Pulsed Eddy Current Corrosion Monitoring in Refineries and Oil Production Facilities – Experience at Shell

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Abstract. Pulsed Eddy Current (PEC) has been applied to monitor wall thickness in piping of refineries and oil production platforms. PEC is a non-intrusive and non-contact NDT method and has a much better reproducibility than e.g. periodic ultrasonic wall thickness measurements and is therefore a preferred choice for corrosion monitoring with relative short intervals. As PEC is a non-contact NDT technique, it can also be applied for wall thickness monitoring at high temperatures.

PEC corrosion monitoring is illustrated here with an example of a hydrocracker unit in a refinery. Precision wall thickness monitoring allowed extension of runtime despite aggressive flow-assisted NH_4HS corrosion. PEC has also been applied at crude distillers and high vacuum units of refineries and to verify corrosion inhibition at oil production facilities.

Introduction

There is a significant economic incentive to extend the run time of equipment and reduce the frequency and duration of shutdowns. An important means of ensuring that equipment is safe to operate over these extended periods is in-service corrosion monitoring. A number of corrosion monitoring methods exist. Some of these are intrusive and require a sensor to be inserted into the product flow. Such probes usually respond quickly to changes in corrosion rate and, because of this, they are often used as part of a corrosion control system. There are instances, however, where internal probes cannot be used. In such cases thickness monitoring is an option, provided the measurements are repeatable(1) enough to detect extremely small changes in wall thickness.

The present paper describes the application of Pulsed Eddy Current (PEC) for wall thickness monitoring. The use of PEC is illustrated with an example of a refinery unit with severe corrosion problems. This proved of great value to the asset owners, as it allowed continued safe operation for almost half a year, whilst preparations were made for a planned shutdown to replace corroded piping

1. The Pulsed Eddy Current method

PEC employs a pulsed magnetic field to generate eddy currents in the steel. Since carbon and low-alloyed steel is ferromagnetic, only the top layer of the steel is magnetized [1], [2].

1 Repeatability is a measure of the consistency of repeat measurements carried out under identical conditions at different moments in time.

This is shown schematically as stage 1 in Figure 1. The eddy currents are initially confined to the steel surface closest to the PEC probe. As time elapses, they diffuse into the test specimen (stages 2 and 3 in Figure 1) until they eventually reach the far surface (stage 4 in Figure 1). The eddy currents induce a voltage signal in the receiver coils of the PEC probe. This 'PEC signal' is displayed in the right-hand side of Figure 1. As long as the eddy currents experience free expansion in the steel, i.e., stages 1, 2 and 3, their strength decreases relatively slowly. However, upon reaching the far surface at stage 4, their strength decreases rapidly. The moment in time when the eddy currents first reach the far surface is indicated by a sharp decrease in the PEC signal. The onset of the sharp decrease point is therefore a measure of wall thickness. An earlier onset of this sharp decay of one PEC signal compared to a reference signal, for instance, indicates wall loss.

