APPLICATION OF THE POTENTIAL DROP METHOD FOR IN-SERVICE MONITORING OF INDICATIONS FOR CRACK INITIATION OR CRACK PROPAGATION - FUNDAMENTAL PRINCIPLES AND PRACTICAL APPLICATION

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ABSTRACT

Developed by TUEV Anlagentechnik, Cologne, for monitoring material areas such as, e.g. welds, for crack formation or crack growth, the potential drop method was put through theoretical examinations, simulations using an electrolytic tank, 5 trials in 4 nuclear power plants and one calibration test. At that time it had reached a stage of development which enabled it to be used for practical applications.
The method was then used so far in 4 power plants for a period of up to 3,5 years in on-line monitoring of indications/findings obtained earlier and has thus been instrumental in ensuring safe continued operation.
Like other established NDT methods, this one is suitable for monitoring also welds for crack formation and crack growth during recurrent inspections (off-line reading with a mobile measuring system) but compared with the conventional methods it saves operations on site and reduces the time required for measuring to a mimimum. Prior to the installation of the area of measurement an initial check for defects needs to be made.

INTRODUCTION

The potential drop method is a technique for non-destructive materials testing that has been familiar for many years and is relatively simple to apply. During the last years, it has been substantially refined by TUEV Anlagentechnik (TAT), Cologne, with regard to calibration and instrumentation [1-3]. The method has by now proved worthwhile in several practical tests for on-line monitoring of indications/findings for growth.

FUNDAMENTALS

Principle And Instrumentation

The installation usually consists of 2 metal skids which are attached to the surface of the component about 150 mm to the right and to the left of the area of measurement, and held in position by means of straps. A direct current of about 100-200 amperes passes through these skids (**Fig 1**). In the area of measurement, 3 to 4 potential contacts are spot-welded in each plane of measurement. Between these contacts, the direct voltages (in the following referred to as potentials) are measured with the current supply alive and dead. In the evaluation the potentials in the dead state are deducted to compensate for disturbing voltages.
One measuring point per plane of measurement is normally attached right above the defect to serve as real monitoring point, while the others serve as so-called reference points. It is possible, through the installation of (neighbouring) reference points which, at the same temperature, are mostly unaffected by the defect, to eliminate for instance the influence of temperature to a large extent.

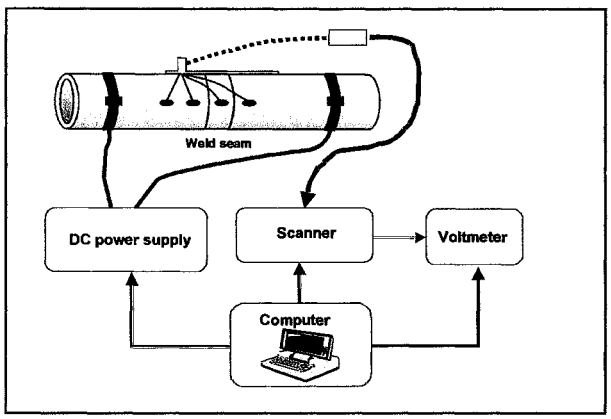


Fig.1 Measurement principle

The measuring process itself is controlled from a PC: The different measuring points are selected via a scanner and interrogated with a responsive voltmeter. The readings are stored on a disk and on a diskette and then e-mailed to TAT for evaluation.
The measuring instruments can be located up to about 30 m away from the component to be monitored. As for the PC - e.g. with high radiation levels on site - the distance can be even greater.

Resolution

During the period under monitoring a certain scatter in the data recorded was noticed. From the long-time monitorings done so far, it can be concluded that the scatter band is <1% of the measured value. A measuring point should therefore be looked into more closely if the average of the potential value has increased by 1%: Such an increase is regarded - even with a scatter band <1% - as limit of resolution inherent in the method.
The resolution for crack formation (with installation on flawless material) and crack growth (with installation in an area affected by a defect) increases progressively as the defect deepens, i.e. as it grows critical (**Fig. 2**).

