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PULSED EDDY CURRENT (PEC)

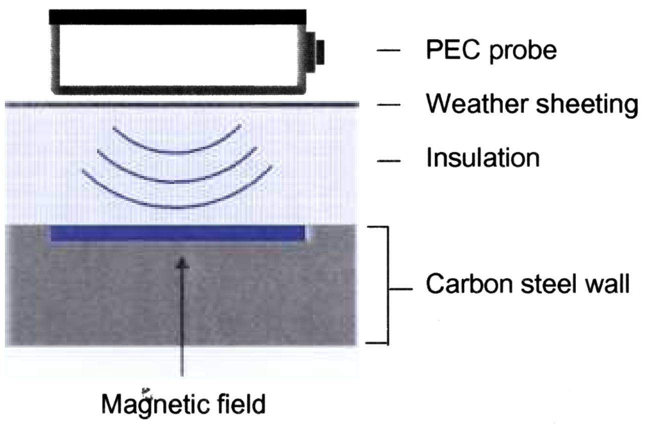
Pulsed Eddy Current

Inspection through insulation

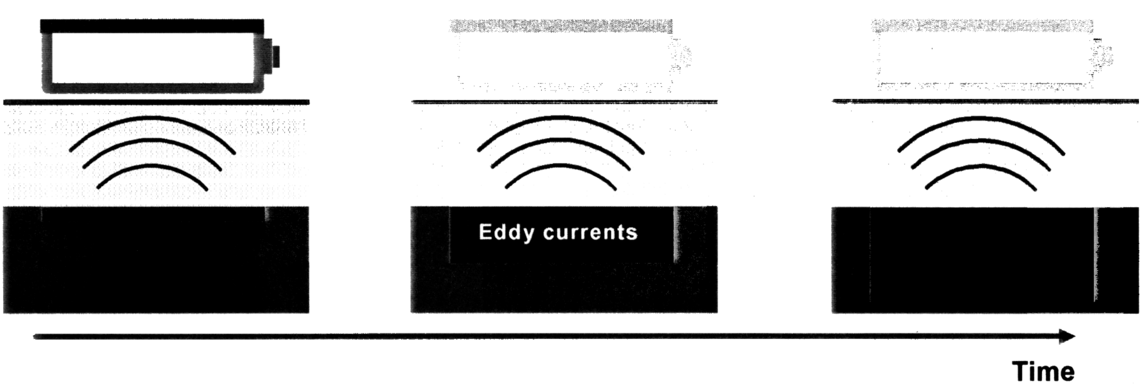
Pulsed Eddy Current inspection of
a steel skirt through fire-proofing

Simplified working principle of a PEC wall thickness measurement

Step 1 - Current switched on - The steel surface is magnetised through the insulation



Step 2 - Current switched off - The eddy currents expand and decay



Inspection through insulation opens unexpected opportunities

Shell Global Solutions in Amsterdam has developed over the past few years an inspection instrument that can measure wall thickness of steel objects like pipes and vessels without making contact with the steel surface. The instrument can measure through coatings, insulation materials, weather sheeting and even corrosion products.

The main benefits this offers include:

- No production loss: the instrument can inspect while the equipment is in service;
- Ability to monitor the integrity of the plant while in service helps to prevent unplanned shutdowns;
- Reduction of inspection costs: no need to remove insulation materials;
- Significant lower cost for underwater inspections.

The technology is based on pulsed eddy current, or simply 'PEC'. The principle of measuring wall thickness measurements with PEC has been known for many years, but only recent developments made it a practical method.

The PEC instrument has been applied extensively at Shell refineries, chemical plants and offshore installations. The technology is now being commercialised for use outside Shell.

