ROV BASED ACOUSTIC EMISSION CONDITION MONITORING & NDT OF SUBSEA FIBER OPTIC NETWORK COMPONENTS

Mohmmad Reza Hedayati, (BE, M Tech., PhD. Elect. Engg.) .
Scientific-Applied Faculty of Post and Telecommunications (Ministry of ICT)
University of University of Applied Science and Technology

Email <hedayati@ictfaculty.ir>
Danesh Blvd., Janah Expressway Azadi Sq., Tehran- Iran

Abstract: For the last 25 years, undersea fiber optic networks have been deployed in the world's oceans and seas to provide telecommunications between countries. As a result of extended usage of the Persian Gulf floor by growing number of industries the installed subsea fiber optic services continues to increase and the potential for external aggression resulting to these cables increased. The repair of fiber optic cable equipments under water presents many complex problems. The harsh environmental conditions and specific problems associated with working underwater area cause many differences. Condition monitoring of subsea fiber optic cable near to the Shahid Rajaee harbor using spectral analysis of surface wave (sasw) and NDT at accident zone of a ship with sub systems discussed in this paper. Spectral analysis of surface wave condition monitoring is related to the identification of certain vibration parameters due to surface waves and their measurement with a view to diagnose underwater part of transmission equipments.In this research work discussed how the use of FFT analyzers can yield fault information based on spectrum and cepstrum analysis of detected signals and it has been shown how this technique utilized to detect defected part of sub systems in case of water penetration and damage of the casing or protection cover. The development of remotely operated vehicle (ROV) based tool to assess the acoustic vibration of subsea fiber optic components using expert system techniques is also discussed in this report.

1. INTRODUCTION

The repair of subsea fiber optic cables presents many complex problems. The harsh environmental conditions and specific problems associated with working underwater or in the splash zone area cause many differences. Proper evaluation of the present condition of the cable structure is the essential first step for designing long-term monitoring, NDT and repairs. To be most effective, evaluation of the existing cables or accessories, requires historical information on the structure and its environment, including any changes made to the structure over time, and the records of periodic on-site inspections or repairs. In contrast to its terrestrial counterpart, each component and subsystem of an undersea telecommunications cable is extremely inaccessible and expensive to replace.

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 [1,6,].The present work surveys the principles and criteria of a non destructive testing and introduces these achievements to an expert system technique. In this paper a new ROV based sensor is discussed and experimental results are presented for an expert system application. Based on the concept of spectrum and cepstrum analysis detected signals and method of measuring defected part of subsea cable or accessories without disturbing their structures for suspected parts. An ROV based transducer using the principle of a vibration sensors has been tried and considered to be suitable for measuring any probable damage due to irregular phenomenal such as water penetration , change in mechanical structure and other changes due to superabundant mechanical stresses on the superficial layer of the subsea cables and their accessories. Such transducers are proposed to be the basis for condition monitoring of armored steel structures in the subsea fiber optic cables by means of analyzing the change in vibration sensed by related transducer of the testing probe. This ROV based system is being designed to provide a "more secure link for traffic" across the Persian Gulf in hops of dodging massive internet outages due to unexpected external aggression

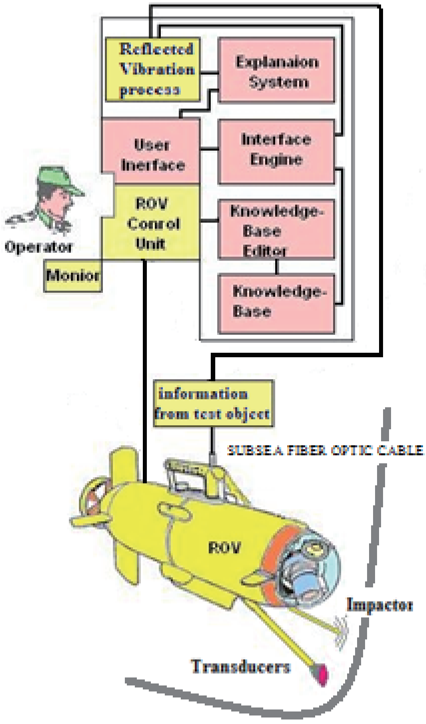

Fig.1. The most important modules of proposed rule-based vibration signal diagnostic expert system

It is a common observation that, when there were surface mechanical stresses, water penetration, or crack the reflected wave detected by the receiving sensor were weaker or stronger than those from the perfect areas. The results showed that the analysis of surface wave testing has the ability to detect changes in the faulty structures. The vibration signals which appear on the perfect part of structure, give a characteristic vibration signature. This signature provides a base line against which future measurements can be compared [2,5].