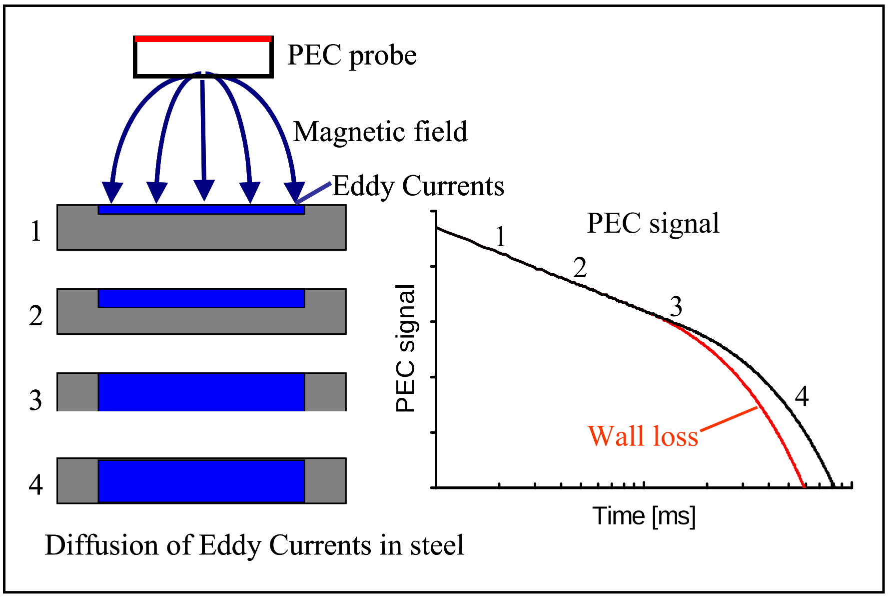

Figure 1. Schematic representation of diffusion of eddy currents in the steel

The PEC wall thickness readings are an average over the probe 'footprint', i.e. a roughly circular area where eddy currents flow. The size of this footprint depends on the distance between the probe and the metal surface, and on the size of the probe itself. In practice, this means that PEC is well suited for measuring general wall loss, but not for detecting very localized damage such as isolated pitting.

2. Application of PEC wall thickness monitoring

A unique feature of PEC is its portability. With PEC, a single sensor can be used to monitor many different locations. Positioning frames and centre pop marks are used to ensure that the PEC probe is accurately located in the same monitor position each measurement. The approach is illustrated in Figure 2, showing the PEC probe attached with a spring in a positioning frame. The PEC probe has three sharp pins that fit exactly in three holes of the frame. This method is not only economical, but also allows PEC to be applied at high temperatures, up to about 550 °C. Furthermore, the monitor positions can be installed while the equipment is running by strapping the frame to the pipe. PEC probes are also available to monitor wall thickness at fixed positions. These are used to determine corrosion rates in areas where it is difficult to use the mobile PEC probe, e.g. in areas where scaffolding is required.

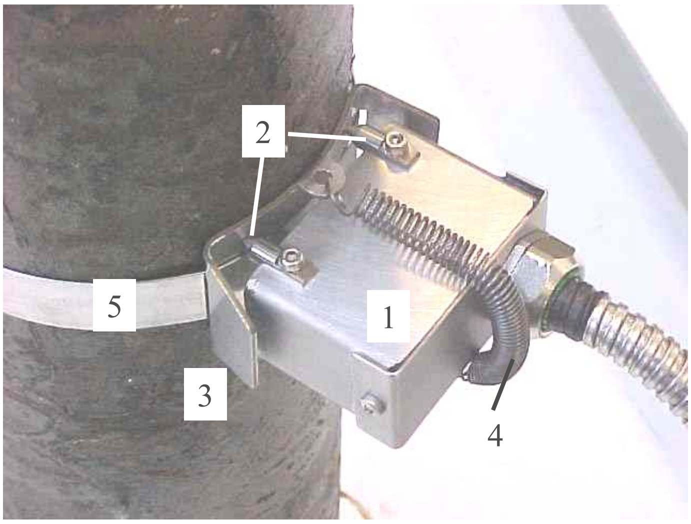

Figure 2. Picture of a PEC sensor (1) that is attached with a spring (4) to a frame (3). The sensor has three sharp pins (2) that fit holes in the frame.

PEC has been applied to monitor the corrosion rate of piping in crude distillers and high vacuum units of refineries during the processing of ‘opportunity crude’, i.e. crudes that have not been processed before and may cause fluctuations in corrosion rate. PEC enabled the owner detect short-term changes in corrosion rates due to processing these different crudes. At gas processing facilities and at oil production platforms, PEC has been used to verify the effectiveness of corrosion inhibitors to evaluate changes in inhibitors and to ensure the inhibition is continuously effective. Another important application of PEC is the extension of runtime of an installation nearing its end of life despite severe corrosion problems. An example of such a case is described below.