Working principle

Pulsed Eddy Current is an electromagnetic method to determine wall thickness of electrical conductors. A simplified explanation of the method is illustrated in the figure opposite. The PEC instrument probe is placed against the metal weather sheeting of an insulation pipe or vessel. A magnetic field is created by an electrical current in the transmitting coil of the probe. This field penetrates through the weather sheeting and magnetises the pipe wall. Next, the electrical current in the transmission coil is switched off, causing a sudden drop in the magnetic field. As a result of electromagnetic induction, eddy currents will be generated in the pipe wall. The eddy currents diffuse inwards and decrease in strength. The decrease of eddy currents is monitored by the PEC probe and is used to determine the wall thickness. The thicker the wall, the longer it takes for the eddy currents to decay to zero.

In-service inspection of a coated offshore riser. PEC showed that a seemingly innocent damage to the coating was in fact hiding severe corrosion

PEC has been used to inspect the annular ring of atmospheric storage tanks while in service. The PEC probe was inserted in 'rabbit holes' dug underneath the tank bottom to obtain a wall thickness profile of the first 0.7 m

Strengths and limitations

As any NDT technique, pulsed eddy current has its strong and weak points. The relevance of these vary strongly from application to application and needs to be considered for each application separately. In order to do so, the strengths and limitations are addressed below. The main strengths of the pulsed eddy current technique are:

No need for direct contact.
Wall thickness can be measured through any material that does not conduct electricity: insulation material, coatings, paint, concrete, bitumen, dirt, sludge and so forth. The layers can be as thick as 200 mm.

PEC can measure through aluminium and stainless weather sheeting. It is in principle also possible to measure through galvanised weather sheeting, but the performance is less.

There is no need for surface preparation. In particular, surface roughness does not affect the PEC readings. Moreover it is not required to remove corrosion products, even up to 20 mm thick.

Wide temperature range: -100°C to 550 °C (-150°F to 1000°F).

The above qualities ensure that the instrument can be applied in-service.

Very good reproducibility of PEC readings at the same locations, typically ± 0.05 mm. This makes PEC very suitable as corrosion monitoring device.

The PEC instrument can be operated by remote control, e.g. for use in Remotely Operated Vehicles (ROV's).

The main limitations of pulsed eddy current are:

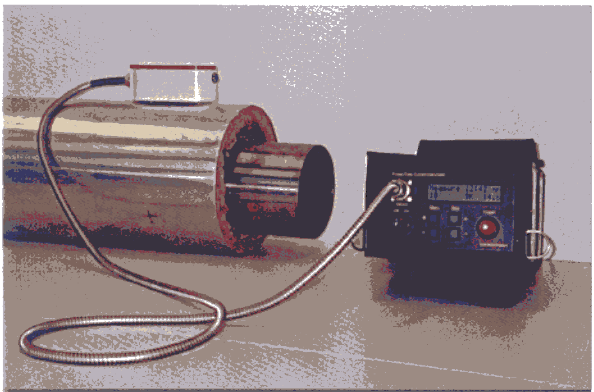
Only applicable to carbon steel and low-alloy steel;

PEC integrates over a relatively large foot print. As a result, the smallest defect that can be detected has a diameter of about 50% of the insulation thickness (between 30 and 120 mm insulation thickness). PEC is therefore suitable for general wall loss, but isolated pitting defects can not be detected.

The PEC wall thickness readings are relative values, showing variations in wall thickness on the object being inspected. Whilst this is sufficient in many applications, absolute readings can be obtained by a wall thickness calibration at one point of the object.

The PEC readings depend on the electromagnetic properties of the material. Variations in these will influence the PEC wall thickness readings. Such variations have occasionally been observed on vessels. Variations in material properties within one object will result in spurious variations in PEC wall thickness readings of typically 10%.

The geometry of the test object should be simple; e.g. straight sections of pipe work. Wall thickness readings are affected by nearby nozzles, welds, internals, and support structures. A clearance of typically 2" is needed. It is not possible to inspect under steam tracing, near supports and in sharp bends. The limitation in geometry is relevant when inspecting for corrosion under insulation.



