New Techniques for the Quantification of Defects Through Pulsed Magnetic Flux Leakage

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Abstract

Although the probability of defect detection using magnetic flux leakage (MFL) inspection is sufficient for most applications for which it is used; inspection of ferromagnetic pipeline, wire rope, etc., accurate defect characterisation is problematic. The use of pulsed excitation in conjunction with MFL provides an opportunity for the extraction of depth information from the MFL signal using analysis of the transient section of the induced signal. This paper explores the use of pulsed magnetic flux leakage (PMFL) for the detection and quantification of defects in rolled steel water pipeline. For the newly developed PMFL system described in this paper, the time-frequency analysis employed in previous work is extended to look at shape features such as skewness. The paper concludes that PMFL can provide enhanced defect characterisation capabilities for flux leakage based inspection systems and could form the foundation of a fully automated defect characterisation system for pipeline inspection.

Keywords: Magnetic Flux Leakage, MFL, Pulsed Excitation, Pipeline inspection, Non-destructive testing, NDT, NDE.

1. Introduction

Magnetic flux leakage (MFL) has been used for decades to detect and characterise defects in ferromagnetic pipelines [2] and other structures such as wire ropes in suspension bridges [3] rail track [4] and pressure vessels. MFL provides a quick and easy way to detect defects in ferromagnetic materials, but determination of defect geometry purely from flux leakage data is problematic [1], accuracy is poor and in many situations MFL is used to identify possible defects and another technique is used for characterisation. Defect geometry estimation errors are compounded where defects are present on both the surface under inspection and the opposite surface, as large defects on the opposite surface are virtually indistinguishable from smaller defects on the surface under inspection.

The addition of pulsed excitation to MFL in the pulsed magnetic flux leakage (PMFL) [5 - 7] technique introduces an additional parameter which can be utilised for defect characterisation; analysis of the transient section of the measured leakage signal. Previous work has shown that time/frequency analysis of the PMFL rising edge can provide additional defect depth information while retaining the defect detection capabilities of traditional MFL.

The theoretical background to the PMFL technique and the use of pulsed excitation is given in section 2; section 3 introduces the experimental system, samples and test procedures; section 4 investigates feature extraction for the determination of defect depth and discrimination between internal and external pipe wall defects and conclusions are given in section 5.

2. Theory

The penetration depth of a magnetic field in a material is governed by the skin effect. The skin depth or penetration depth (δ) is defined as the distance at which the wave amplitude decreases by a factor of e^{-1} (~37%). The skin depth in a conductive material is given by:

$$\delta = \frac{1}{\sqrt{f\pi\mu\sigma}} \tag{1}$$

where f is the frequency of the periodic EM wave in Hz, μ is magnetic permeability (H/m) and σ is electrical conductivity. It can be seen from Eq. (1) that δ decreases as f increases, so the skin depth reduces as the frequency of the applied wave increases.

Pulsed excitation is achieved by the application of a step current to an electromagnet, usually in the form of a periodic square wave. In a real world system, this step input is not a sharp transition; rather it is made up of an initial sharp increase followed by a gradual decrease in the rate of change, followed by a period at the maximum signal level. The applied magnetic field therefore has different frequency components at different times in the excitation cycle, corresponding to a variation in the penetration depth of the applied field at different points in the excitation cycle. In PMFL, this relationship is used to draw conclusions about the defect under inspection, through the interaction between the penetration depth of the applied field at different times in the excitation cycle and defect depth.

3. Experimental Probe, Procedures and Samples

The PMFL probe (figure 1a) incorporates eight Hall Effect sensors arranged around the circumference of the pipe with the axis of sensitivity in line with the applied field and parallel to the pipe wall. The PMFL probe features a constant current source which is switched between zero and maximum at a rate of 0.5Hz creating a unipolar excitation pulse. In these tests the tool's axial position is incremented in 2mm steps and two pulse repetitions are acquired in each position. All tests are carried out by scanning the external pipe wall.

