Guidelines for Offshore Structure Monitoring

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Introduction

In today's offshore industry the size and cost of structures and vessels continue to grow. One of the issues in the design of these vessels is that the technology used is not changing at an equivalent rate to the size and cost. In offshore petroleum production the only thing monitored is the oil production, leaving the structural components open to deterioration without full knowledge of their integrity. With full knowledge of the structural integrity of offshore structures, repairs could be performed when they are required on a given section and not be limited to a periodic servicing. This would not only make the structure more reliable but could also decrease the costs of repair.

In this paper issues involved in the different sectors of petroleum engineering are examined along with some of the solutions that are currently available. Issues such as various load conditions, environmental effects, and thermal effects are examined. Some solutions for monitoring and controlling structures is given by implementing piezoelectrics, fiber optic sensors, and lasers and ways to address issues with the use of laminated composites is also examined.

Issues in the Petroleum Industry

There is no health monitoring of a petroleum structure in place anywhere in the world. This is an alarming statistic since petroleum structures are subjected to conditions that are not paralleled by any other. For instance, in drilling and completion the structural system is exposed to large stress, extreme thermal conditions under aerobic and anaerobic conditions, which is extremely harsh on metallic systems. In the production operation systems experience microbial activities, sour gas due to bacteria growth, and high thermal gradients, which results in a highly corrosive environment. With enhanced oil recovery factors such as thermal stress, chemical composition, depletion induced stress, and vortex shedding are of major concern. When these systems are moved offshore difficulties are greatly increased with the addition of tidal waves, salinity, fatigue, wind, and thermal shock with the changing of the seasons.

From the structural point of view, different sections of the structure are affected in different ways thermally, chemically, and mechanically. These effects are all complicated with the presence of anaerobic, aerobic, salinity, waves, and wind variations. Conventionally these structures are not monitored and their integrity is not known, with repairs being performed on a periodic basis. With structural monitoring, repairs can be performed when they are required keeping the integrity of the structure constant through time and not decreasing, as would be the modern trend. For instance, with repairs being performed as required, the structure could be able to withstand an explosion in the third year of operation that would not be possible in current practice. This shows the need in monitoring of stress levels, biological and chemical corrosion, along with the chemical composition of petroleum fluids to fully understand the deterioration of the structure through time.

Innovative Solutions

One of the major effects in the petroleum industry is the effect of thermal gradients. In some situations the thermal gradient can be as high as 80^{o}C over a distance as small as a several centimeters. This results in very high thermally induced stress across the section, which in most cases would be a steel pipeline. With the introduction of laminated composite piping these thermal stresses can be greatly reduced or totally eliminated. This is possible through a proper lay-up sequence of layers in the composite, such that the net thermal expansion of the pipeline section is zero. Also, not only can a composite pipeline have a zero net coefficient thermal expansion but also is corrosion resistant. This will allow the section to retain its full structural integrity while reducing the stresses, which will greatly reduce the chances of a failure saving production time, production cost, and increasing safety. With composite piping the decrease in weight of the materials allows for decreased construction time, resulting in a lower production cost. Another advantage of composite piping is the ease of embedding sensors. With steel piping the sensors would have to be surface bonded in most cases leaving the sensor exposed to the environment, reducing the chances of a successful monitoring system. In composite sections the sensors can be embedded into the section with ease protecting it from the environment. It has also been show with proper embedding techniques and sensor selection that the structural integrity of the system will not be affected.

The sensors that are currently available for use in smart structures include piezoelectrics, magnetostrictives, fiber optics, and lasers. Each of these materials have their advantages and disadvantages, with the first three being explained in detail in our other conference paper, “A Critical Review of Materials Available for Health Monitoring and Control of Offshore Structures”. These sensors allow for a system that can be used to monitor real time continuous data for stresses, temperatures, and chemical composition to name a few. With the use of piezoelectrics and magnetostrictives the system can then be controlled in real time to eliminate the unwanted stimuli. However, the use of magnetostrictives can be limited due to the size of the equipment required in operation.

With the use of piezoelectric elements continuous monitoring can be performed and the unwanted stimuli can be actively controlled only when required. Current systems used to control the response increase the mass of the section which may no be designed for, leading to failure. With the introduction of piezoelectric materials the effect on the dynamic response of the system is limited, which allows for easy design.