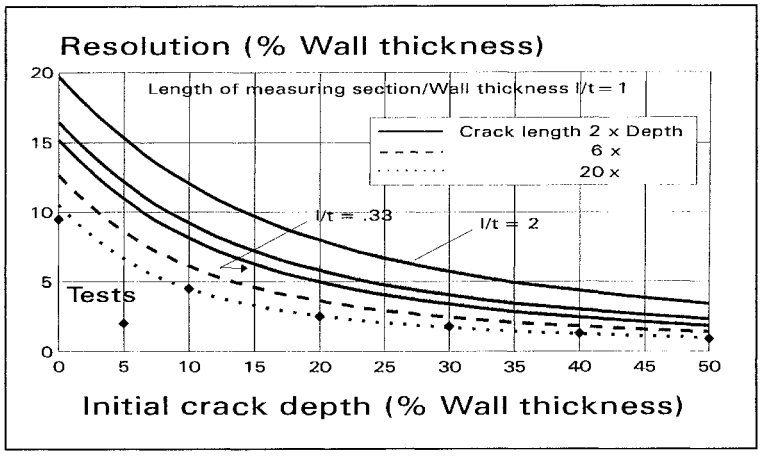


Fig. 2 The tests confirm the highest resolution calculated

Calibration

Several ways were tried to calibrate the method - i.e. to determine the relation between the indication of potential and the size of the defect. First of all, the pertinent literature was searched for analytical relations for indefinitely long defects in the side where the measuring system is installed (accessible side). After that, analogue relations were derived also for defects lying in the opposite side. The relations relevant to application for rather short surface defects in the accessible side and in the opposite side were determined in an electrolytic tank. This tank permits the calibration curve to be established for any shape of defect by immersing a sheet cut to size into the electrolyte. About 1000 curves for semi-elliptical defects in the accessible and on the opposite side were established this way, with wall thickness, depth and length of defect being varied. The calibration curves determined by means of the tank were then verified on large flat tensile test specimens affected by semi-elliptical defects.
If using measuring sections for reference purposes those carrying out the tests should find out first whether crack growth in the measuring section for monitoring purposes also adds to the potential above the measuring section for reference purposes. This effect can be estimated on the basis of the results obtained from a calibration test performed in the qualification process. A notch was cut into a root edge of a 20.5 mm thick welded austenitic plate, progressing by steps of 0.2 mm to reach a final depth of 15.4 mm. The increases in potential were measured during this operation. Some of the results are the tests in Fig. 2. By staggering the potential sections in relation to the notch it was possible to study also the crack which is not in the center of the measuring section and to examine its influence on the neighbouring reference measuring section. Coefficients of reduction were deduced from the measured values. These coefficients represent the loss in resolution compared with the crack lying in the centre of the measuring section which is related either to the starting potential or to the potential of a measuring section that is completely unaffected by the crack.

Monitoring For Changes

The potential drop method is applied to monitor the defect for changes. If during monitoring the potential increases by more than 1% (limit of resolution), the defect is supposed to have grown. In case the initial size of the defect is known, e.g. from measurements using non-destructive test methods before the potential monitoring system is installed, the increase in potential can be converted into crack depth growth. If the initial crack depth can be estimated solely in a conservative approach, also the final crack depth with crack growth monitored with the aid of the potential drop method must be determined conservative.

Trials In Nuclear Power Plants

After extensive preliminary tests, a start was made in August 1993 to test out and improve the method in the nuclear industry. In the 5 installations undertaken in 4 nuclear power plants, circumferential welds were monitored for one year, each with between 10 and 62 measuring points [4]. The installations were made in the pipework of different systems exposed to temperatures ranging from 40 to 285°C. The pipes, with diameters of 220 to 600 mm, were manufactured from ferritic or austenitic steels. The instruments were improved from one installation to the next. As a result, the scatter band of measured values was limited to 1%.

Evaluation

For evaluation, the related potential values, i.e. indication/reference measuring point are plotted against time. Changes in potential can be quantified more precisely if 2 points of state, with possibly the same temperature (2 inspections or 2 operating points), are compared in tabular form.

EXAMPLES OF APPLICATION IN ON-LINE MONITORING

Monitoring Of A Dissimilar Weld Over Several Years [5]

Since June 1997 (inspection) a 4 to 10 mm deep ultrasonic indication in a SAFE-END dissimilar weld of the YPS nozzle of the reactor coolant pipe has been monitored in service. The outer diameter of the pipe is about 322 mm and the wall thickness is about 29.5 mm in the area to be monitored. To cover the position of the indication, the potential field of measurement was arranged such to include 7 planes of measurement (Fig. 3): The measuring points bearing even numbers P2, P4, ...P14 serve as measuring points for monitoring, while the measuring points bearing odd numbers P1, P3, ...P13 represent the measuring points for reference. In the 1998 inspection additional reference measuring points numbered P16, P17, ...P22 were installed. They are further away from the indication and may thus be influenced less by crack growth, if any.

