metals Science (SGM), Hengelo.

The results and conclusions of the project can be summarized as follows:

1 - The apparently simple manually applied FTR technique frequently gives signals from other modes than tip diffraction. Signal interpretation requires theoretical knowledge and an analytical attitude. FTR application needs a case-by-case approach by a specialist. If the signals can be well interpreted as tip signals, the accuracy of the results is good: both in flaw hights and in depth positions of separate flaw tips a root-mean-square deviation from the actual values of 1 to 1.5 mm has been found.

2 - The TOFD technique is manually applicable when simple geometries are involved. Good level II ultrasonic operators can apply the technique after a few days training course.

3 - Use of the Multiple Display Unit with manual FTR and TOFD is possible, but in general hardly contributes to better signal interpretation or higher accuracy. Since the MDU is a heavy instrument without internal storage facilities, its use will not often be worthwhile in practice.

4 - Both manually applied TOFD and TOFD with advanced systems give accurate flaw sizing results. As with

the FTR technique, root mean square deviations are 1 to 1.5 mm, both for flaw hight data and flaw tip depth locations.

5 - Several good advanced TOFD systems exist. The accuracy of their results is similar, but they differ in practical applicability. The suitability of a system might be influenced by:
   * size and geometry of the inspected object (available manipulator types, contact or immersion technique, available software for special geometries)
   * smallest wall thickness that can be measured (sampling frequency)
   * scanning speed (in practice mainly important for flaw detection, much less so for sizing of already detected flaws).
   * vulnerability to weather conditions, shocks, etcetera; (lack of) portability.

6 - The RTD laboratory TOFD system is suitable for many different inspection geometries. It is easy to operate and portable, but rather vulnerable for shocks, dust and moisture. The measuring speed can be high.

7 - Nucon's Nerason system is transportable and can stand field conditions. At present only flat geometries can be inspected. The measuring speed is low. The immersion technique as applied with this system in general has the following disadvantages:
   * the immersion tank limits the size of the inspectable objects
   * variations in water path may complicate the data evaluation
   * if the immersion probes have fixed orientations, small irregularities in the object's shape have a strong influence on the beam angles and thus on signal strengths.

8 - The Harwell Zipscan and the Flaw Monitoring System are transportable and will stand field conditions. These systems are suitable for many different geometries and have a high measuring speed. The present Zipscan version is not suitable for wall thicknesses less than approx. 15 mm because the sampling frequency of 21 MHz is insufficient.

9 - Flaw <u>detection</u> with TOFD is only possible when advanced systems with TOFD B-scan presentation are used. On the flat plate samples used in this project, the detection rates were high, in particular with the systems using contact probes: 83% (RTD system), 90% (Zipscan/Flaw Monitoring System) and 66% (Nerason system). Apart from defects in the well known dead zone of the TOFD technique (the upper 3 to 4 mm), several shallow root defects were missed. Detection scores on root defects were 78% (RTD system), approx. 75% (Zipscan/FMS) and 44% (Nerason system). The necessity to perform only a longitudinal scan along the weld makes TOFD a potentially

fast technique.

10- An advantage of TOFD, which is particularly important in the case of flaw detection, is the fact that probe positioning and defect orientation are not critical.

11- Flaw sizing accuracy with manual TOFD of defects just under the dead zone was less accurate than elsewhere. This was not found for TOFD with advanced systems. The sizing accuracy near the back wall was the same as near the middle of the wall thickness.

12- On complex geometries like tubular joints, TOFD can be applied if suitable scanners and special data interpretation software are available; depending on the pipe diameters and the local geometry, a (slow) manual probe manipulation may be required. Data evaluation in this case requires special skill and experience.

13- Flaw sizing on complex geometries appears to be as accurate as on flat plates.

14- The sizing accuracy of supersaft is similar to that of FTR and TOFD, or slightly less.

15- As compared to TOFD, supersaft is much more time consuming and requires a higher skill and experience.