The PEC instrument with probe

Typical Performance Parameters

Wall thickness range	3 - 35 mm	(0.12" - 1.4")
Typical accuracy	± 0.5 mm	(± 0.02")
Same spot reproducibility	± 0.05 mm	(± 0.002")
Lift-off range	0 - 200 mm	(0 - 8")
Pipe diameter	75 mm - flat plate	(3" - flat plate)
Material temperature	-100 °C to +550 °C	-150 °F to 1000 °F
Defect sensitivity	diameter larger than 50% of insulation thickness (at 30 - 120 mm lift-off)	
Remaining wall thickness of defect	± 1 mm	(± 0.04")

The Pulsed Eddy Current instrument

The main characteristics of the Pulsed Eddy Current instrument are:

Single operator tool, portable instrument, handheld probe.

- Instrument weight is 6 kg (12 pounds); size is 350 x 200 x 130 mm (13.5 x 8 x 5 ").
- Battery operated.

Suitable for use outdoors: robust design and splash-water tight.
No computer required during data taking.

Suitable for use in safety zone 2 (i.e., no sparks are generated under normal conditions).

- Up to 1000 points can be stored in the data logger.
  Downloading of stored data to personal computer is done using an EXCEL spreadsheet.
- **Data collection**
  Is simple and fast (about 5 seconds per reading; still being improved) and can be done by a single 'Level I' operator. The PEC instrument takes point measurements. During the 5 seconds it takes for a PEC reading, the probe has to be held stationary; it is not possible to move the probe while collecting data.

Data Analysis
The instrument gives an instantaneous estimate of the wall thickness. For some applications this is sufficiently accurate and no further analysis is required.
More demanding applications require more detailed analysis. This is done after the inspection by connecting the instrument to a PC and downloading the stored data. The data can be processed using dedicated software by a level II or III inspector. This off-line processing can be done remotely, e.g. by sending the data by electronic mail. This implies that the level II inspector does not need to be on site nor present during data collection. This split in data collection and analysis proves to be cost-effective.

Performance and Validation

The performance of Pulsed Eddy Current depends on a number of parameters such as wall thickness, insulation thickness, temperature of the object and type of weather sheeting. In addition, the performance is influenced by the presence of electrical distortions and mechanical vibrations. As a result, it is difficult to predict the exact PEC performance. Nevertheless, based on a large number of field tests typical performance parameters can be deduced. The typical performance with aluminium and stainless steel weather jackets are listed in the table opposite.

