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The Effects of Defect Depth and Bending Stress on Magnetic Flux Leakage Signals

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Abstract

The corrosion defects of buried oil and gas pipelines are usually detected by magnetic flux leakage (MFL) measurements. The MFL signals are sensitive to the depth of defects and to the external stresses generated mainly by the line pressure. MFL signal variations have been studied from the inside wall in the presence of various circumferential bending stresses and magnetic flux densities for three outside wall pits of depths 30%, 50% and 80% of the wall thickness. MFL signal is found to increase with defect depth. External bending stress also changes the MFL signal by more than 40%.

1. Introduction

In many of the non-destructive techniques used for materials evaluation, such as magnetic particle, eddy current and magnetographic methods, surface and sub-surface flaws in the metals are detected by measuring the leakage fields developed as a result of the interaction of an excitation electromagnetic/magnetic field with the flaw. In the presence of a pit in a magnetized ferromagnetic material, some of the magnetic flux lines leave the material to avoid the void. This causes an increase in magnetic flux density outside the material in the immediate neighborhood of the pit. This leakage field, usually measured by using a Hall probe or an induction coil, allows an estimation of the pit size. This method is called the magnetic-flux-leakage (MFL) measurement technique and is used for in-line oil and gas pipeline inspection [1,2].

The awkward boundary geometries and material characteristics hampered early progress in the detailed theory of MFL defect signals [3-5]. More recently, finite-element methods have been used to generate MFL signals from variously shaped defects [6,7] but these still failed to predict the full details of the MFL measured. Therefore, in the absence of adequate calculations, experimental measurements are the best help for understanding and using MFL signals obtained in the field. The leakage flux is affected by the depth and shape of the defect [2,8], the magnetization of the pipe wall, the stress developed by the line pressure and so on [2,8,9]. The velocity of the inspection tool also changes the measured MFL signals due to eddy-current effects [10]. Therefore, when estimating the size of defect from MFL signals, all these effects should be incorporated.

Several kinds of defects, such as corrosion pits, are developed on the outside surface of buried oil and gas pipelines. MFL signals are measured from the inside by pumping an inspection tool through the in-service lines. It has been observed previously that circumferential hoop stress can change the MFL signals by more than 40% [9]. This is due to the changes in permeability, coercivity and other magnetic properties of the pipe-wall steel caused by stress. It was also observed that the leakage signal increases with the increase in pipe-wall flux density and that the influence of stress on MFL signals diminishes as the pipe-wall magnetization approaches its saturation value [9]. In the present work, MFL signals have been studied for exterior pits of various depths by measuring the leakage field at the inside surface in the presence of various circumferential bending stresses and pipe-wall flux densities. It has been observed that the flux-leakage signal decreases with increasing bending stress and increases with defect depth. In all existing theories on flux-leakage problems [3,4], the expression for the leakage field is derived for the same side of the wall as that in which the pits are present. So no attempt has been made to fit these expressions with the present experimental data because our results were measured on the far-side pipe wall relative to the pits.

2. Experimental details

A schematic diagram of the MFL measurement apparatus is shown in Fig.1. It consists of a semicircular sample pipe section with a bending stress arrangement. The pipe section is 610 mm long with 9 mm wall thickness and is made of API X70 grade steel with 1.46% Mn, 0.12% C and 0.003% S by weight. The bending stress apparatus allowed one end of the semicircular pipe section to be moved inwards or outwards while the other end is held fixed. When the movable end was displaced inwards, tensile stress was developed on the outside surface and compressive stress, on the inside surface. The tensile stress on the outside surface could be varied in the range 0-350 MPa and was measured by strain gauges on several regions of the surface.

The pipe wall was magnetized in the axial direction by a magnetizer incorporating several high-strength Nd-Fe-B permanent magnets. The strength of the magnetizer could be changed by varying the number of permanent magnets in each pole arm and by changing the cross sectional area of the back iron in the magnetizer. The leakage flux was measured by using a Hall probe over a 40 mm x 40 mm area of the inner surface centred on a 14 mm diameter electrochemically milled circular pit on the outside surface. The signal from the Hall probe was amplified and received by a PC data-acquisition system. The axial, radial and circumferential components of this leakage field could be measured

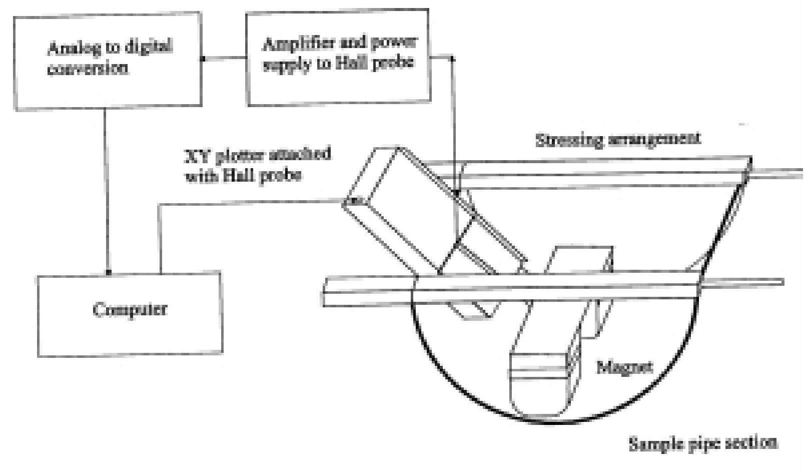

Fig.1: The experimental set-up for measuring MFL signals in the presence of various bending stresses

by adjusting the Hall probe to the corresponding orientation. The magnetization of the pipe wall was measured by integrating the induced voltage in a pick-up coil, wound through the wall, corresponding to the change in wall magnetization caused by a 180° rotation of the magnetizer. Three circular pits of diameter 14 mm and depths 30%, 50% and 80% of the wall thickness (9 mm) were created on the outside wall of the pipe section by electrochemical milling. These simulated corrosion pits and were free of any residual stress around the defect, which might have been developed had we used mechanical drilling.