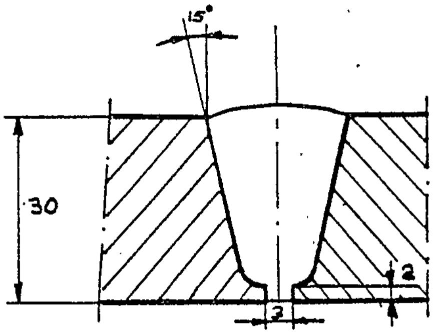
16- Supersaft gives more information on the defect type than TOFD.

17- Supersaft is not (yet) suitable for complex geometries in general. It may sometimes be applicable depending on the local geometry.

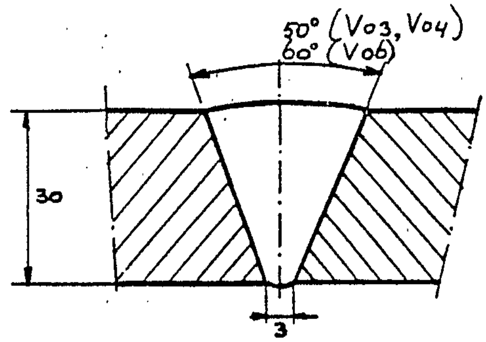
18- The DCPD technique as applied in this project is not suitable for defect sizing. Even its defect detection capability on the used test samples is still very limited.

19- The ACPD technique as applied in this project on welded plates with unworked surface condition, is not suitable for flaw hight measurement.

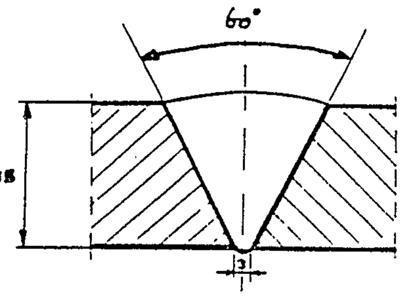
Enclosure 2 gives an overview of which techniques and systems have been used on which test samples, and on which of these measurements the various above conclusions are based. An impression of the applicability of the various techniques and systems is given in enclosure 3.