3. Application example at a hydrocracker unit

Ammonium bisulphide (NH_4HS) corrosion is a well-known corrosion problem for hydrocrackers at refineries [3]. Figure 3 displays a simplified flow diagram, showing the circuit between the reactors to the hot high-pressure and the cold low-pressure separators. Here the reactor effluent, a mixture of H_2, H_2S, hydrocarbons and salts like NH_4HS, is cooled via a series of heat exchangers and air coolers. Wash water is injected upstream the air coolers to dissolve and dilute corrosive species and to counteract salt deposition and fouling of equipment. During the original design the selection of carbon steel with a limited lifetime prevailed over alloy 825 for the part of the piping for economical reasons. The corrosion allowance in the carbon steel was estimated to be large enough for a minimum design life of 15 years.

During regular standard inspections it was found that, due to fouling and more severe operation conditions than expected, the flow-assisted NH4HS-corrosion appeared to have increased beyond the design corrosion rates. The ultrasonic wall thickness measurements on the air cooler outlet piping indicated, over a 18-month period, corrosion rates of over 2 mm/y and higher. This is a factor more than 4 higher when compared to the 0.5mm/y predicted for the original 15-year design life.

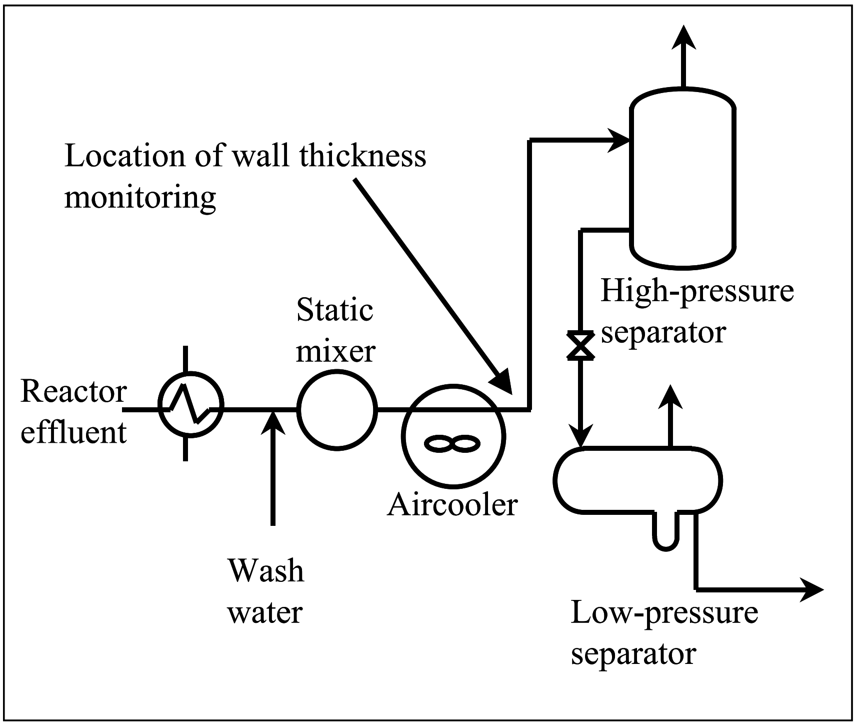

Figure 3. Simplified process flow diagram of the reactor effluent portion of a hydrocracker unit at a refinery

Research in more recent years has determined that the old methods for corrosion prediction were not conservative for hydro-crackers and that in extreme cases, much higher corrosion rates have to be taken in to account. This knowledge plus the inspection findings meant that the remaining life of the piping was severely shortened and that consequently a full replacement and upgrade of the air-coolers inlet and outlet piping with alloy 825 was needed at next scheduled shutdown in 1.5 years time. Meanwhile an extended corrosion-monitoring program was needed to keep close track of corrosion and to enable continued safe operation.

The two key parameters required for remnant life assessment are the actual minimum wall thickness and the predicted corrosion rate. If these can be determined accurately, it is possible to reliably forecast when the minimum allowable wall thickness is reached. To this end, extensive ultrasonic thickness measurements were carried out on all 48 outlet pipes of the air cooler. Wall loss appeared so severe that it was expected that some elbows of the outlet piping would reach minimum allowable wall thickness before the scheduled shutdown.

