Hybrid ROV Based method for Hall Inspection, Monitoring and Preventive Maintenance

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Abstract

Hull and harbor infrastructure inspections and monitoring are frequently performed manually and involve high level of risk and human and monetary resources. In any kind of threat and resource constrained environment, this involves unacceptable levels of risk and expenses. A major effort is always required to extend the time between the dry docking of the ships so that a large amount of money and manpower will be saved this way. At the present, it is essential that the major shipping lines have access to a remotely operated vehicle (ROV) to conduct underwater inspection of existing ship hulls. Simply, the ROV eliminates the need for diver operation as well as it postpones the dry docking by gathering information from the hull surface and body. This paper addresses the evolving subsea especially designed hybrid acoustic-electromagnetic flux leakage searching arm as a part of associated maintenance arrangement of a remotely operated vehicle incorporating the expert system techniques in the diagnostic method of subsea ship hulls based on the concept of both Vibration spectrum and Ampere’s law and methods of probable damages without any physical destruction by testing the suspected section which is already subjected to acoustic sonic vibration and alternating current flow with selected frequencies. Using these methods, the soundness of the hull surface, body and absence of cracks and imperfections due to corrosion may be ensured in the data receivers outside the water. The ROV may also be equipped on its arm with ultrasonic test probe, paint thickness measures, hull plate thickness measure, and other specific equipment which may be helpful to testing and maintenance of the hull.

Keywords: Hull inspection, emfl method of NDT, Acoustic sonic vibration, Preventive maintenance, Expert system

1. Introduction

Ship hulls, as well as port dock piling, and other underwater structures need to be inspected for public maintenance. This paper presents the results of investigation and project of a semi automated vehicle for measuring, by means of acoustic and emfl (Electromagnetic flux leakage), thinning and metal defect due to corrosion of hull of cargo ship or other heavy subsea structures. Fig.1 depicts the prototype of the ROV based test Module.

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 [1, 2].

Figure 1: The proposed prototype of test module and hybrid inspection sensors at Shahid Rajaee harbor
The present work surveys the principles and a criterion of the diagnosis signal processing and introduces these achievements to an expert system technique. In this paper application of two different incorporated sensors are discussed and experimental results are presented for an expert system application, based on the concept of vibration spectrum-cepstrum and electromagnetic flux analysis detected signals and method of measuring defected part of subsea ship hull or steel structures. Within the complex areas such as the harbor pier pilings and the running gear of the ship without disturbing their structures for suspected parts. Fig. 2 illustrates the most important modules of proposed rule based hybrid diagnostic expert system.

A pair of transducers using the principle of a vibration sensors and electromagnetic flux leakage (emfl) has been tried and considered to be suitable for measuring any probable damages mostly due to surface corrosion, delamination, thinning and other physical or chemical causes on the suspected part of the subsea hull or structures. Such hybrid transducers are proposed to be the basis for condition monitoring of above mentioned structures by means analyzing the change of vibration sensed by related transducer of the testing probe and electromagnetic flux leakage asymmetries in the magnetic circuit. Deciding on the appropriate action to take after a defect has been discovered depends on the potential hazard of the defect, the risk of continued structural deterioration, the technology available to repair the defect, the cost associated with the needed repair, and the intended remaining life of the hull or structure. Following are the possible methods of subsea steel structure inspection:

- Condition monitoring based on visual & video observations.
- Tactile inspection (Inspection by touch)
- Leaser detection and monitoring
- Sonic vibration suiting
- Ultrasonic fault health monitoring
- Gama ray condition monitoring
- Electromagnetic flux leakage (EMFL) diagnostic method