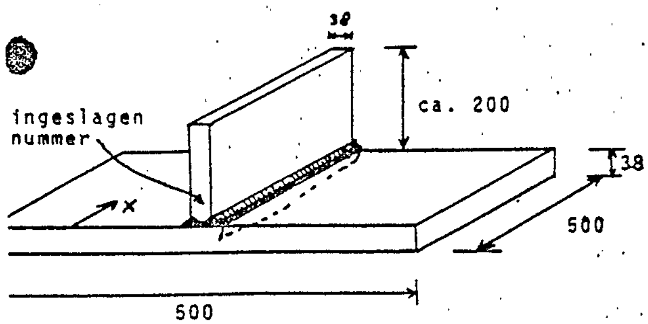
30 mm U-naad



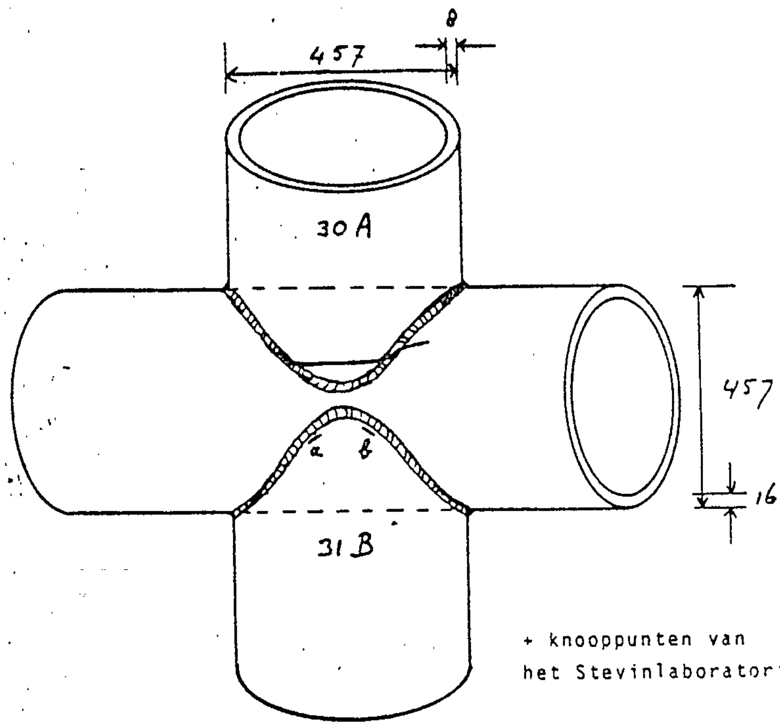
30 mm V-naad



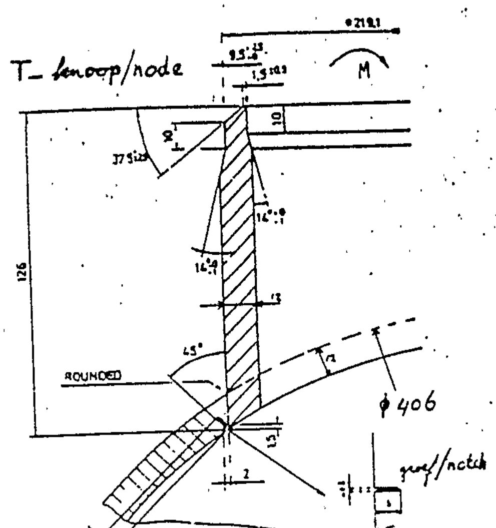
15 mm V-naad

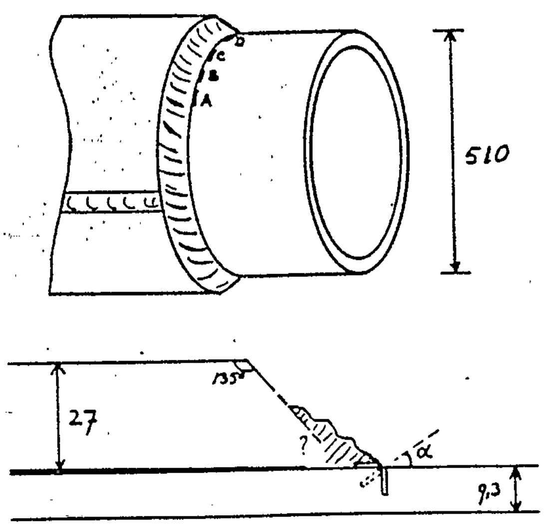


T-platen van de
Koninklijke Marine



+ knooppunten van
het Stevinlaboratorium





Pijpreparatie type
split-tee; Gasunie.

groef	lengte	diepte	α
A	15	2	0°
B	5	2	0°
C	5	1,5	0°
D	5	1,5	60°
E	5	3	60°
F	15	2	60°
G	15	2	90°
H	5	2	90°
I	5	2,5	90°

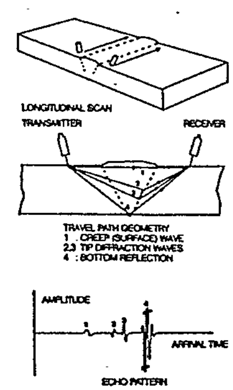
fig. 4.1.

TIME OF FLIGHT DIFFRACTION (TOFD)