Although ultrasonic wall thickness measurements on the air cooler outlet piping gave a reliable measure of the minimum wall thickness, the data could not be used to reliably estimate the corrosion rates over intervals of a few weeks. This was due mainly to data scatter caused by the relative poor repeatability of the ultrasonic testing methodology, despite efforts to optimize measurement consistency. It is estimated that the best repeatability achievable with ultrasound on corroded surfaces is in the order of 0.4mm at a 95% statistical confidence level. This proved insufficient to predict remaining life with sufficient confidence. PEC was therefore chosen as a complementary NDT technique for estimating the corrosion rates and the corrosion trends. PEC typically achieves an *in-service* measurement repeatability of 0.2% (e.g. 0.02mm on a 10mm wall thickness). With such a high repeatability PEC is able to establish corrosion rates in less than one tenth of the time needed by ultrasound, and is therefore able to pick-up changes in corrosion-rates much more quickly. An additional advantage of PEC is that it is relatively simple to set up; data acquisition is quick and largely independent of the skill of the operator.

Based on the relative strengths of each technique, the strategy was adopted to use ultrasonic testing to survey the minimum remaining wall thickness of each outlet pipe and PEC to monitor the corrosion rate. The positions for PEC monitoring were selected at 96 positions corresponding to local minimums in the wall thickness as measured by ultrasound.

4. Results

Figure 4 is an example of the results, showing the wall thickness measured at the first elbow of one of the outlets. Note the expanded scale of the figure and the small measurement uncertainty in the PEC readings. The quality of the data confirms the excellent reproducibility of the PEC measurements. There appear to be three regimes of corrosion: one from day 1 since the start of the PEC measurements till about day 30 with a corrosion rate of 2.7 mm/y, subsequently until day 77 at 7.5 mm/y and then 1.5 mm/y. The change in corrosion rate is related to the operation conditions. At day 70 the throughput of the HCU was reduced, which is reflected in the lower corrosion rate at this position.

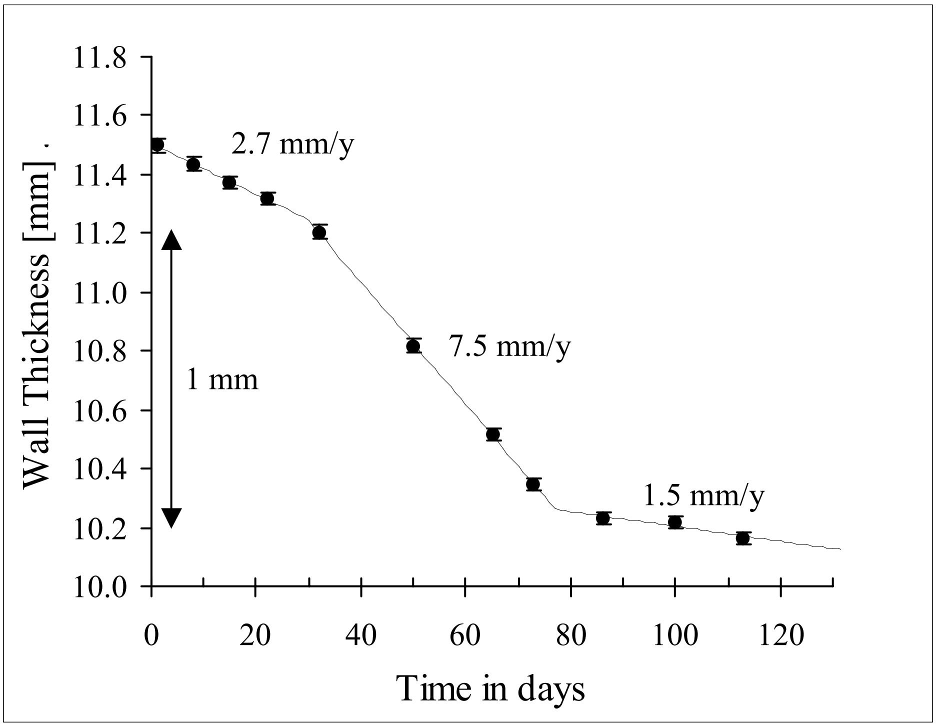

Figure 4. Example of a PEC result recorded on one of the outlet pipes. Note the expanded scale on y-axis. 2σ measurement error bars are indicated.

