Capabilities of MFL Inspection in DUPLEX Steel Pipelines

Hendrik Aue and Werner Thale
ROSEN Technology and Research Center Germany
Am Seitenkanal 8, 49811 Lingen, Germany

Age E. Pedersen and Samuel Moe
TOTAL E & P Norge
Stavanger, Norway

Abstract
DUPLEX stainless steel is commonly used for offshore pipeline applications. DUPLEX combines the advantages of ferritic and austenitic steel: corrosion resistance, high strength and toughness; therefore making it ideal for use on riser sections exposed to wave loads and bending. DUPLEX pipe is relatively expensive and usually only used for the riser, whereas the rest of the pipeline consists of conventional carbon steel. This mixture of pipeline materials combined with the special magnetic properties of DUPLEX create a challenging environment for inline inspection tools utilizing Magnetic Flux Leakage (MFL) technology.

ROSEN inspected a TOTAL pipeline with a DUPLEX riser in 2008, and then came together in 2009 to investigate the results of the MFL inspection. This paper is discussing the results of this investigation based on pull tests in a 12” DUPLEX test pipe with artificial metal loss features.

1. Introduction
ROSEN inspected a TOTAL pipeline using an inline inspection Corrosion Detection tool. The riser close to the end of the line is made of DUPLEX steel, which has significantly different magnetic properties than the rest of the line. To get a better understanding of the magnetic properties of the DUPLEX pipe material, and to allow an adequate identification and sizing of the detected features, it was decided that pull tests would be necessary using DUPLEX pipe joints from TOTAL to analyze DUPLEX steel samples gathered from the test joints.

ROSEN, together with TOTAL, performed a series of pull tests in 2009 using the 12” Corrosion Detection tool (CDP). This paper will discuss the capabilities of MFL in-line inspection (ILI) in DUPLEX steel, as well as the results from the pull tests, and a detailed analysis of DUPLEX material samples.
2. **DUPLEX Pipeline Applications**

DUPLEX steel combines the advantages of ferritic and austenitic steel: extreme strength, resistance against stress corrosion cracking and degrading corrosion; making it especially suitable to resist the extreme forces found on platform riser sections (see Figure 1).

![Exemplary Offshore pipeline riser](http://www.total.com)

DUPLEX steel is useful for offshore platforms in terms of line pipe and other process applications. The amplified strength of DUPLEX steel allows for reduced wall thickness and reduced weight. DUPLEX is also used for onshore applications, for example in pipelines where high erosion rates are present. Carbon steel elbow installations have been replaced by DUPLEX material in high flow velocity gas pipelines with erosion due to solid particles. In addition, it is used for other pipeline installations like valves and T-pieces. Furthermore, this steel is useful for pipelines in cold regions because it also retains its strength in low ambient temperatures, for example down to -40°C. Relatively long DUPLEX pipeline sections can be found in Alaska; however, due to the expense, DUPLEX is usually only used for special pipeline applications, as above mentioned.

3. **DUPLEX Material**

DUPLEX steels are called “DUPLEX” because they have a mixed two-phase microstructure of grains of austenitic and ferritic steels (see Figure 2), each having a content of about 50%. This is why DUPLEX steel combines the advantages of ferritic

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3 Source: http://www.total.com

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and austenitic steels as corrosion, erosion and stress corrosion cracking (SCC) resistance as well as amplified strength and toughness.

![Austenite and Ferrite](image)

Figure 2: DUPLEX steel sample under a microscope, showing the two-phase microstructure of austenite (light blue) and ferrite (dark blue) grains

Although DUPLEX steel has a higher tolerance, it is still susceptible to metal loss due to corrosion, erosion, milling features or third party damage.

Austenitic steels are non-magnetic while ferritic steels are ferromagnetic. DUPLEX as a mixture of both is somewhere “in between,” depending on several factors (like the chemical composition). The investigation described in this paper shows the magnetic properties of DUPLEX and, as a result, the capabilities of MFL inspection in DUPLEX pipelines.