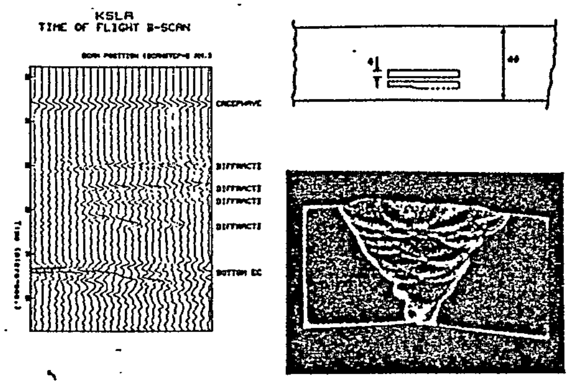
TOFD - HIGHLIGHTS

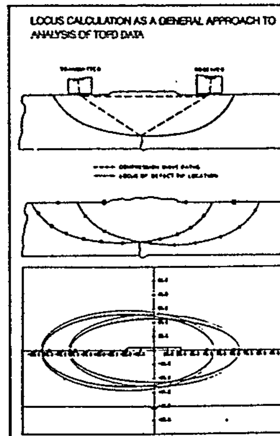
- TOFD is a most accurate defect sizing technique
- high accuracy results from the use of diffraction waves from defect edges and the measurement of traveltime
- applicable on a wide range of geometries:
  - flat plates from about 10 mm wallthickness upto 300 mm and more
  - T-butt welds
  - tubular joints
  - nozzles
- probe positioning during scanning is not critical

PRINCIPLE



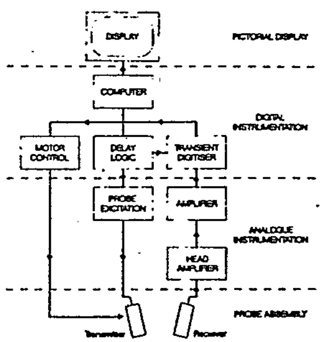
EXAMPLE OF LONGITUDINAL SCAN

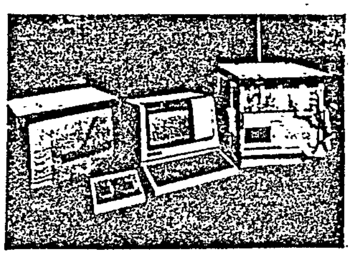


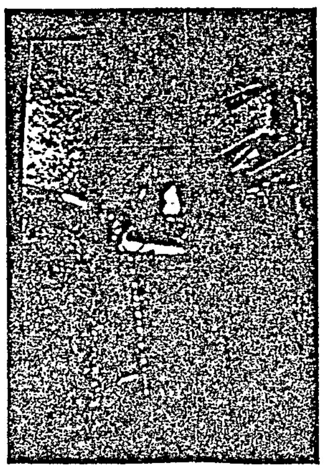


LOCATING THE EDGES OF A LACK OF FUSION DEFECT

SCHEME OF TOFD EQUIPMENT



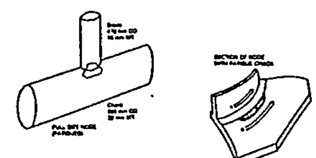




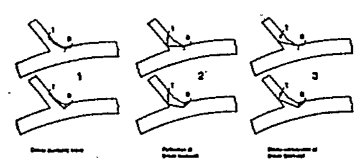
LONGITUDINAL SCANNING TOOL
(operated by diver underwater)

TOFD RESULTS ON A 90° T-NODE

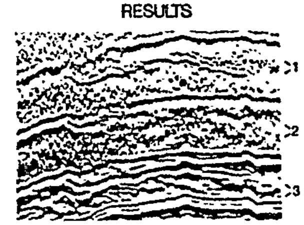
TESTSAMPLE GEOMETRY



TRAVEL PATH GEOMETRIES

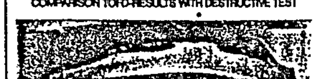


RESULTS



LONGITUDINAL SCAN RESULTS (Left part of defect only)

COMPARISON TOFD-RESULTS WITH DESTRUCTIVE TEST



TESTSAMPLE AFTER DESTRUCTIVE TEST

CONCLUSIONS

- TOFD is very suited for sizing but less suited for detection and characterization
- achievable sizing accuracy: 1 to 2 mm
- thickness of the near surface dead zone: 3 to 6 mm
- TOFD on simple (flat plate like) objects requires simple equipment with easy interpretation;
  TOFD on complex objects (e.g. nodes) or complex (multiple) defects requires dedicated equipment and skilled operators.
- Two validation test of TOFD with divers in a testtank and in 17 m. deep open water have demonstrated the applicability of the technique for use under practical circumstances.