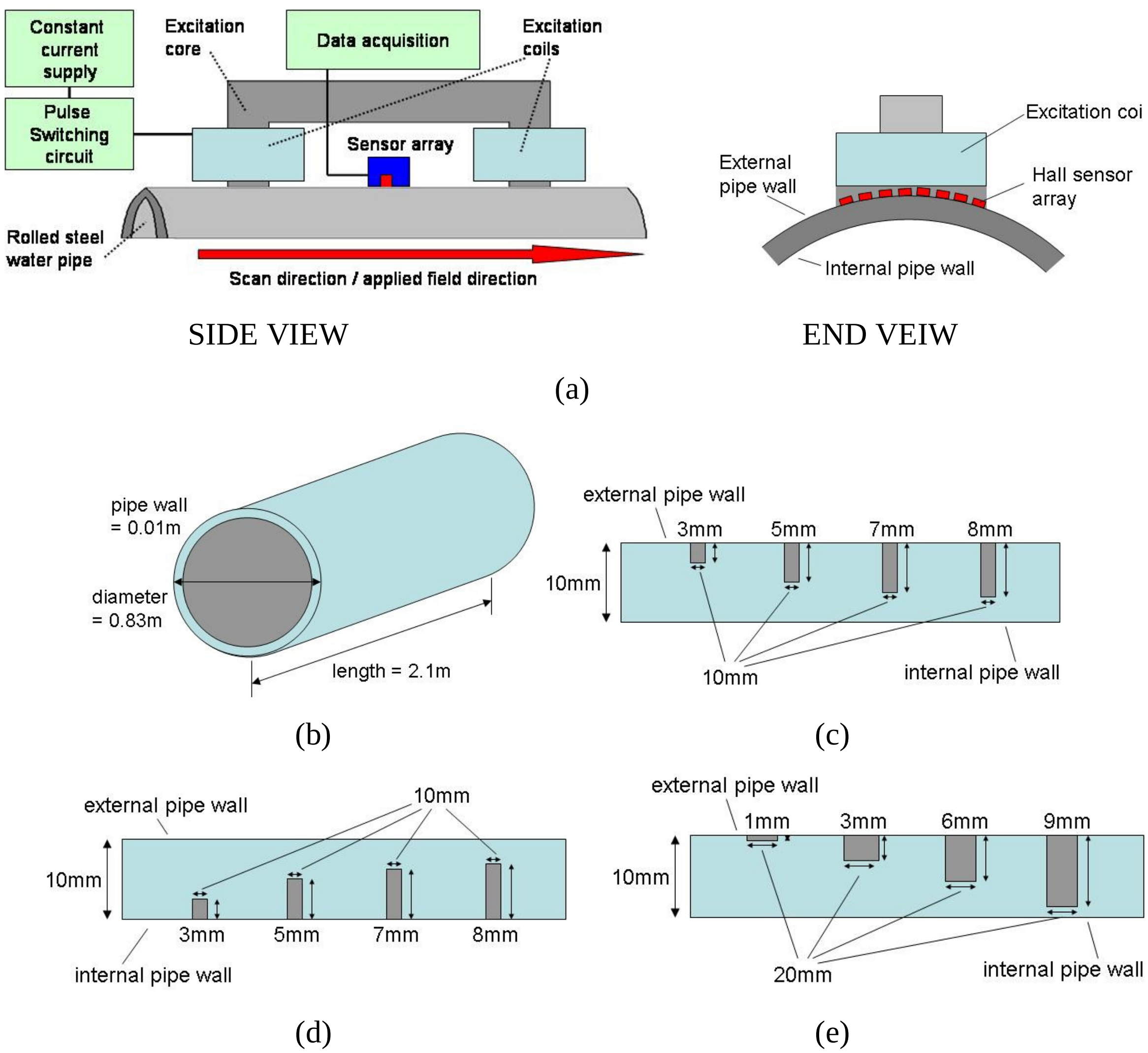

Figure 1: a) Test system, b) Test sample, c) External defect set 1, d) Internal defect set 1, e) External defect set 2