Inspection of a shell of
an insulated heat exchanger

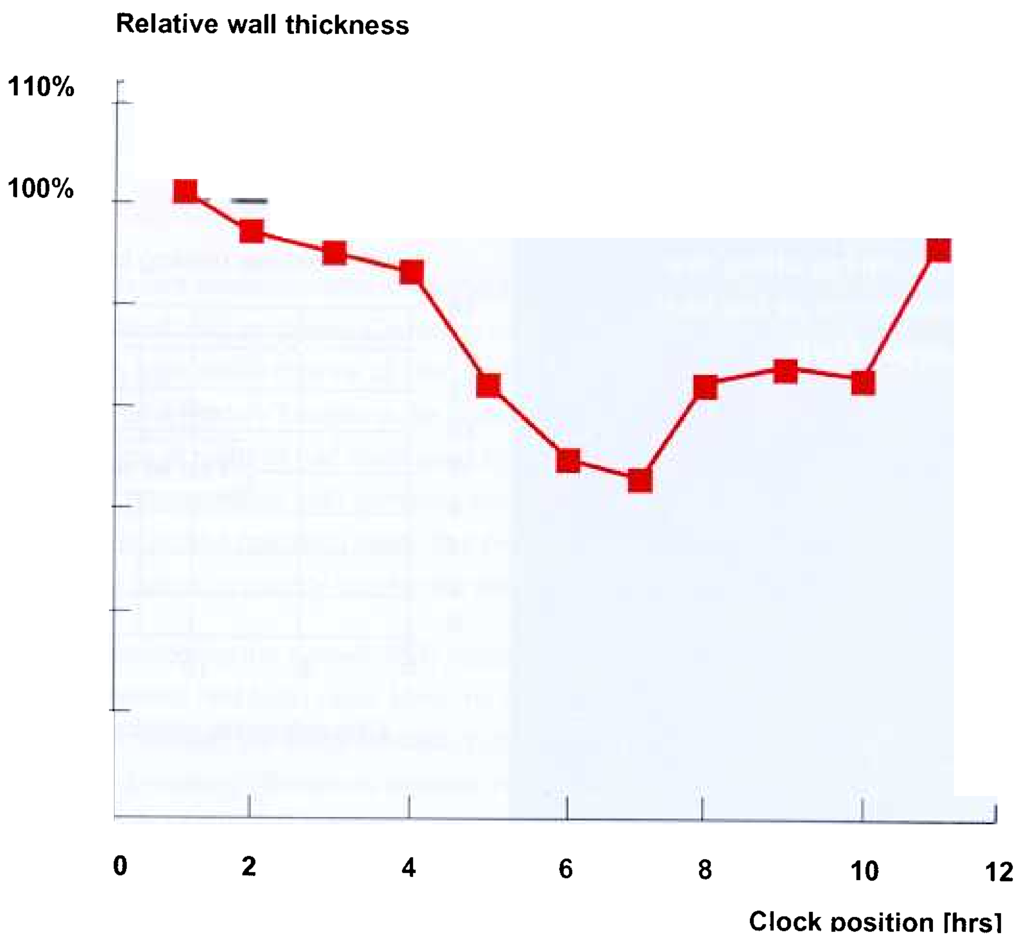
Inspection of an insulated line
Several readings are taken
along the bottom of the pipe

Applications

A vast body of experience has been collected over the past two years. The PEC instrument has been tested at over 20 different Shell Operating Companies. Local Shell staff have provided much feedback and in this way greatly contributed to the development of the PEC instrument. Several examples of experiences are presented below.

Corrosion Under Insulation

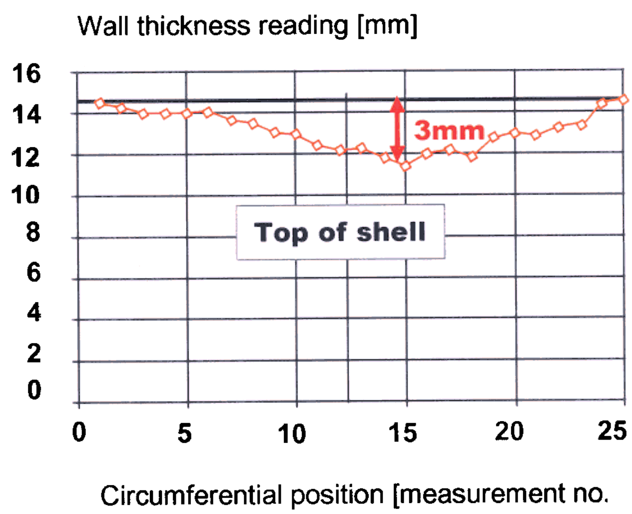
A large range of insulated and coated equipment has been inspected for corrosion under insulation (CUI): pipes, vessels, columns, heat exchanger shells and storage tanks. Inspections have been carried out on equipment both with and without metal weather sheeting around the insulation. The inspection involves taking several readings on the equipment and searching for variations in wall thickness. An example of wall loss on a failed pipe is displayed below. Here, readings were taken along the circumference of the pipe and normalised to 100% at the top of the pipe (12 O'clock). A wall loss of 30% was observed near the bottom of the pipe.