4. DUPLEX Sample Analysis
Four samples were taken from two DUPLEX pipe joints received from TOTAL (14.0 and 16.7 mm wall thickness, cut out in axial and circumferential pipe direction) and sent to an external institute for analysis purposes. The B-H curves (showing magnetic material properties, see Figure 3) have been measured and prepared for input into the Finite Element Method (FEM) software. The investigations on the B-H curves of the DUPLEX steel have shown significant differences in the magnetization compared to carbon steel material.

Figure 3 shows the results of the measurements and compares them with the carbon steel B-H curve. The graph illustrates that the saturation flux density is about three times smaller than that of carbon steel.

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2 DUPLEX microstructure example, prepared by ROSEN

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Figure 3: B-H curve comparison between DUPLEX steel and carbon steel

For the permeability the effects are even greater, see Figure 4 for illustration. A factor of more than 10 in maximum can be observed between the DUPLEX steel and carbon steel. Additionally, the saturation state is completely different. Here the permeability is much smaller, so that the magnetic flux cannot be conducted by the pipeline, as is the case with carbon steel.
Figure 4: Permeability comparison between DUPLEX steel and carbon steel

Figure 5 shows a TOTAL investigation which is visualizing the permeability as a function of the ferrite content. The permeability is increasing with increasing ferrite content.

Figure 5: Permeability as a function of the Ferrite Content

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5. **FEM Calculation**

FEM Calculations have been conducted simulating the MFL in-line inspection tool in the pipeline (Figure 6). The model is reflecting the identical situation of the later discussed pull-test. Using the information from the measured BH curves, the magnetic field generated by the ILI tool in the pipe wall, was calculated. The resulting magnetic field strength can be plotted as a function of the wall thickness of the pipe (Figure 7).

As input for the FEM calculation an average B-H curve extracted from the individual Duplex steel samples (see Figure 3) has been used. As a result of this Figure 7 shows the comparison of the magnetic field strengths of the DUPLEX pipe to those of the carbon steel ones.

![FEM-Model of the DUPLEX pipe including the magnet circuit of the inspection tool](image)

**Figure 6: FEM-Model of the DUPLEX pipe including the magnet circuit of the inspection tool**

Compared to carbon steel, the field strengths of DUPLEX steel are much higher with the same magnet circuit. For the magnet circuit of the inspection tool used for the below mentioned pull tests, field strengths higher than 40 kA/m are calculated at the specified wall thickness range in standard carbon steel.

For the simulations of defects in the DUPLEX pipeline a full model of the magnet circuit of the inspection tool is needed. This can be seen in Figure 6 where the meshed model is shown, including yoke, magnet-package, brush and pipeline. The colors represent the
strength of the magnetic flux density. Blue colors indicate low flux density values whereas red tones mark strong flux densities.

Exemplary FEM calculations determine feature amplitudes of the same magnitude and with comparable behavior (amplitude versus depth etc.) for simulated defects in DUPLEX as in standard steel, which indicates that a comparable sizing procedure can be applied for both DUPLEX and standard pipeline steel. Figure 8 shows the FEM calculation results for a 20% deep and 10 mm diameter internal defect³.

³ signal amplitude corrected by the background magnetization level
6. **Pull Test Investigation**

A pull test series was performed by ROSEN and TOTAL at the ROSEN Technology and Research Center in Lingen, Germany, in 2009 using a 12” Corrosion Detection tool (CDP). Two DUPLEX joints (14.0 mm and 16.7 mm wall thickness) welded together were provided by TOTAL.

A set of artificial features was prepared in the pipe body to investigate the detection and sizing capabilities of DUPLEX pipe with the CDP. Additional test features were prepared at and next to the girth weld. All test features were prepared with electric discharge machining (EDM). The figures below shows the (cylindric and rectangular) EDM features.
Figure 9: cylindric flat bottomed EDM feature in 12 inch DUPLEX pipe (red box)

Figure 10: cylindric (through wall) and rectangular EDM features at girth weld (red boxes)
Figure 11 shows that all features are visible in the MFL data: even the smallest external feature with 10mm diameter and 30% depth is clearly visible.