It is important to note that similar fiber optic structure in good condition will have similar vibration 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 cables and subsea accessories to check their structural condition.
- Trouble shooting for suspected part of subsea cables & installations.
- Check to ascertain that the cable and subsea installation has returned to good operating condition after implementing the reconstruction or repair.
- Check to enable planning of repair of the subsea cable prior to line service shut- down.

Different defects cause the vibration signatures to change in different ways. A changed vibration 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 signal processing and condition monitoring of subsea cables in the splash zone and underwater part of accessories located in lakes, rivers, oceans, and ground water.

2. STUDY OF THE PROBLEM

The telecommunications service providers have worked out several diagnostic techniques including optical time-domain reflectometer method (OTDR) suiting to individual requirements [1,3]. 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 cable . Following are some of the possible methods of inspecting and condition monitoring of subsea fiber optic cables.

- Condition monitoring based on visual inspection
- Tactile inspection (Inspection by touch)
- Leaser detection and monitoring
- Sonic and Ultrasonic fault health monitoring devices.

3. Electromagnetic flux leakage (EMFL)diagnostic method

3. DIVING TECHNOLOGY

Underwater work can be generally classified into one of three broad categories for accessing the Work site:

- manned diving
- one-atmosphere armored suit
- manned submarine
- remotely operated vehicle (ROV)

The industry standards currently allow a diver using compressed air to work at 30 ft (10 m) for an unlimited period of time. If work is being performed at 60 ft (20 m), however, the diver can only work for approximately 60 minutes over a 24-hour period without special precautions to prevent decompression sickness. The industry standard upper limit is 30 minutes of work time at 90 ft (30 m) in seawater. If these limits are exceeded, precautions must be taken to decompress the diver.

ROVs look much like an unmanned version of a submarine (Fig. 2). They are compact devices that are controlled by a remote crew. The operating crew and the vehicle communicate through an umbilical cord attached to the ROV. The crew operates the ROV with information provided by transponders attached to the frame of the ROV. ROVs may be launched directly from the surface or from a submarine mother ship. Most ROVs are equipped with video and still photography devices. The vehicle is positioned by ballast tanks and thrusters mounted on the frame. Some ROVs are also equipped with robotic arms that are used to perform tasks that do not need a high degree of dexterity. ROVs have been used at depths up to approximately 8000 ft (2400 m).Over 1000 robotic uninhabited undersea vehicles (UUVs) also presently in regular operation worldwide [ ]. Structural investigations of underwater facilities are usually conducted as part of a routine preventive maintenance program, an initial construction inspection, a special examination prompted by an accident or catastrophic event, or a method for determining needed repairs. The purpose of the investigation usually influences the inspection procedures and testing equipment used. Underwater inspections are usually hampered by adverse conditions such as poor visibility, strong currents, cold water, marine growth, and debris buildup. Horizontal and vertical control for accurately locating the observation is difficult. A diving inspector must wear cumbersome life-support systems and equipment, which also hampers the inspection mission.[6,7]

Underwater inspections usually take much longer to accomplish than inspections of similar structures located above the water surface. This necessitates more planning by the inspecting team to optimize their efforts. Inspection criteria and definitions are usually established before the actual inspection, and the inspection team is briefed. The primary goal is to inspect the structural elements to detect any obvious damage. If a defect is observed, the inspector identifies the type and extent of the defect to determine how serious the problem may be. The inspector also determines the location of the defect so repair crews can return later to make the repair, or another inspection team can reinvestigate if necessary. Many divers who perform structural inspections do not have specific engineering training for this task. In this case, another person with the appropriate engineering background is normally employed to interpret the results of the inspection and make the appropriate evaluations.

4. SCRUTINY OF IMPLEMENTED NDT TECHNIQUES FOR SUBSEA CABLES

Studies of nondestructive testing (NDT) of subsea cables have shown that the following techniques and instruments are applicable to underwater work.

Soundings: Soundings are taken by striking the suspected surface to locate areas of internal damage of armors or delaminating of the cable cover as might be caused by the effects of excess mechanical stresses and puncture of primary cover or corrosion of steel armored reinforcement. Although the results are only qualitative in nature, the method is rapid and economical and enables an expeditious determination of the overall condition. The inspector's ability to hear sound in water is reduced by waves, currents, and background noise. Soundings are the most elementary of NDT methods.

Fig.2 The proposed ROV and diagnostic arm

Ultrasonic pulse velocity: Ultrasonic pulse velocity is determined by measuring the time of transmission of a pulse of energy through a known distance of the sub sea cable. Many factors affect the results, including material content and reinforcing steel location. The results obtained are quantitative, but they are only relative in nature. A special form of this technique is the pulse-echo method. The pulse-echo method has been used for the in-place determination of the length and condition of subsea installations.