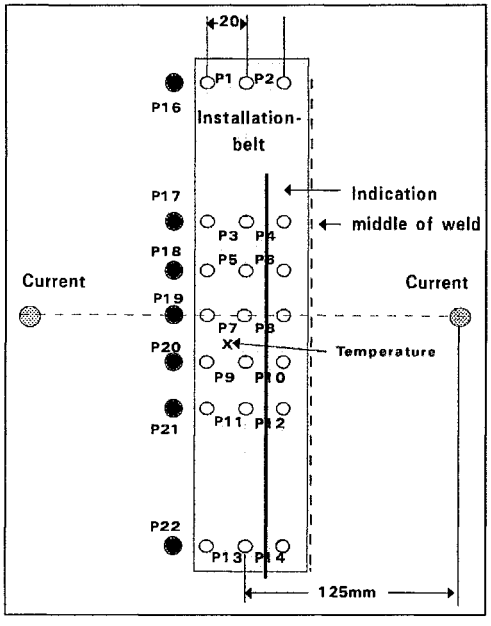


Fig. 3 Area of measurement

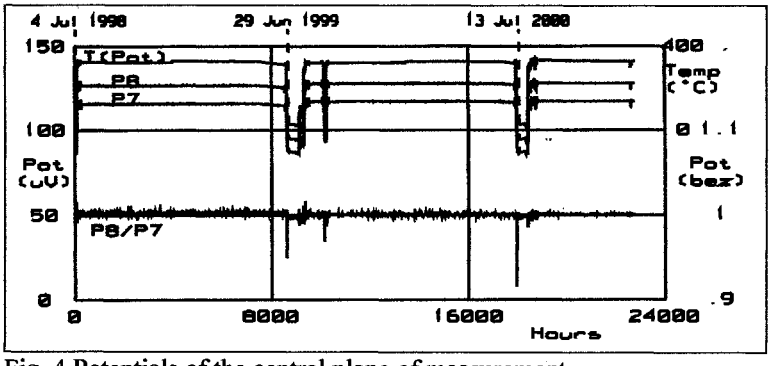


Fig. 4 Potentials of the central plane of measurement

Fig. 4 illustrates the results measured since the 1998 inspection by using the central plane of measurement as an example. It can be seen that the related potential value P8/P7 remains very constant even over the long period of monitoring. The scatter of the measured values could be reduced again after August 2000 thanks to mean values taken from 5 almost consecutive measurements. The changes in potential recorded so far during the previous monitoring period of 3.5 years can be seen from the table below. (To take account of the changes made to the installation during the 1998 inspection the periods before and after are evaluated separately):

Period		Maximum increase in related potential indication/reference	Limit 1% ≙ increase in depth
Insp98/Insp97	(cold/cold)	0.4 %	2.0 mm [1]
Insp00/Insp98	(cold/cold)	0.0 %	1.3 mm
01-01/Insp98	(hot/cold)	0.3 %	

Wall thickness 29.5 mm, maximum depth of indication 10 mm, length of indication 176 mm
[1] Established in a conservative approach

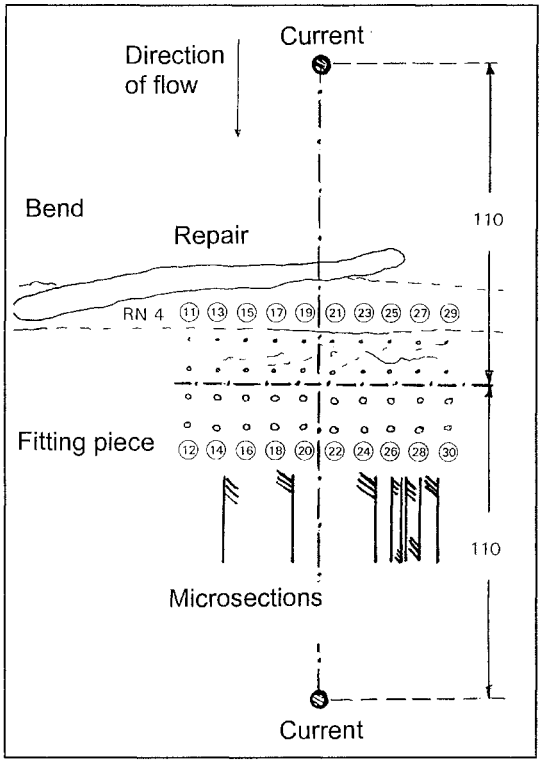
The measured increases in potential are below the limit of 1% established for growth of indication. This limit is derived from calibration curves for a postulated 10 mm deep crack (wall thickness 29.5 mm) and is supposed to be 2 mm for Insp98/Insp97, and 1.3 mm for subsequent measurements. With this inaccuracy, crack growth during the monitored period of 3.5 years can be ruled out without any doubt. Keeping a close watch on the PC monitor on site makes sure that changes are noticed immediately.

