Inspection of Clad Materials Using Massive Multi-Frequency Excitation and Spectrogram Eddy Current Method

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Abstract. Clad material is manufactured by creating a metallurgically bonded between few metals. The most important advantage of the materials is that the end product combines the superior properties of each component. A tested sample is commonly used for underwater petroleum pipelines. The sample consist of two metals: carbon steel, and Inconel. The aim of this paper is to present a massive multi-frequency excitation and spectrogram eddy current method for detection of surface cracks and dissections in clad materials. The system consists of a small differential eddy current transducer and four subsystems: a scanner, an excitation subsystem, a data acquisition subsystem and a controlling computer. The signal measured during transducer movement can be presented in the form of spectrogram. Properties of the spectrograms can be used for defect’s detection and identification. The experimental verification is done and selected results are presented.

Introduction

Clad material is manufactured by creating a metallurgically bonded between few metals. The most important advantage of the materials is that the end product combines the superior properties of each component [1]. The analysed material is commonly used for underwater petroleum pipelines. It consists of two metals: carbon steel, and Inconel alloy. Such kind of materials can be easily inspected using eddy current method. Eddy current testing is widely used technique for nondestructive evaluation of conducting materials. Sensitivity of the measurements depends on several factors, like dimensions of the transducer, an excitation frequency and properties of tested specimen (permeability, permittivity and conductivity). Enlargement of the probe dimensions will result in a higher sensitivity (for deeply loaded defects) and a lower spatial resolution of the measurements. Unfortunately high sensitivity and high resolution most often may not be achieved at the same time. Especially effective in the presented case is to utilize measuring system based on Massive Multi-Frequency Excitation and Spectrogram Method (MMFES) which was proposed in [2]. Idea of this method is to use a complex signal containing big number of sinusoidal components as an excitation signal and a spectrogram for detection of various kinds of defects. Big variety of the frequency components creates opportunity that all defects can be detected using optimal testing frequency.
2. Measuring system

All measurements were carried out using the Massive Multi-Frequency Excitation and Spectrogram (MMFES) system. In the MMFES system a complex signal containing selected harmonic components is used as an excitation:

\[ y(t) = \sum_{i=1}^{n} U_i \cdot \sin(2\pi f_i t + \varphi_i) \]

A resulting signal obtained from the search coil is measured and presented in a form of spectrogram. The spectrogram (Fig. 1) is a two-dimensional display of the relative amplitude of the frequency components of a signal from the search coil versus the sensor position. The spectrogram amplitude is a difference between the current amplitude and the amplitude measured for the fault free specimen. Selected parameters of the spectrogram like:

- \( S_{\text{MAX}} \) – the maximum value of the spectrogram,
- \( F_{\text{MAX}} \) – the frequency for which the spectrogram achieves the maximum value,
- \( S(f)|_x=X_{\text{MAX}} \) – the frequency characteristic at the point \( x=X_{\text{MAX}} \)

are defined and calculated. These parameters could be successfully utilized [3] in a preliminary evaluation of the flaw parameters (position, depth, width).

Fig. 1. Spectrogram, frequency characteristic and parameters corresponding to the material defect.

A block scheme of the MMFES system is shown in Fig. 2. It consists of an eddy current transducer and four subsystems: a XYZ scanner, an excitation subsystem, a data acquisition subsystem and a controlling computer. The function synthesizer supplies the excitation coil through the power amplifier. The analog signal obtained from the search coil is converted into digital form by the data acquisition subsystem. This subsystem consists of a multiplexer, a computer-controlled amplifier, an anti-alias filter and a high performance A/D converter. The high speed (10 mega samples per second) and excellent dynamic range (24 bits resolution) of the converter are crucial for the performance of the whole system. Signal from the pick-up coil is fed to a control computer, where it is decomposed by the FFT algorithm. The signal received during transducer movement is presented in the form of spectrogram. Additional signal processing algorithms can be applied in order to reduce influence of noises or the trend signals (Fig. 2).
**Fig. 2.** Block scheme of the Massive Multi-Frequency Excitation and Spectrogram (MMFES) system.

