Ship Hull Inspection and NDT using ROV based flux leakage expert system

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Abstract

This paper addresses the evolution of an especially designed subsea Remotely Operated Vehicle (ROV) with dedicated electromagnetic flux leakage searching arm as a part of associated Non Destructive Testing arrangement to inspect the outer surface of large ship hull and floating production storage offloading (FPSO) platforms. Current research achievements apply the expert system techniques in the diagnostic system of subsea exterior underwater hull and components base on the concept of Ampere's law and method of measuring circulating currents without any physical destruction by testing the suspected section of ship hull which is subjected to alternating current flow with selected frequencies.

Keywords: ship hull inspection, ROV based NDT, electromagnetic flux leakage, expert system

1. INTRODUCTION

Corrosion continues to be a point of attention for the owners and operators of almost all steel structures. Periodic or continuous inspection of objects for occurrence of corrosion or monitoring the extent and severity of known corrosion areas should ensure operation of the installation within the safe zone.

Several mechanisms of corrosion are present in the outer surface of large ships hull and FPSO platforms, Worsen by the abnormal static operation regime of the vessel and other causes.Port & Maritime Organization (PMO), Offshore Mechatoronic Information Technology Co. and Faculty of ICT (Ministry of ICT) jointly developed the Non Destructive Testing Remotely Operated Vehicle (NDT-ROV) under funding from PMO.

The objective of the project was to design a small and low-cost vehicle capable of precision maneuvering in very shallow water environments, with a focus on ship hull inspection for corrosion and mechanical problems in such structures, worsen by the abnormal static operation regime of the vessel and other causes. This situation requires a detailed program of inspection, using several non destructive detection (NDT) and testing techniques.

Reduction of the human experts involvement in the diagnosis process has gradually taken place upon the recent developments in the modern artificial intelligence (AI) tools. Artificial neural networks (ANNs), fuzzy and adaptive fuzzy systems, and expert systems are good candidates for the automation of the diagnostic procedures and e-maintenance application [6, 9]. The present work surveys the principles and criteria of the diagnosis process and introduces these achievements to an expert system technique. In this paper a new sensor design is discussed and experimental results are presented for an expert system application, based on the concept of

Ampere's law and method of measuring alternating circulating currents without disturbing their paths for suspected part of subsurface area of ship hull. A transducer using the principle of a toroidal search coil has been tried and considered to be suitable for measuring any probable damage due to irregular phenomenal of corrosion and mechanical damages on the suspected superficial portion of the ship's hull or FPSO platforms. Such transducers are proposed to be the basis for condition monitoring of steel structures by means of analyzing the change of e.m.f induced by primary winding of the testing probe (Fig.1).

Fig.1 The proposed ROV and diagnostic arm

2. ROV's and underwater inspection technologies

According to Canadian Shipping Act (2004), Japanese Ship Safety Law (2004), and US Coast Guard (2004), at least once every three years, the Marine Facilities Division shall carry an examination of each marine terminal to determine whether the structural integrity of the terminal, the oil transfer operations system and the safety equipment are designed and being maintained in a safe working condition. This law and regulation are to ensure that the seaworthiness of vessels and to protect lives. The objective of the inspection is not only to document and assess the criticality of deficiencies, but also to enhance reliability, safety and structural integrity of the terminal and its operation. The inspection is to be carried out by a qualified technician with adequate knowledge of hull structure inspection under the surveillance of a surveyor.

The surveyor shall be satisfied with the method of live pictorial representation and the method of positioning of the technician on the structure. Underwater hull inspection involves the examination of the exterior underwater hull and components to determine the condition and needs for maintenance, repair and routine inspection. Underwater hull inspection can only be done by a qualified divers or an ROV. The inspection report must includes, general examination of the underwater hull plating, detailed examination of all hull welds, propellers, tail shafts, rudders, hull appurtenances, thickness gauging results, bearing clearances, a copy of the audio and video recordings, sea chests condition, and remove and inspect all sea valves. The Marine Inspector will evaluate the hull examination report and grant a credit hull exam if satisfied with the condition of the vessel. If approved the ship owner may receive a credit hull exam up to 36 months (with divers) and 60 months (with ROV) (US Coast Guard, 2004).