Enclosure 1

MEETPROGRAMMA (planning)		proefstuksoort					
techniek	uitvoerder	vlak 15 & 30 mm	vlak 10 mm	T-platen	T-knoop	+ knoop	split-tee Gasunie
FTR/hand	RTD	4 x 4 (*)	1	1 (*)	1	1	1
TOFD/hand	RTD/Billiton	2 + 3 x 4	-	-	-	1 (-)	-
FTR/MDU	RTD	2	-	-	-	1 (-)	-
TOFD/MDU	RTD	2	-	-	-	1 (-)	-
Lab. app.	RTD	4	1 (2)	1	1	1 (2)	1
Nerason	Nucon	4	1 (2)	2	-	-	-
Zipscan	RTD/Harwell	3	1	-	-	1 (2)	1
Supersaft	RTD/SVC	2 (3)	-	- (2)	1	1 (-)	- (1)
ACPD/DCPD	SGM	4 (7)	- (2)	2	1 (-)	1 (2)	1

Tussen haakjes staat vermeld wat in werkelijkheid is uitgevoerd, indien dit afwijkt van de planning.
(*): Zie voor details tabel 6.1 in referentie 6.

Enclosure 2

REFERENCE TO CONCLUSION NO		proefstuksoort/sample type					
techniek technique	uitvoerder applied by	vlak/flat 15 & 30 mm	vlak/flat 10 mm	T-platen	T-node/ knoop	+ nodes /knopen	split-tee Gasunie
FTR/man.	RTD	1	1	1	1	1	1
TOFD/man.	RTD/Billiton	2,4,11	-	-	-	-	-
FTR/MDU	RTD	3	-	-	-	-	-
TOFD/MDU	RTD	3	-	-	-	-	-
Lab. app.	RTD	4,5,6,9,11	4,5,6,9,11	4,5,6	4,5,6,13	6,12,(13)	4,5,6
Nerason	Nucon	4,5,7,9,11	4,5,7,9,11	4,5,7	-	-	-
Zipscan	RTD/Harwell	4,5,8,9,11	4,5,8,9,11	-	-	8,12,(13)	4,5,8
Supersaft	RTD/SVC	14,15,16	-	14-16	14,15,16	17	14,15,16
ACPD/DCPD	SGM	18,19	18,19	18,19	-	18,19	18,19

Enclosure 3
Toepasbaarheid van technieken en systemen voor fouthoogtebepaling; deze tabel geeft een snelle, maar **ongenuanceerde** impressie. Zie de conclusies voor meer details.
Applicability of techniques and systems for flaw hight measurement. This table is for quick reference only; see "Summary and Conclusions" for more details.

	proefstuksoort/sample type					
techniek technique	vlak/flat 15 & 30 mm	vlak/flat 10 mm	T-platen	T-node/knoop	+ nodes /knopen	split-tee Gasunie
FTR/man.	o	-	o	-	-	-
TOFD/man.	+	+/o	-	-	-	-
FTR/MDU	o	-	o	-	-	-
TOFD/MDU	-	-	-	-	-	-
Lab. app.	+	+	+	+	+	+/o
Nerason	+	+	(-)	-	-	-
Zipscan	+	-	+	+	(+)	-
Harw. FMS	+	+	+	+	+	+/o
Supersaft	+	+/o	+	(+)	-	+
ACPD/DCPD	-	-	-	-	-	-

\+ goed toepasbaar / well applicable
o beperkt toepasbaar / limited applicability
\- slecht of niet toepasbaar / not suitable

Noot: niet alle mogelijke proefstuk/techniek combinaties zijn binnen het project getest; een aantal beoordelingen in de tabel zijn vanuit de ervaringen met andere combinaties geëxtrapoleerd.
Note: not all possible combinations of test samples and techniques have been tested within the project. For combinations which were not tested, the table contains extrapolations from experiences with other combinations.