Problem Description

Ship and offshore structures are complex engineering systems that need to be designed, operated and maintained in such a way that they are safe to the public and to the environment. Fatigue cracks are common defects found in these structures due to the cyclic nature of wave loading. As fatigue cracks initiate and grow, the operators are obliged to perform inspections periodically. Detected cracks can have different risk levels as a result of its size, location and consequence in case of brittle failure. Obviously, cracks with an unacceptable risk for safe operation need to be repaired immediately, while cracks with a low risk profile may not require any action at all. The problem at hand lies with the intermediate risk levels for which it is often unknown what action to take. Typically, when a crack is assigned a medium risk level, more frequent inspections are advised, which is very costly. A typical single tank inspection can cost up to 150K Euro and requires the tank to be out of service for 7-10 days. When a crack is assigned a high risk level, repair will be planned. Until the repair is finished, this crack forms a hazard to safe operation.

Objective

Precompetitive research and development of an affordable system for monitoring detected cracks, which will result in less inspections and reduced risk.

Table 1: Relative magnetic permeability of different materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Ferromagnetic</th>
<th>Permeability</th>
<th>Diamagnetic</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platinum</td>
<td>1.00000037</td>
<td>0.99999988</td>
<td>1.00000000</td>
<td>0.99999997</td>
</tr>
<tr>
<td>Aluminum</td>
<td>1.000022</td>
<td>0.99999988</td>
<td>1.00000000</td>
<td>0.99999997</td>
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<tr>
<td>Silver</td>
<td>1.000265</td>
<td>0.99999988</td>
<td>1.00000000</td>
<td>0.99999997</td>
</tr>
<tr>
<td>Copper</td>
<td>0.999992</td>
<td>0.99999988</td>
<td>1.00000000</td>
<td>0.99999997</td>
</tr>
<tr>
<td>Ferrite steel</td>
<td>1.00000000</td>
<td>0.99999988</td>
<td>1.00000000</td>
<td>0.99999997</td>
</tr>
</tbody>
</table>

Theory

The need for monitoring the condition of structures, also referred to as Structural Health Monitoring, has resulted in the development of non-destructive evaluation (NDE) methods for characterizing materials and detecting the presence of defects such as cracks. Magnetic NDE methods are very promising for monitoring cracks as well. These magnetic methods are only applicable to ferromagnetic materials, which have a high relative magnetic permeability. Table 1 gives a few examples of paramagnetic, diamagnetic and ferromagnetic materials and their relative permeability.

One particular magnetic NDE method is called Magnetic Flux Leakage (MFL) testing, see Figure 2. In the vicinity of a crack in a magnetized steel plate, flux is "leaking". This can be measured with a magnetometer, such as a Hall effect sensor, that measures the out-of-plane flux density. CrackGuard does exactly this but with the Earth’s magnetic field as only source. This technique is also referred to as Metal Magnetic Memory (MMM) testing. The possibility of passive monitoring makes this method very attractive for a wireless crack monitoring system because it can be low power and easy to install.

Theory Validation

In order to validate the theory of MMM testing, measurements and numerical simulations were performed on a test plate. This plate is made of Fe E235 steel, is 300x300x5 mm and has a wire cut slit of half the plate’s length and 0.3 mm width that resembles an artificial crack. With a single probe Hall sensor, the out-of-plane flux density was measured along a number of lines perpendicular to the artificial crack and 3 mm above the plate surface, see Figure 4. The Earth’s background field during the measurements had a component perpendicular to the crack of 15T (left to right) and an out-of-plane component of 30T (downwards). The measurements confirm a disturbance of the magnetic field in the vicinity of the crack. The peak-to-peak values increase with increasing distance from the crack tip.

The same test plate was also numerically simulated as an FEM model in Ansys Maxwell, see Figure 5. The results along the same lines are displayed in Figure 6. The peak-to-peak values are much smaller than those that were measured, see Figure 7. This difference can be explained because the numerical model only accounts for the induced magnetization. This has already been demonstrated in a special facility that can create a [near] zero magnetic field.

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