Ph.D. Dissertation Defense

A Comprehensive Integrity Monitoring System for Bolted Flange Connections

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Bolted flange connections are commonly utilized to link together pressure vessels and pipeline systems onshore and offshore. Although there exists a series of design codes and standards for specifying the design of flange joints, multiple adverse factors, such as unexpected loads and excessively high pressures and temperatures, can directly cause leakage failures of the flange connections in service. Leakage failures can incur crippling economic losses and even sometimes irreversible environmental damages, especially for offshore applications. Therefore, an integrity monitoring or inspection system for both onshore and offshore bolted flange connections becomes necessary.

In this dissertation, a comprehensive integrity monitoring system is proposed and developed through the implementation of cutting-edge sensing technologies to thoroughly investigate the integrity of a bolted flange assembly under tensile loads, internal pressure loads and a combination of both. API 6A flanges (4-1/16", Type 6B, 2000 psi) were selected to perform the proposed research. Fiber Bragg grating (FBG) sensor-embedded bolts offer a direct measurement of the bolt strains in the flange assembly. The piezo-based active sensing method and the electromechanical impedance method provide different approaches to monitor the characteristic variations in the metal-to-metal sealing condition. Once the connection seal failed, the acoustics generated by the sudden release of the escaping pressurized nitrogen gas were readily detected by the acoustic emission (AE) system. Meanwhile, the internal pressure of the flange assembly was simultaneously recorded as a reference for other measurements. Through the data analysis, this comprehensive integrity monitoring system provides an in-depth understanding of flange connection behaviors under different internal pressures and tensile loads, including a preliminary result of a leakage failure envelope considering the bolt torques and tensile loads. Furthermore, a touch-based sensing mechanism was also explored and further applied on a specifically designed robotic manipulator, which was incorporated on an undersea remotely operated vehicle (ROV) to achieve a remote inspection system for undersea bolted connections. The inspection performance was demonstrated through an undersea field evaluation. Thus, the developed comprehensive integrity monitoring system offers potential solutions for assuring the performance and integrity of onshore and offshore bolted flange connections in practical applications.