Applied eddy current differential transducer [3] consists of a cylindrical ferrite core with five symmetrically placed columns. A pickup coil is wound on the central column and four excitation coils \((E_A, E_B, E_C, E_D)\) are placed on remaining columns in pairs, on two perpendicular axes (Fig. 3). Both pairs generate in the pickup coil opposite directed magnetic fluxes. The resulting flux in the pickup coil is close to zero in equilibrium state. An output signal depends on difference of fluxes \(\phi_x\) and \(\phi_y\). Differential configuration of the transducer enables us to detect minor flaws with high SNR rates.

**Fig. 3.** The schematic view of the EC transducer and simplified electrical scheme.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil (E_A) winding turns</td>
<td>25 turns, (0.14)mm</td>
</tr>
<tr>
<td>Coil (E_B) winding turns</td>
<td>25 turns, (0.14)mm</td>
</tr>
<tr>
<td>Coil (E_C) winding turns</td>
<td>25 turns, (0.14)mm</td>
</tr>
<tr>
<td>Coil (E_D) winding turns</td>
<td>25 turns, (0.14)mm</td>
</tr>
<tr>
<td>Coil (S) winding turns</td>
<td>100 turns, (0.02) mm</td>
</tr>
<tr>
<td>Core made of ferrite with initial permeability</td>
<td>10000 (DC)</td>
</tr>
</tbody>
</table>

\[
U_{out} = -j \omega n (\phi_x - \phi_y)
\]
Dimensions of the transducer are provided in Fig. 4. Additionally, the transducer enables easy detection of the defect’s orientation (Fig. 5). A flaw parallel to one pair of exciting columns (for example columns $A$ and $B$) causes growth of the output signal’s amplitude comparing with the signal’s amplitude from unflawed area. If the flaw is parallel to the second pair of columns ($C$ and $D$), the output signal decreases.

### 2. Results of measurements

The measurements were carried out for the clad material sample with artificial defects (notches), which is shown in Fig. 6.
AC excitation currents $I_x$ and $I_y$ of 70 mA (peak value) are applied to the excitation coils. For this specimen a signal consisting of 20 sinusoidal components having frequencies from 10 kHz to 100 kHz (with increment of 5 kHz) was utilized. This frequency band was optimized to evaluate both: surface defects (1,2,3) and the subsurface defect (4). For this purpose a numerical analysis of the simplified model was carried out. Example of the results achieved during such analysis is shown in Fig. 7.

Normally, when the tested material is uniform, amplitudes of the harmonics of the signal from the pick-up coil should be equal. However, to achieve such situation, the components of the excitation signal must be precisely selected (using iterative algorithm), what is presented in Fig. 8. Plot of the resulting signals is shown in Fig. 9.

![Fig. 7. Example of results of numerical analysis (flux lines and eddy current distribution) obtained for clad structure having different properties of the base material (magnetic permeability - $\mu_S$ and electrical conductivity - $\sigma_S$).](image)

![Fig. 8. The frequency spectrum of the a) signal fed to the exciting coils; b) signal measured on the pick-up coil](image)

![Fig. 9. Signal a) fed to the excitation coils; b) measured on the pick-up coil](image)
The probe was moved using the $X$-$Y$ translation stage over the flaw in steps of 0.25 mm. The $x$-axis was parallel to the flaws longitudinal direction. The probe lift-off (the distance between the probe base and the top surface of the test plate specimen) was measured to be 0.24 mm. The measured signals in the form of spectrograms are shown in Fig. 10. The corresponding frequency characteristics are plotted in Fig. 11.

**Fig. 10.** Spectrograms measured for the surface and internal flaws (notches); width of the notches 0.2 mm, length of the notches 5 mm, depth of the surface notches: 1 – 0.75 mm, 2 – 1.5 mm, 3 – 3 mm, the subsurface notch is located 4 mm below the surface.

**Fig. 11.** Frequency characteristics measured for the surface and internal flaws (notches).
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References