The calculated behavior of magnetic field strength versus wall thickness based on the measured magnetic properties of the DUPLEX test segment (with FEM) is confirmed by the pull test results. Figure 12 shows the measured magnetization levels of the two DUPLEX joints compared to the magnetization curve of the 12 inch pull test joints of the ROSEN pull test rig.
The first important result is that the CDP is not only capable of detecting external metal loss features, but also that the MFL amplitudes of the external test features are comparable with the corresponding test features in standard steel pipe (e.g. API 5L grade X52). Figure 13 shows the signal amplitudes of the external test features in the DUPLEX test joints with 14.0 mm compared to the corresponding features in the carbon steel pull test joint with comparable wall thickness.
Whereas external features show a similar behavior, MFL amplitudes of internal features differ strongly from corresponding features in carbon steel, especially shallow internal features have much higher amplitudes in DUPLEX than in standard pipe steel.

From the above mentioned it follows that a special sizing model has to be used for the inspection of DUPLEX and that some minor restrictions have to be considered, for example a restricted detection probability for shallow external features and a restricted sizing accuracy, especially for internal features.

Apart from the smallest internal feature, all internal features show clear signals on the internal / external discrimination channels; therefore, it is estimated that the internal / external discrimination in DUPLEX is comparable, or only slightly restricted, compared to standard pipeline steel.

The DUPLEX test segment consists of two test joints welded together with an intentionally defective girth weld. At girth welds (of standard steel pipelines) the magnetization is usually lower than at the pipe body, due to the extra metal at the cap and the root. At the DUPLEX girth welds it is observed that the magnetization is higher than at the pipe body. This is probably due to fact that the magnetic properties of the girth weld materials differ distinctly from the pipe body.

TOTAL prepared three girth weld anomalies: lack of fusion, lack of penetration, and excessive root penetration, each extending over ca. one third of the circumference.

Figure 13: Comparison of feature amplitude vs. depth characteristic
Figure 14: Girth weld of DUPLEX test segment with intentionally prepared girth weld anomalies and additional artificial test features.

The few artificial test features machined at the girth weld (see Figure 10) are not suitable for assessing the sizing accuracy of the welding areas, the more so as they are superimposed with the intentionally prepared “natural” girth weld anomalies (lack of fusion and lack of penetration). Nevertheless, these features are visible in the data (see Figure 14), but it must be emphasized that the detection capabilities are restricted, a sizing accuracy cannot be specified.

In addition to the girth welds, extra metal have been detected in the pull test data of the duplex joints. This means that not only metal loss features, but also references like extra metal, valves or tees can be reported for DUPLEX pipelines.

7. Conclusion
DUPLEX steel known as a useful material to protect pipelines against, for example, stress corrosion cracking, revealed magnetic properties which allow for an inspection with a high resolution MFL in-line inspection tool. The pull tests showed that metal loss feature detection and sizing is possible with ROSEN Corrosion Detection tools.
With help of the pull test results, a special calibration for MFL feature sizing was generated. The CDP is not only capable of detecting external metal loss features, but also the MFL signal amplitudes of the external test features are comparable with the corresponding test features in standard steel pipe (e.g. API 5L grade X52). The data evaluation showed that the metal loss defect internal/external discrimination in DUPLEX is comparable, or only slightly restricted, to standard pipe line steel.

Deep metal loss features in girth welds, as well as girth weld anomalies like excessive root penetration, severe lack of fusion, or lack of penetration, are visible in the data. Also references like extra metal, valves or tees can be reported for DUPLEX pipelines. Minor MFL detection and sizing restrictions are also discussed in this paper.

8. References