Fiber optic sensors can be implemented to measure any stimuli and have a very large operating temperature, which is ideal for the petroleum industry. With the introduction of fiber optics the chemical composition of a fluid can be easily monitored, which can allow for the corrosiveness of the material to be determined, as shown in Figure 1.

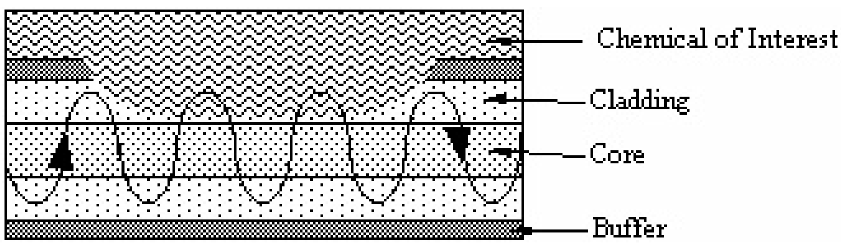

Figure 1: Fiber Optic Evanescent Wave Absorption Technique [(4)]

With the use of the evanescent technique, given in Figure 1, the cladding and buffer on one side of the fiber is cut away such that the light sent down the fiber passes through the chemical of interest. From the returning light signal the chemical composition and therefore corrosiveness of the fluid can be determined. Fiber optic sensors can be implemented to measure the strain in the section due to the total effect of thermally and mechanically induced stress or just the mechanical stress through the use of non-compensating or self-compensating Fabry-Perot interferometers respectively. Non-compensating Fabry-Perot interferometers have mirrors deposited on the tips of multimode optical fibers, as shown in Figure 2. When the cavity length changes in the senor due to mechanical and/or thermal stresses, which will change the light signal enabling the strain in the section to be determined.

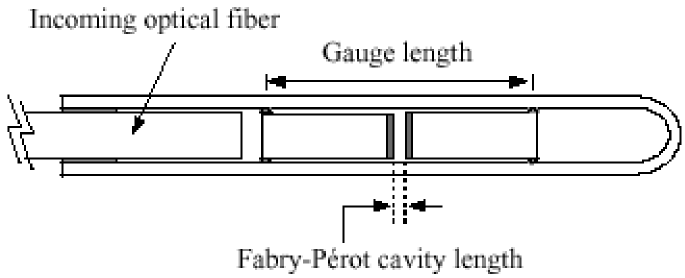

Figure 2: Non-Compensated Fabry-Perot Interferometer [5]

In self-compensated Fabry-perot interferometers a metallic fiber is used for the reflecting wire as shown in Figure 3. This metallic fiber is manufactured such that it has the identical coefficient of thermal expansion as the section it is implemented in. This will result in thermal stresses being counter acted by the fiber, allowing for only the mechanical strain to be determined.

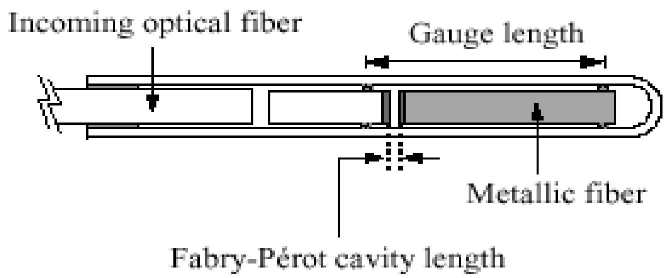

Figure 3: Self-Compensated Fabry-Perot Interferometer [5]

With the use of a laser Doppler vibrometer one can implement a non-contacting measurement technique to determine the structural integrity of a section. This is generally performed through monitoring the dynamic response of the system. When there are flaws in the system, the dynamic characteristics at the position of the flaw will change. When a laser vibrometer is scanned across a section, the dynamic characteristics can be used to pinpoint any irregular patterns. This will allow for the detection of delaminations and matrix cracking in laminated composites, or cracks and corrosion in steel sections. This will allow for early detection of flaws, allowing for repairs before failure resulting in a safer structure and cost savings.

Summary

With the implementation of smart materials in offshore structures and petroleum applications there are some needs that have to be addressed. In order for the system to operate it would require a local system to record the data, and headquarter to monitor and interpret the results. The connection between these two systems could easily be performed with the use of wireless communication. The need for these monitoring systems is an issue at present time to allow for more practical and safer designs. There are many different and versatile techniques available to monitor and control these systems with each having advantages and disadvantages. The major issue is that it is a multidisciplinary problem requiring all field of engineering.

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