Monitoring Of A Crack-Affected Area Until Replacement [6]

In October 1998, after a service time of 15 years, a feed water suction pipe in a nuclear power plant developed a hole from which water fell in drops. Metallographic specimens were taken to closely investigate the damaged area. Radiographic and ultrasonic examinations of the other three suction pipes revealed cracks with a maximum depth of about 2 mm on the inside of the pipes with a wall thickness of 7.1 mm. For continued service until replacement, a fracture mechanics analysis was made and two representative areas of circumferential welds RN 4 and RN 8 were monitored for crack growth by means of the potential drop method.

Fig. 5 illustrates as an example the potential field of measurement designed to monitor the crack field around the repair weld in circumferential weld RN 4. Also included in this figure are the planes for the sections which were prepared after the removal of the pipe to identify the actual size of the defect.

Fig. 6 represents the potential profile P27/P28 for the area where the deepest crack having a depth of 2.9 mm was located later on. It can be seen that the related potential value is very constant indeed. The slight rise during the start-ups is not attributable to growth in indication as it goes again down during shut-downs. Even in the other planes of measurement no increase in potential suggesting growth in indication was noticed. Subsequent metallographic examinations corroborated this result in full: they demonstrated that during the service year in question crack growth in both crack-affected areas which were monitored can be ruled out.



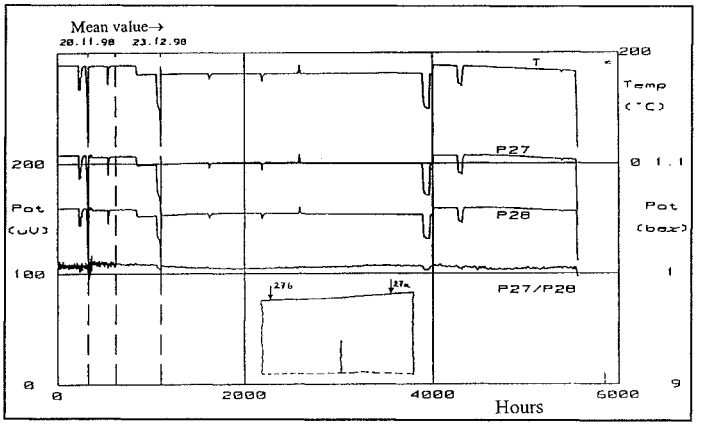


Fig. 6 Potentials of the plane of measurement with the deepest crack

Fig. 5 Area of measurement

The following maximum increases in related potential indication/reference were measured:

Period	Installation	Maximum increase in related potential indication/reference	Limit 1% ≙ increase in depth
99-07/98-11 (cold/cold)	RN 4	0.6%	0.2 mm with 2.9 mm
99-07/98-12 (cold/cold)	RN 8	0.0%	0.3 mm with 1.5 mm

Wall thickness 7.1 mm, maximum depth of defect measured: 2.9 mm (RN 4), 1.5 mm (RN 8), assumed length of defect 10 mm

As the measured increases in potential are below the limit of 1%, growth in indication could be ruled out.

Monitoring Of A Defect Until Repair

An indication in the circumferential weld of a residual heat pipe (NW 300, wall thickness 30 mm) was to be monitored in a nuclear power plant for one year of service until repair. The indication localised by means of radiography and US-SAFT was found to measure 5 mm in depth and 50 mm in length.