2. Study of problem

For ship hull surveys, the ROV performs the data collection for further protection of the ship from dangers. As it is not always possible to diagnose the cracks and other imperfections through video inspection, the principle of a toroidal search coil and acoustic sonic vibration mutually are applied for more precise inspection to ensure the soundness of the hull. The irregular mechanical impact loads on the superficial layer of the ship hull and the corrosion on the metal, make changes to the structure of steel body resulting in cracks, corroded structure, and defects in the hull surface and body. The alternating flux generated by semicircular active part of designed sensor is affecting the suspected portion of the hull surface. At the same time the suspected location is subjected to impactor vibration at sonic frequencies and the reflected waves detected by the receiving sensor. When there were thinning due to corrosion, delamination or crack the reflected waves detected by vibration sensor were weaker than those from the perfect areas. The results showed that the analysis of surface wave testing has the ability to detect changes in the corroded hull. Cepstrum analysis is carried out to identify a series of harmonics or sidebands in the spectrum. In the proposed method of emfl, asymmetries in the magnetic circuit of damaged section are due to uneven air gap-caused by displacement and misalignment of standard steel micro structure. Such asymmetries, are inevitable after ageing of the ship, and mechanical impacts on the surface of the ship hull, and change the permeability of the tested section. Saturation of the steel surface 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 [2].

The predominance of one component or the other will depend on both the type of the asymmetry and misalignment of the selected section, which is related to the type of emfl engineering information to be generated for the knowledge base which contributes data with the proposed expert system shell through interface engine and knowledge base editor. The vibration case specific data plus the above information with the help of explanation subsystem, allows the module to explain its augment's to the user and will provide the signatures expert system shell requirements. The half circle transducer clamped over the suspected part of the under surveillance and induced current variation is recorded with respect to healthy portion of the hull body. General outlines of the process of hull inspection with the proposed test module are listed as following:

- place the test module in the water at amidships
- pursuit ship's hull to bow below waterline
- maintain the test along bottom of hull from bow to stern
- overall observation of hull condition
- Check key areas such as bow thruster, sea chest & keel coolers, etc.
- close observation of running gear and investigate any other suspected areas

2-1. EMFL condition monitoring of undersea ship hull

According to the proposed method 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 impact on the suspected superficial part of the subsea steel body. Such transducers are proposed to be the basis for condition monitoring of the steel body of the hull by means of analyzing the change of emfl induced by alternating current with selected frequencies circulated through the selected portion of the hull.

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 greater care than similar measurements in an externally forced current circuit [3], whilst the induced emf in the closed contour of the circulating current circuit is a unique value.

\[ E = -N \frac{d\Omega}{dt} \]  

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 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 section current in the enclosed conductor. Such a coil must have an inner diameter just more than the diameter at the mounting location [5]. 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 amperes over a wide frequency range, with the help of FFT analyzer.

Figure 3: Current measurement principle for the proposed toroidal of test probe

It is well known that the current flowing in a conductor gives rise to the flux around. Mathematically, Ampere’s law is expressed as:

\[ \oint H \cdot ds = I \text{ enclosed} \]  

For a circular path C, around suspected part of the hull plate carrying a 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:

\[ N\Phi = (\mu I L N / 2\pi) \left[ \ln \left( \frac{r_2}{r_1} \right) \right] \]  

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

\[ i = I_{\text{max}} \sin \omega t, \]
\[ e_{\text{rms}} = \mu L N f \left[ \ln \left( \frac{r_2}{r_1} \right) \right] T_{\text{rms}} \]

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

Fig (4) shows a sample traces of the hull plate for change in reluctance and local faults due to loss of metallic area. The fault is a section located at distance about 42 m from the origin which the diagnosis and testing is stared.

2-2. Vibration Condition Monitoring & Spectrum-cepstrum analysis

It is a common observation that, when there were thinning due to corrosion, delamination or crack the reflected waves detected by the receiving sensor were weaker than those from the perfect areas. The results showed that the analysis of surface wave testing has the ability to detect changes in the constructed structures. The vibration and emfl signals which appear on the perfect part of hull structure, give a characteristic vibration and emfl signature. These signatures provide a base line against which future measurements can be compared. It is important to note that similar subsea steel structure in good condition will have similar vibration and emfl signature differing only in respect of their constructional and structural conditions tolerances.

Vibration condition monitoring makes use of vibration analysis for the following purposes:

- Periodic routine vibration measurement of hull and other subsea structures to check their structural condition.
- Trouble shooting for suspected constructional problems.
- Check to ascertain that the subsea steel structure has returned to good operating condition after implementing the reconstruction or repair.
- Check to enable planning of repair of the ship hull or structures prior to service shut-down.

Different defects cause the vibration beside the emfl signatures to change in different ways. A changed vibration or emfl signature provides a means to determine the source of problem as well as prior warning of the problem itself. This research work is limited to implementing the acoustic and emfl signal processing and condition monitoring of steel structures in the splash zone and underwater portions of structures located in lakes, rivers, oceans, and ground water.