Magnetic reinforcing bar locator: A commercially available magnetic reinforcing bar locator (or pachometer) has been successfully modified for underwater use. The pachometer can be used to determine the location of armored reinforcing bars in the cable, and either measure the depth of casing cover or determine the nature of placement of the reinforcing bar in case they are subjected to enormous mechanical stresses. Techniques are available for approximating each variable if neither is known. Laboratory and field tests of the instrument demonstrated that the modification for underwater use had no effect on the output data [4].

Impact testing: A standard impact hammer, modified for underwater use, can be used for rapid surveys of covering surface conditions. The underwater readings, however, are generally higher than comparable data obtained in dry conditions. These higher readings could be eliminated by further redesigning of the Schmidt hammer for underwater testing of cables. Data also can be normalized to eliminate the effect of higher underwater readings.[3]

Echosounders: Another ultrasonic device, the echosounders (specialty fathometers), can be useful for underwater rehabilitation work using trench installed cable , both to delineate the groove to be filled and to confirm the level of the trench installations. They are also effective in checking scour depth in a stream bed. They consist of a transducer that is suspended in the water, a sending/receiving device, and a recording chart or screen output that displays the water depth. High-frequency sound waves emitted from the transducer travel through the water until they strike the bottom and are reflected back to the transducer. The echosounder measures the transit time of these waves and converts it to water depth shown on the display. When an echosounder is used very close to the subsea cable, however, erroneous returns may occur from the underwater structural elements.

Side-scan sonar: A side-scan sonar system is similar to the standard bottom-looking echo sounder, except that the signal from the transducer is directed laterally, producing two side looking beams. The system consists of a pair of transducers mounted in an underwater housing, or "fish," and a dual-channel recorder connected to the fish by a conductive cable. In the past several years, the side-scan technique has been used to map surfaces other than the ocean bottom. Successful trials have been conducted on the slopes of ice islands subsea utilization , and on vertical subsea structures. Although the side-scan sonar technique permits a broad-scale view of the underwater objects and structure, the broad beam and lack of resolution make it unsuitable for obtaining the kind of data required from inspections of faulty subsea cables structures.

Radar: Certain types of radar have been used to evaluate the condition of structures up to 800 mm thick. Radar can detect delamination, cover deteriorations, cracks, and crushes due to excessive mechanical stresses. It can also detect and locate changes in placement of armored reinforcements. Radar has been used successfully as an underwater inspection tool, and is being developed for possible future use. Radar with the antenna contained in a custom waterproof housing was used in 1994 in conjunction with pulse velocity testing to investigate the structural integrity submerged 46 m in a water supply tunnel.

Underwater acoustic profilers: Because of known prior developmental work on an experimental acoustic system, acoustic profiling has been considered for mapping underwater structures and installations. Erosion and down faulting of subsea cables and pipes have always been difficult to accurately map using standard acoustic (sonic) surveys because of limitations of the various systems. Sonic surveys, side-scan sonar, and other underwater mapping tools are designed primarily to see targets rising above the plane of the sea floor. Sampling and destructive testing also can be use when other methods are not possible

Electromagnetic flux leakage (EMFL): Based on the concept of Ampere's law and method of measuring alternating circulating currents without disturbing their paths for suspected part of undersea fiber optic cable. A transducer using the principle of a toroidal search coil is tried and considered to be suitable for measuring any probable damage due to irregular phenomenal impact on the suspected superficial portion of the cable. Such transducers are proposed to be the basis for condition monitoring of armored steel structure in the cable by means analyzing the change of e.m.f induced by primary winding of the testing probe [4].

5. Spectrum &cepstrum analysis

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.[6]

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:

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

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

The figure given below shows a spectrum from a subsea fiber optic cable 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 give in the side. Fig. (4)

shows the edited spectrum of the impactor frequency for a healthy and intact cable. It may be seen that the cepstrum identifies these two families of harmonics (with a spacing of 48.5 Hz and 119.4 Hz respectively). Fig. (5) 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 119.4 Hz component at all. It indicates that this component originates from the lower frequency range. The cepstrum does retain the 48.5 Hz component indicating its origin in the medium frequency range. It may thus be concluded that the acoustic wave at 49.8 Hz may show an incipient fault while the sonic waves at 119.4 Hz indicates excess mechanical stresses or casing fault.

In this research the accousto – vibration (AV) technique utilized to detect defects, such as voids and mix separations in the constructed pats.