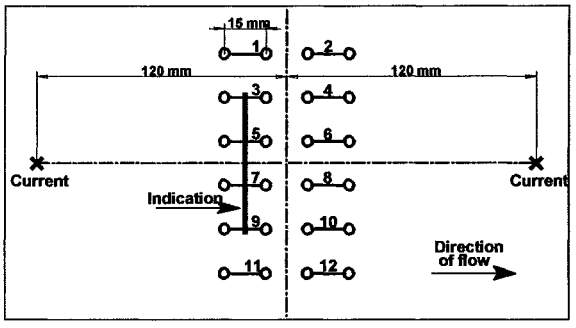


Fig. 7 Area of measurement

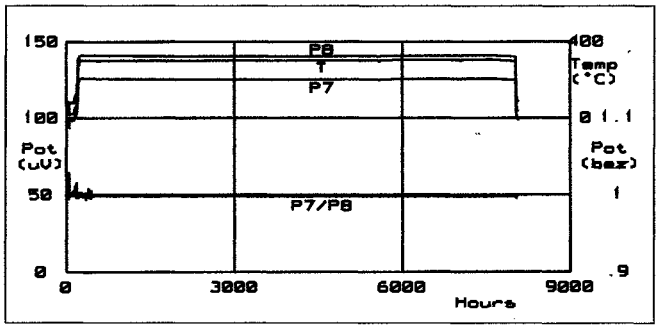


Fig. 8 Potentials of a central plane of measurement

Fig. 7 illustrates the potential measuring field installed for monitoring purposes, and Fig. 8 shows the potential values recorded for a central plane of measurement. It is clear that the related potential value is very constant over the entire period of monitoring of 1 year. When a stable power supply system was used immediately after start-up, the scatter of measured values was extremely small as a result of the means taken from 5 consecutive measurements. The resolution capacity for crack growth is thus very sensitive:

Period		Maximum increase in related potential indication/reference	Limit 1% ≙ increase in depth
After start-up (99-03/Insp99)	(hot/cold)	0.3%	1.2 mm
Service prior to shut-down (00-02/Insp99)	(hot/cold)	0.3%	
Service prior to shut-down (00-02/99-03)	(hot/hot)	0.2%	
Insp00/Insp99	(cold/cold)	0.0%	

Wall thickness 30 mm, depth of defect 5 mm, length of defect 50 mm

As the measured increases in potential are below the limit of 1%, growth of indication could be ruled out, even at a point shortly after start-up, despite a possible temperature component of the potential values.

Monitoring Of An Outside Crack In The Housing Of A Quick-Acting Valve

An outside circumferential crack had been detected in the housing of a quick-acting valve in use in a conventional power plant. This crack was to be monitored for 2 years of service at a temperature of up to about 530°C until replacement of the cast housing. The wall thickness of the housing in the crack-affected area was about 95 mm and the depth of the crack was 30-50 mm.

Fig. 9 illustrates the potential measuring field installed to monitor the circumferential crack. Fig. 10 shows, by the example of the central plane of measurement, the related potential values P5/P6 that have been measured so far over more than 1 year. Right at the beginning of the first start-up a very sharp drop in the related values was

noticed: about 50% of this drop is due to a skip and the other 50% to a reversible temperature component (the temperatures at the measuring points for monitoring purposes are slightly lower than at the measuring points for reference purposes).

Period		Maximum increase in related potential indication/reference	Limit 1% ≙ increase in depth
00-08/00-01	(cold/cold)	0.0%	0.7 mm
01-02/99-12	(hot/hot)	0.0%	

Wall thickness 95 mm, maximum depth of crack 50 mm, length of crack 130 mm

As the measured increases in potential are below the limit of 1%, it can be ruled out that the postulated surface crack with a maximum depth of 50 mm deepened during the monitoring period of more than one year up to now including several start-ups and shut-downs.