General Techniques used for ship hull

Underwater inspections method can be classified generally into four types;

CCTV, photographic, Non-destructive test (NDT) and diver physical inspection. An underwater inspection is not just to record the video and save the data; it is an activity where the inspector probes and searches for signs, which may lead to future problems or any other possible damage and threat. In order to save the cost and minimize the loss time while **performing ship** hull inspection, ROV used as alternative. According to Lynn (2000), the ROV-based hull surveys can collect all the necessary information within a short period of time on the hull systems and allowing the US Navy to refine their work packages far ahead of the dry-docking. The US Navy spends about $300M/year to dry-dock ships, of which $80M is for paint removal and replacement. However this procedure required a supervision of expertise. The NDT service providers have worked out several diagnostic techniques suiting to individual requirements [1]. Some of these are listed as below:

- Condition monitoring based on video observations
- Leaser detection and monitoring
- Ultrasonic fault and health monitoring device
- Electromagnetic flux leakage (EMFL)diagnostic
- Eddy current/Full saturation eddy current…
- Radiography (X-Ray…)

3. Expert system description

The information already gathered for a healthy section of ship hull stored in a data base which can be used by expert system shell. The test personnel interact with the system through a user interface which uses menus and style of interaction. An inference engine is used to reason with both the expert knowledge (extracted from our experienced expert) and data specific to the problem solving. The expert knowledge is in the form of a set of IF-THEN rules. The case specific data includes both data provided by ROV's test personnel (user) and partial conclusions (along with certainty measures) based on this data [4, 6, and 9]. The explanation subsystem, which allows the program to explain its reasoning to the test personnel beside knowledge base editor help the expert or knowledge engineer to easily update and cheek the knowledge base as shown in the Fig. 2.

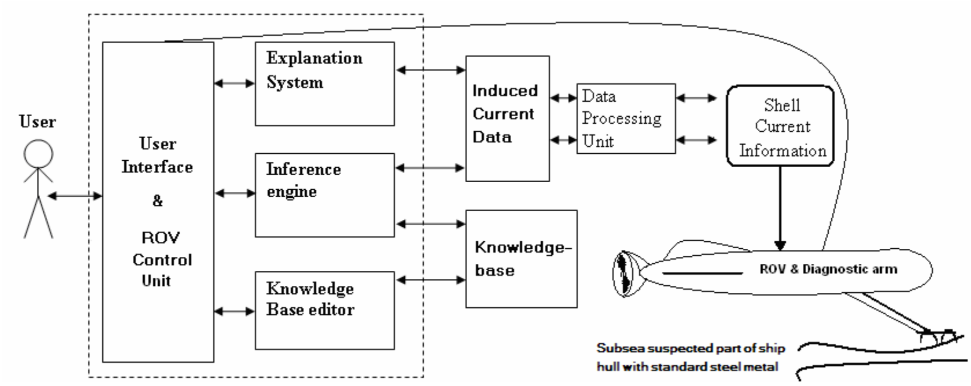

Fig.2 The most important modules of proposed rule-based diagnostic expert system

4. Study of problem

The alternating flux generated by semicircular active part of designed sensor is affecting the suspected portion of the ship hull. In the proposed method asymmetries in the magnetic circuit of damaged section of ship hull are due to corrosion effect on the reluctance path of steel structure. Such asymmetry are inevitable after a high mechanical impact load , stress or corrosion on the surface of subsea ship hull and changes the permeability of the tested section. Saturation of the steel hull plate also introduces high order harmonics in the search coil. The important components of induced currents are fundamental, the third and the fifth harmonic, corresponding to the most dominant components in the magnetic field.

The predominance of one component or the other will depend on both the type of the asymmetry and defect of the selected part of hull, which is related to the type of engineering information to be generated with respect to the structure of the ship hull, for the knowledge base which contributes data with the proposed expert system shell through interface engine and knowledge base editor. The two half circle transducers attached on the suspected part of the under surveillance and induced current variation is recorded with respect to healthy portion of the ship hull.

5. Principle of EMFL contact less NDT of undersea ship hull inspection

In Proposed technique the current value depends on the way the measuring instrument is connected, i.e. the way the connecting leads are laid out. Since it has been seen that in circulating current circuits, the current is the only uniquely defined quantity, its measurement needs grater care than similar measurements in an externally forced current circuit [3, 9]. Whilst the induced emf in the closed contour of the circulating current circuit is a unique value.