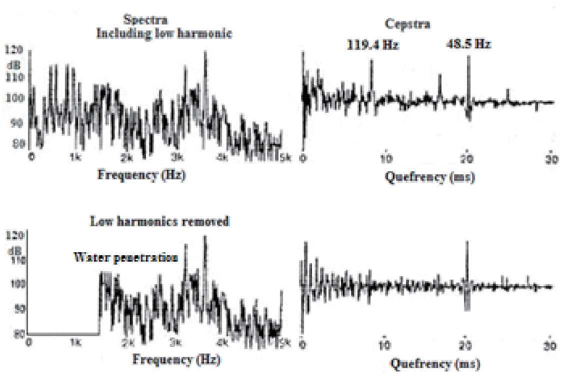

Fig.3 The spectrum from a subsea fiber optic cable structure in its deteriorated condition

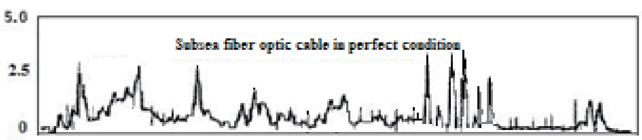

Fig.4 Frequencies below that of half of the Impactor frequency are removed - healthy subsea cable

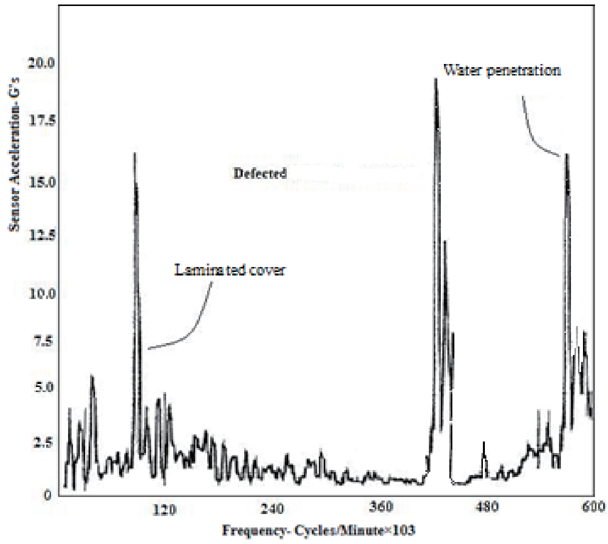

Fig.5 Frequencies below that of half of the Impactor frequency are removed - faulty subsea cable

6. Conclusions

It is apparent that in the proposed method the perfect undersea subsea fiber optic cable structure should not produce vibration signal more than normal value. This is never the case, for it is impossible to eliminate all asymmetries in the materials and geometry of the subsea fiber optic cable and steel armature in the Structure. It follows from the measurements having been carried out that several predominant frequencies arise in the specimens under test.

To extract knowledge from the expert the knowledge engineer must become familiar with problem of vibration and acoustic analysis. The rule base system is goal driven using back ward chaining strategy to test the collected structure vibration and acoustic properties 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 subsea sub-sea fiber optic cable defects. The respective amplitudes of the mentioned signals may exceed each other in a different way in repeated measurements of the same specimen. 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 subsea subsea fiber optic cable structure has altered and diagnosis is made.

7. References:

[1] F Filippetti, G Franceschini C Tassoni "AI techniques in induction machines diagnosis including the speedripple effect" IEEE Transactions on Industry Application, Jan/Feb 1998Volume:34, Issue:1 pp: 98-108

[2] J.Skala, Z Chobla "Frequency inspection as a tool to access the armature corrosion" in proc. workshop NDT, Brno university of technology Brno,2005,pages 159-161.

[3] Ko Enská, M Chobola, Z Mikulková, PMartinek, J.,"On the application of impact-echo method to assess the quality of ceramic roofing tiles". In: , 2003, Krakow 2003, pp. - 239 – 244.

[4] G Dobmann Fraunhofer "Magnetic NDT Technology for Characterizing Materials – A State of the Art Survey" Indian Society for Non-Destructive Testing National Seminar on Non-destructive Evaluation Dec. 7 - 9, 2006, Hyderabad-India.

[5] M R Hedayati, "On-line condition monitoring of locomotives", the 7th Railway conference, Sharif University, (Persian language) 2004, Tehran- Iran.

[6] M R Hedayati, "Sub-sea fiber optic cable maintenance using a ROV based flux leakage expert system, Journal of artificial life and robotics, Volume 14, No.4/December, 2009,Pages 511-514

[7] P T Cole, J R Watson "Acoustic Emission for Corrosion Detection" Journal of advanced materials research Volumes 13-14 February, 2006 Pages 231-236

[8] M Petrik, VKus "Localization of acoustic emission sources by means of statical models" 2nd internet workshop "NDT in progress 2003",Prauge, CNDT 2003,Page320.