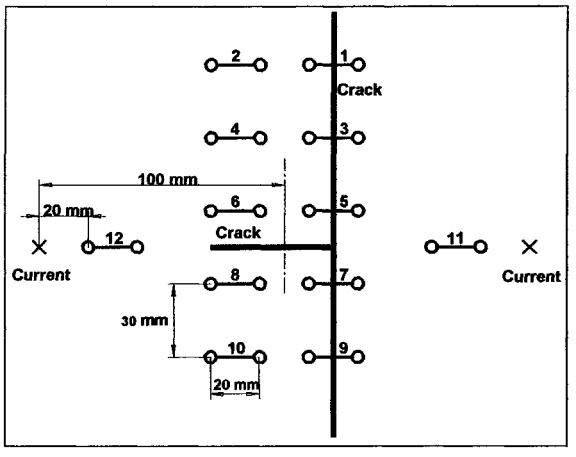


Fig. 9 Area of measurement for the circumferential crack

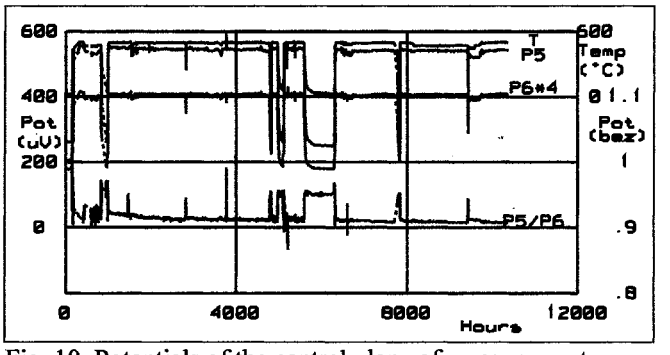


Fig. 10 Potentials of the central plane of measurement

This confirmed that the potential drop method can be relied on to monitor existing findings of crack growth in-service - until the component monitored is repaired or replaced, where appropriate.

POSSIBILITIES FOR APPLICATION IN OFF-LINE MONITORING

As for the results presented so far, the potential values were recorded during the period of monitoring at regular intervals - e.g. during service every 12 or 24 hours and during start-up and shut-down every hour. However, account must be taken also of the many cases of application in which such a high density of measurements is not necessary or not desired. One measurement during the inspection and during recurrent tests will often do. In theses cases instrument leads and circuits should be permanently laid and potential values should be recorded during the inspection by means of a mobile system of measurement. There are some aspects that give this type of measurement certain advantages over the conventional non-destructive test methods:

- One-off operations (laying of instrumentation leads and circuits, scaffolding, stripping off of insulation) and reduction in exposure to radiation
- The measurements can be taken quickly (they take only a few minutes)
- Expenses are low
- Quantified high resolution for crack formation and crack growth

Experience has shown that the installations used up to now have excelled at high resolution. In all cases the measured increase in potential from inspection (cold) to inspection (cold) is below the limit of 1% specified for growth of indication.

Power plant	Period	Maximum increase in related potential indication/reference	Limit 1% ≙ increase in depth	Initial depth → definite depth (with 1% limit)	Wall thickness
A	Insp98/Insp97 (cold/cold)	0.4%	2.0 mm [1)]	10.0 → 12.0 mm	29.5 mm
	Insp00/Insp98 (cold/cold)	0.3%	1.3 mm	10.0 → 11.3 mm	
B	99-07/98-11 (cold/cold)	0.6% (RN 4)	0.2 mm	2.9 → 3.1 mm	7.1 mm
	99-07/98-12 (cold/cold)	0.0% (RN 8)	0.3 mm	1.5 → 1.8 mm	
C	Insp00/Insp99 (cold/cold)	0.0%	1.2 mm	5.0 → 6.2 mm	30.0 mm
D	00-08/00-01 (cold/cold))	0.0%	0.7 mm	50.0 → 50.7 mm	95.0 mm

[1)] Established in a conservative approach

The satisfactory resolution in long-time monitoring qualifies this method for application e.g. to highly stressed or highly contaminated components or components that will not be accessible any longer at a later point in time: One or several conventional non-destructive methods are used to examine the relevant area of the material for defects and to size these defects. After that, the potential measuring field is installed. During the next inspections a mobile set is employed to measure only the potentials. An evaluation gives a directly applicable quantified statement, e.g. for fracture mechanics evaluations, about crack formation, if any, provided the area was flawless at the time of installation, or about crack growth, provided a flaw was already present at the time when the potential measuring field was installed.

CONCLUSION

The potential drop method further developed by TUEV Anlagentechnik, Cologne, was explained. Special attention was given to details of installation and calibration. Monitoring of potential in 4 power plants over periods of 1 to 3 years demonstrated the high resolution for growth of indications or cracks respectively over extended periods. Crack depth growth ranging from 0.2 to 2 mm in the worst case could be resolved as a function of the existing depths of indication (1 to 50 mm) and wall thicknesses (7 to 95 mm).
For one of the installations a metallographic examination was made after removal of the pipe. This examination corroborated what had been concluded with the aid of the potential drop method: during the 1 year period of monitoring there had been no crack growth.
In addition to on-line monitoring including fully automatic measurements at a given interval, this method also lends itself to off-line application: the potentials of the measuring field installed are recorded e.g. only during inspection using a mobile system. The advantage over conventional methods of non-destructive testing is that scaffolding, stripping off of insulation need to be done once only and that the personnel involved is exposed to radiation only once. A baseline examination of the area concerned using ultrasonics or any other non-destructive method is a prerequisite for a quantified statement about crack formation or crack growth. This possibility for application in recurrent tests therefore is of particular importance in tackling current problems with dissimilar welds in nuclear power plants.

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