A section of rolled steel water pipeline with an external diameter of 0.83m and a wall thickness of 10mm was used for the tests (figure 1b). The section of pipeline has several sets of cylindrical defects machined into it on both the outer pipe wall (external defects) and the inner pipe wall (internal defects). Three sets of defects are used in the tests: External defect set 1 (figure 1c): diameter = 10mm, depths = 3mm, 5mm, 7mm and 8mm; Internal defect set 1 (figure 2d): diameter = 10mm, depths = 3mm, 5mm, 7mm and 8mm; External defect set 2 (figure 2e): diameter = 20mm, depths = 1mm, 3mm, 6mm and 9mm. All defects are sited well away from the ends of the sample and there is a minimum of 100mm separation between defects.

4. Defect characterisation

Figure 2a shows the overall amplitude change for 10mm diameter internal defects, 10mm diameter external defects and 20mm diameter external defects. It can be seen from the plots that the presence of either internal or external defects causes a monotonic increase in signal amplitude, with the internal and external defects causing a similar change in amplitude for the same change in defect depth, but with an overall lower field level for the internal defects. It is apparent from the plot that the increase in external defect diameter from 10mm to 20mm has very little effect on the field amplitude, given defects with equivalent depths. It is also apparent from the plot that without further information the change in the leakage field due to a shallow external defect and a deeper internal defect cannot be discriminated.

Figures 2b and 2c illustrate the change in pulse shape as the inspection tool approaches a defect. The plots show normalised pulses from a single sensor approaching 8mm external (figure 2b) and 8mm internal (figure 2c) defects. It can be seen from the plots that as the defect is approached, the rising edge of the pulse is distorted, with a large change in signal shape between 0.2 and 0.8 seconds. This modification of the signal rising edge is quantified using a skewness calculation, the result of which is shown in figure 2d. It can be seen from the plot that although the skewness calculation does not have a monotonic relationship with defect depth, unlike amplitude measurement, it does allow discrimination between internal and external defects.

Figure 2e shows a plot of the signal features chosen to quantify defects in the PMFL system. It can be seen from the plot that the three defect sets can be clearly discriminated, with external defects exhibiting lower overall skewness than the internal defects. As the defects shown in this plot represent internal defects from 30% to 80% wall thickness and external defects from 10% to 90% wall thickness, it is unlikely that internal and external defects could be confused using this system. The peak to peak amplitude measurements exhibit a monotonic relationship with defect depth and once the internal/external status of the defect is known, peak to peak amplitude can be calibrated to determine defect depth.