Variation of wall thickness along the circumference of an insulated pipe

In-service inspection of a heat exchanger at high temperature. Several readings are taken along the circumference of the shell

Wall thickness along the circumference of the heat exchanger shell



High temperature applications

Ultrasonic inspection becomes difficult at high temperatures above about 200 °C. PEC offers an alternative for these applications. By placing a ceramic block in between probe and hot wall, the probe can be shielded from the heat and readings can be taken as normal. In this way, PEC is able to measure up to about 550 °C.

An example of a high-temperature inspection was at a refinery where two heat exchanger shells had been exposed by mistake to hydrogen chloride attack. As a result, wall loss was suspected at the top of the shells. The insulation material was removed from the heat exchangers to take ultra sound wall thickness readings. The high temperature of the heat exchangers hampered the ultra sonic measurements, and reliable data could only be obtained at a limited number of points. PEC was used with more success. PEC data were obtained collected along the circumference of the heat exchanger at several points. The PEC data proved consistent with ultra sound data at those points where there was a reliable ultra sound reading.

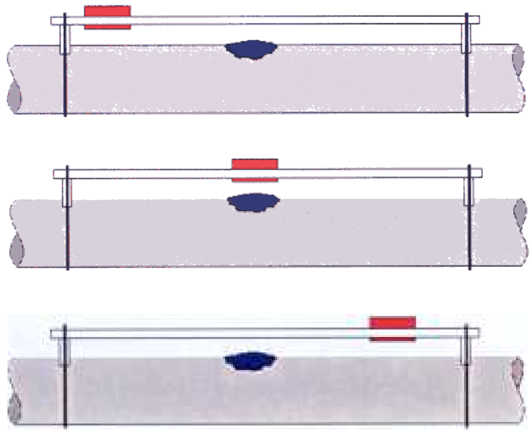
The worse case of wall loss as detected by PEC is displayed in the figure opposite, showing about 3 mm wall loss. As this was acceptable from the integrity point of view, the asset owner decided not to replace the shells.

In-service corrosion monitoring

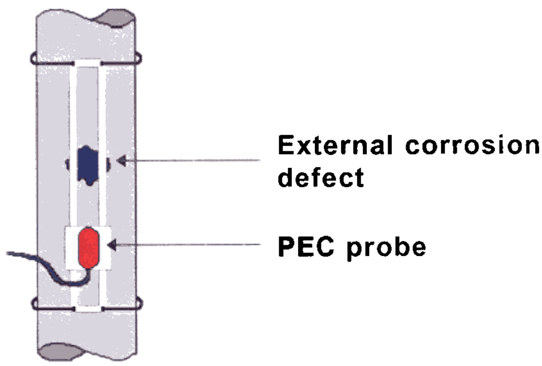
Pulsed eddy current measurements are generally highly repeatable. This makes it well suited for corrosion monitoring purposes. Corrosion rates can be deduced from wall thickness measurements over a time interval at fixed locations. PEC corrosion monitoring was recently put to the test on a refinery furnace outlet operating at 420 °C. The asset owner discovered that a wrong type of material had been used in the construction of the elbows of the outlet, which leads to unacceptable high corrosion rates. Measurements at two weeks time intervals confirmed the expected corrosion rates. The high reproducibility of PEC readings at one spot allow the asset owner to quickly monitor the degradation of the plant over time.

In addition to monitoring the elbows, PEC readings were also obtained at locations where the right kind of material had been used. Here, no measurable corrosion rates were expected at these locations. Indeed, the wall thickness on these locations showed less than ± 0.04 mm (one standard deviation) differences between readings separated by 5 weeks, which confirmed the reproducibility of the PEC readings.