Remnant life calculations, based on ultrasound and PEC findings, quickly showed that the air cooler outlet piping would not reach the scheduled shutdown and an extra shutdown was required to replace the most severely corroded outlet pipe sections. Three pipes were clamped because the pipe minimum allowable wall thickness was reached. The timing and number of clamps was predicted with the help of PEC and ultrasound data. As an extra safety measure it was not allowed to corrode till perforation of the wall, also this point in time was predicted with the PEC/UT data and would invoke shutdown of the unit. With the accurate remaining life estimations at frequent intervals, bi-weekly PEC/UT measurements, it was possible to continue operating the HCU for five more months, thus providing sufficient time for replacement material to be ordered and for planning the extra shutdown.

Figure 5 displays the corrosion rate, averaged from day 1 through to day 120, as a function of the position of the outlet pipe relative to the inlet header. It is apparent that the corrosion rate is maximal for the piping of those air cooler banks connected to the middle of the header. The corrosion rate at the edges is significantly lower than at the middle. This pattern of corrosion rates is attributed to fouling in the headers that caused imbalance of the flow regime. This was later confirmed during shutdown, where severe fouling was found in the headers.

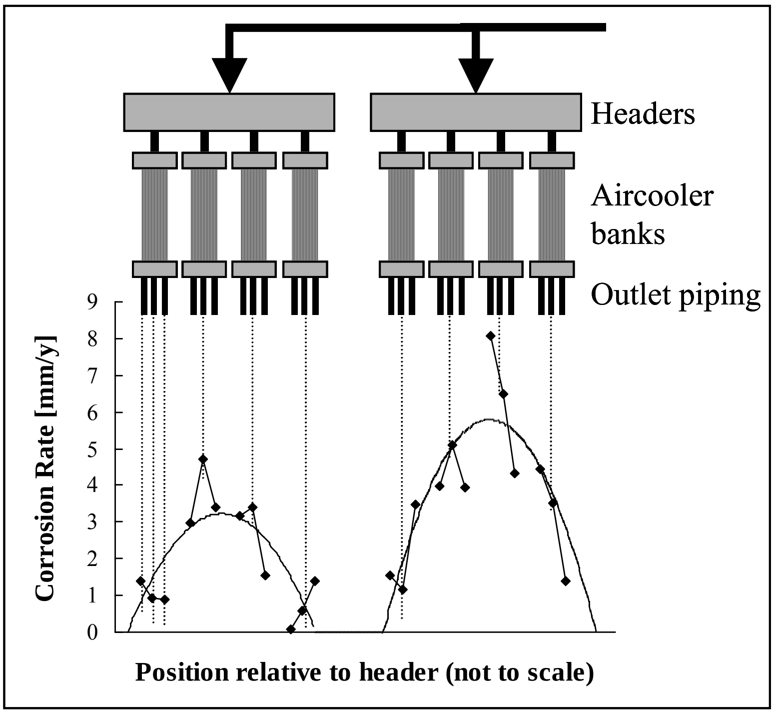

Figure 5. Corrosion rates measured by PEC at the 24 outlet pipes over the first 8 air cooler banks. The dashed lines indicate which pipe corresponds to which data point. The full curves serve to guide the eye to the average rate in each air cooler.

5. Post Mortem

Following the unplanned shutdown, a selection of cut-outs from the air cooler outlet piping was sectioned to understand more about the corrosion morphology and to validate the inspection results. Figure 6 displays one of the sections. Sectioning confirmed that the outlet pipes had suffered severe wall loss at the apex of the bends and that this was consistent with flow assisted NH_4HS corrosion. Unexpectedly, however, up to 4mm long blisters were observed in the pipe wall, just below the corroded surface. The blisters are most likely the result of hydrogen diffusion and entrapment. Furthermore, the blisters had a concave shape and could not be distinguished by ultrasound from back wall echoes. Consequently, ultrasound reported minimum remaining wall thicknesses that were always 2mm to 4mm less than the actual values. As a result, the remnant life predictions made prior to the shutdown were moderately conservative. The formation of blisters also explains why some of the corrosion rates derived from ultrasound were erratic and extremely high, as ultrasound may pickup the sudden formation of blisters. PEC, in contrast, is largely insensitive to laminations and blisters within the pipe wall. Had PEC not been available and one would have to rely on ultrasonic measurements alone to estimate the corrosion rates, the unit would have been shut down prematurely.