The vibration spectrum can be expressed on a linear frequency scale with constant bandwidth. This type of spectrum provides fine resolution at higher frequencies but a poor resolution at lower frequencies. Whereas a constant percentage bandwidth analyzer uses logarithmic frequency scale and cover three decades with equal resolution. It is for
this reason that the best analysis method for the comparison of spectra and fault detection is the use of constant percentage bandwidth with a logarithmic frequency scale.

Cepstrum analysis is carried out to identify a series of harmonics or sidebands in the spectrum. Cepstrum may be considered to be the frequency analysis of frequency analysis. The power cepstrum is defined as:

\[ C_p(\tau) = F^{-1}\{\log F_{xx}(f)\} \]

(6)

Where \( f_x(t) \) is the time signal and its Fourier transform is \( F_{xx}(f) \).

The figure 5 given below shows a spectrum from a ship hull structure in its deteriorated condition. It contains several harmonics. It is not possible to detect from this spectrum that there are two series of harmonics indicating two different phenomena. Cepstrum of this spectrum is also given in the side. It may be seen that the cepstrum identifies these two families of harmonics (with a spacing of 56.5 Hz and 165.3 Hz respectively). Fig. (6) shows the edited spectrum such that frequencies below that of half of the impactor frequency are removed. The cepstrum of this spectrum is then calculated. The cepstrum does not show the 165.3 Hz component at all. It indicates that this component originates from the lower frequency range. The cepstrum does retain the 56.5 Hz component indicating its origin in the medium frequency range. It may thus be concluded that the impactor rotation at 49.8 Hz may indicate some fault while using acoustic sonic vibration technology for condition monitoring of hull plates it results specific determination of defects such as thinning, delamination, and crack.

Figure 5: The spectrum from a concrete structure in its deteriorated condition

Figure 6: The sample signatures of hybrid condition monitoring for a typical hull structure
Based on the concept of Ampere’s law and method of measuring alternating circulating currents the suspected part of the hull body is inspected. The information already gathered for a healthy hull is 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 [2, 6, ]. 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 check the knowledge base as shown in the Fig (1).

3. Typical test results

For construction of knowledge base and serving expert system shell, measurement of vibration and induced current in the suspected part of the ship hull, incorporated through vibration data processing unit and induced current data modules. Fabrication, calibration of split toroidal search coil and vibration actuator-sensor which are mounted on the articulated arm of ROV for NDT of suspected parts, resulted to obtain the following induced values on a test section. Test results in suspected areas (Which are damaged due to corrosion or mechanical impact load) indicate that the third harmonic component is predominant. At the same time the analysis of surface wave testing has the ability to detect changes in the corroded steel structures. Variation in the behavior and operating condition of the test piece will be reflected in the data processing unit and knowledge base module of expert system for proper decision making.

Typical induced section current values are recorded for an undersea ship hull. Fig. (3) 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.

5. Conclusions

A novel hybrid method for surface non-destructive testing for ship hull inspection is presented. The proposed method is based on ROV visual surface tracking. The method integrates emfl and vibration sonic analyses for condition monitoring. It has been appreciated that using the proposed hybrid method the perfect undersea hull plate should not produce induced voltage or vibration signature. This is never the case, for it is impossible to eliminate all asymmetries in the material and structure of the hull structures and plate microstructures.

In comparison to individual application of emfl or acoustic sonic vibration, the hybrid method results better identification and classification of hull plate defects. This combined methodology also facilitates faster and trustful corrosion signature recognition on the hull body and other subsea steel structures.

To extract knowledge from the expert the knowledge engineer must become familiar with the both problems of electromagnetic flux leakage and induced current and acoustic sonic vibration. The rule base system is goal driven using back ward chaining strategy to test the collected vibration and induced current information are 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 body defects. Alternating induced current in ship hull body and vibration signatures can be measured conveniently and with reasonable accuracy using toroidal coil and hydrophone located by an ROV.

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 hull plate structure has altered and diagnosis is made. The proposed subsea condition monitoring has been tested extensively in real world applications and trials and are demonstrated using real data and examples.

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