Measuring remaining wall thickness through an external defect without removing any corrosion products



Side view



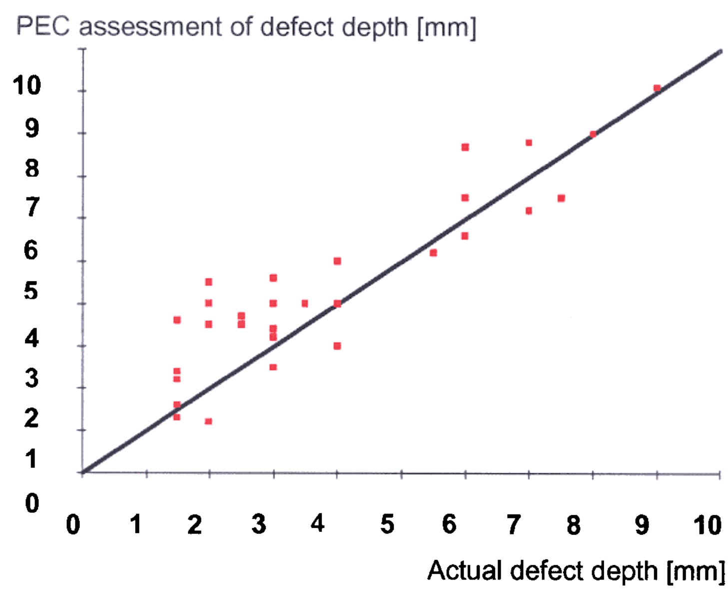
Top view

Inspection of heavily corroded equipment

Another application of PEC is in-service assessment of heavily corroded pipes and vessels. Often safety considerations do not allow the corrosion products to be removed on stream. In this case PEC has the crucial advantage that it can be applied without disturbing or even touching the corrosion products. The inspection procedure involves taking reading on the defect and comparing these with readings next to it. To this end, a slider was developed to move the probe over the defect area without having to touch the surface of the pipe.

The PEC method was validated on 40 different natural defects on a non-critical water line. PEC was used to measure the remaining wall thickness underneath layers of corrosion products while the equipment was in service. After the PEC measurements the corrosion products were removed and the remaining wall thickness was determined by a mechanical profilometer.

The figure shows the correlation between the two methods. Although the correlation is not perfect (standard deviation 1 mm), it shows that PEC can distinguish between serious defects and less severe cases of corrosion. This information is of great value, as it allows to plan which part of the pipe needs to be replaced and which part can be repaired by simple grit blasting and painting.



Minimal remaining wall thickness of 40 naturally corroded defects

Inspection of a caisson using rope access techniques. The PEC probe (not seen on the picture) is moved along the caisson using a jig

PEC inspections with an ROV

Under water inspection of offshore risers and caissons

Pulsed Eddy Current has been used with much success for underwater inspections of coated risers and caissons. The advantage of using PEC over conventional technologies is that there is no interference with production, that it doesn't require surface preparation and that there is no need to remove coatings.

Inspections were carried out both in the 'splash zone' as well as in deeper water. The splash zone inspections were carried out using abseil techniques, whereby the inspectors and PEC tool remained above the water level. The PEC probe was moved through the splash zone down to eight meters under the water level by using a jig that can move the probe along the riser or caisson. The inspection has been applied at several locations now. In one instance, a defect with only 4 mm remaining wall thickness was detected in a riser with 10 mm nominal wall thickness.

Underwater inspections have also been carried out by placing the PEC instrument onboard a Remotely Operated Vehicle (ROV) and attaching the PEC probe to the manipulator of the ROV. The PEC was operated by remote control. Fifteen caissons have been inspected in this way in the North Sea in July 1998. Four of these showed serious wall loss due to mechanical wear associated with pumps inside the caisson. An example of an inspection outcome is presented in the table below.

36" Sea water lift caisson

Nominal wall thickness 12.5 mm

Location	10 O'clock	2 O'clock	4 O'clock	8 O'clock
+ 0.5 m	11.8	12.3	12.4	11.9
Pump at 16.0 m depth	3.6	4.2	13.3	12.5
-0.5 m	8.6	7.7	11.3	11.0

Repeatability: 0.1 mm scatter (= 0.8%)

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