$$e = -N\, d\Theta/dt,$$

If the current starts flowing in it, the potential drop between any two points on it is no longer a single-value function. A split type, uniformly wound, flat induction coil with equal cross-section all along the turns, is used for contact less induced hull plate current measurement, Fig.3. Such an arrangement facilitates the determination of the enclosed current. If the coil is arranged as a closed loop around a conductor, then the line integral corresponds to the induced metal sheet current in the enclosed section of hull plate. Such a coil must have an inner diameter just more than the diameter at the mounting location. Depending on the type of the coil, it can cover a wide range of induced currents from a few milliamperes to a few tens of milliamperes over a wide frequency range, with the help of FFT analyzer. It is well known that the current flowing in a conductor gives rise to the flux around, Fig. 3, illustrating the principle of ampere's law. Mathematically, Ampere's law is expressed as:

$$\oint H.ds = I \text{ enclosed}$$

For a circular path C, around suspected part of the ship hull carrying an induced current. Integrating over the circular contour ,C,

$$B = \mu I / 2\pi r$$

Flux linkage for a toroid of axial length L meter and N turns, of the dimensions as shown in Fig. 3, we have

$$N\Phi = (\mu I L N / 2\pi) [\ln (r_2/r_1)]$$

Voltage induced across the toroidal coil of axial length L meters and N turns, and then induced current,

$$i = I_{max} \sin \omega t,$$

$$e_{rms} = \mu L N f [\ln(r_2/r_1)] T_{rms}$$

The above expression is used for designing toroidal search coil used for measurement of current in the suspected part of the Ship hull.

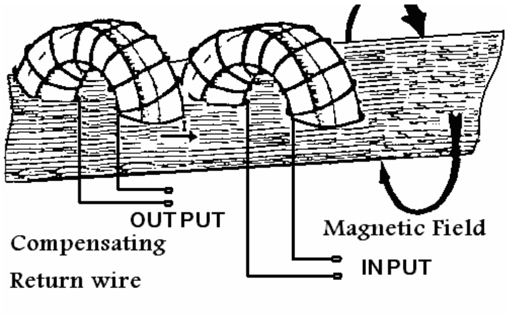

Fig. 3 Current Measurement Principle in the suspected part of subsea ship hull

6. TYPICAL TEST RESULTS

For construction of knowledge base and serving expert system shell, measurement of current in the suspected part of ship hull, incorporated through data processing unit and induced current data modules. Fabrication, calibration of split toroidal search coil and mounting on the suspected part, resulted to obtain the following induced values on a test ship hull.

Test results in suspected portion (Which already subjected to mechanical impact load or corrosion) indicate that the third harmonic component is predominant. Variation in the structure and condition of the ship hull will be reflected in the data processing unit and knowledge base module of expert system for proper decision making. Typical induced ship hull current values are recorded as shown in Fig. 4. for a subsea ship hull. Fig. 5 shows several typical discontinuities and how their corresponding signals may appear on a test screen monitor. Fig.6 shows the nature of the change can be analyzed and diagnosis made according to the fault and used for construction of knowledge base module.

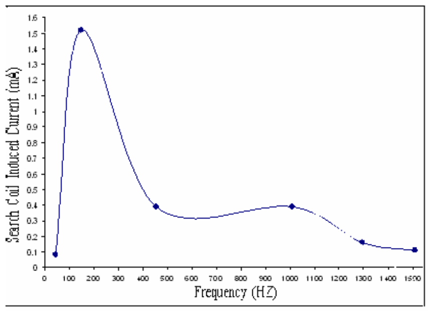

Fig.4 A typical variation of transducer signal for ship hull current measurement

Fig.5 Signal From search coil to data processing unit

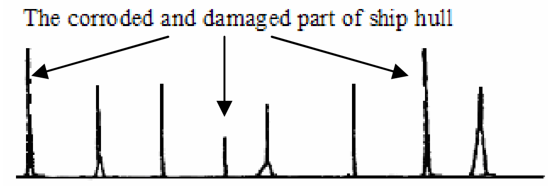

Fig.6 Samples Data for Knowledge Base Module

7. CONCLUSIONS

It is apparent that in the proposed method the perfect subsea ship hull should not produce induced voltage more or less than normal value. This is never the case, for it is impossible to eliminate all asymmetries in the materials and geometry of the steel hull plates in the ship hull. To extract knowledge from the expert the knowledge engineer must become familiar with problem of electromagnetic flux leakage and induced current. The rule base system is goal driven using back ward chaining strategy to test the collected induced current information is true. The case specific data plus the above information with the help of explanation subsystem, allows the program to explain its reasoning to the user and will provide the expert system shell requirements. Significant difference can exist between the signals created by ship hull defects. Alternating induced current in subsea ship hull can be measured conveniently and with reasonable accuracy using toroidal coil located by an ROV and proposed diagnostic arm. This device serves as a base for development of expert system monitoring module. The change of reference signal with proposed expert system implies that something within the ship hull structure has altered and diagnosis is made.

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