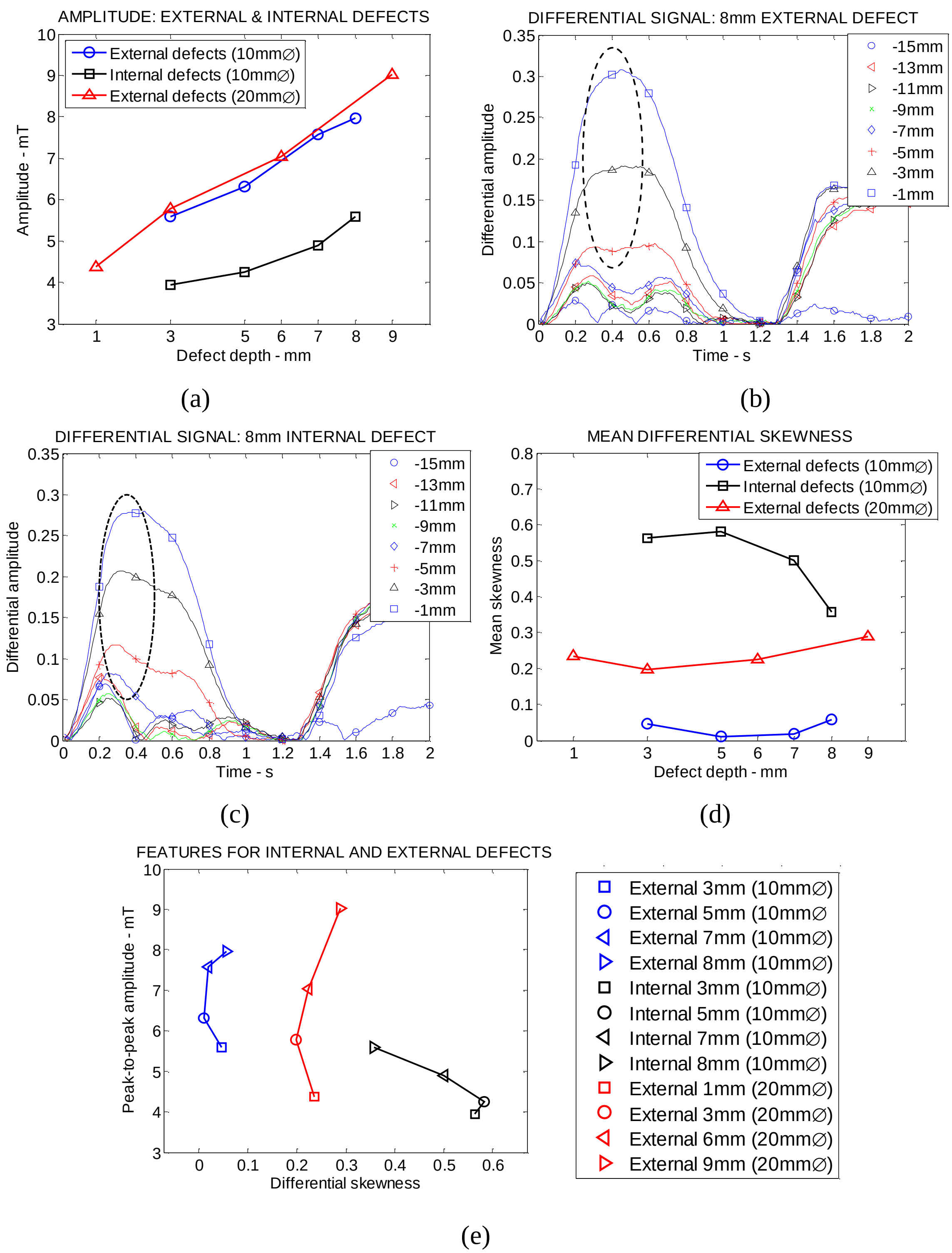

Figure 2: a) Overall amplitude for all defects, b) Change in differential signal approaching 8mm external defect, c) Change in differential signal approaching 8mm internal defect, d) Mean differential skewness for all defects, e) Amplitude against differential skewness for all defects

4. Conclusions

This paper has identified PMFL signal features which can be used to discriminate internal and external defects and provide geometrical information for defects in rolled steel water pipeline. A combination of peak to peak amplitude measurement and statistical analysis of a differential signal computed by subtracting a reference signal taken on a defect free section of the pipeline from a defect signal were chosen as suitable features to classify PMFL defects. Three defects sets have been tested; 10mm diameter external defects, 10mm diameter internal defects and 20mm diameter external defects and the chosen features have proven successful in discriminating between these defect sets.

The work shows that PMFL provides defect detection capabilities which are equivalent to traditional MFL, while providing additional signal features for determination of defect geometry and discrimination between internal and external defects, which is a difficult task using traditional MFL. Future work will be geared towards further development of feature integration techniques for the determination of defect geometry and the production of a signal analysis model which can output defect geometry without prior knowledge of the defects present.

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