The sectioning results highlight the importance of understanding the corrosion-degradation morphology and what each non-destructive technique is responding to when using repeat thickness measurements to estimate corrosion rates.

Meanwhile the refinery has successfully managed the extra shutdown for repairs and has installed new alloy 825 air coolers and piping in the next shutdown to ensure safe production in future.

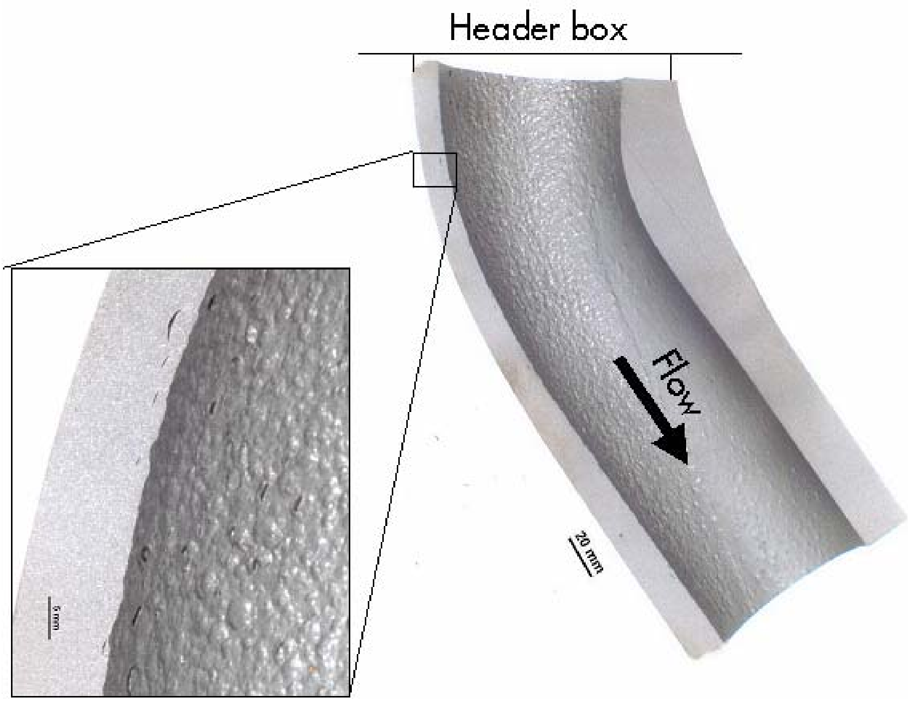

Figure 6. Cross-section of a bend of air cooler outlet pipe, showing the position of maximum wall loss and the presence of blisters in the pipe wall.

6. Conclusions

PEC is an effective and versatile method of wall thickness monitoring for quick and precise corrosion rate monitoring. It is highly robust and can be applied at high temperatures. The combined use of ultrasound and PEC on the air coolers outlet piping provided the refinery with fast, consistent and reliable wall thickness and corrosion rate information that enabled key decisions to be made and the run-time of the HCU to be extended while replacement materials were ordered and the shutdown was prepared. A post mortem has shown that if the plant had relied exclusively on existing ultrasonic thickness measurements it would have resulted in an overly conservative early, unplanned shutdown of the HCU. The approach saved the unit considerable downtime and expense because proper preparations could be made for an extra but planned shutdown.

References

[1] P.W. van Andel, “Eddy Current Inspection Technique”, US patent nr 6,291,992 (September 2001)
[2] P.C.N. Crouzen, “Method for inspecting an object of electrically conducting material, US patent nr 6,570,379 (May 2003)
[3] Chapter 9, Corrosion Control in the Refining Industry, NACE International, 1999