Monitor and Assess Corrosion Damage/Degradation of Concrete Coated Steel Pipelines under Marine Flow Impact Conditions: Evaluation of Closed-Loop Cathodic Protection Effectiveness

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Concrete-coated steel is extensively used in offshore and coastal infrastructure, including pipelines, piles, risers, and platform legs. In marine environments, such structures face continuous coating degradation driven by turbulence, wave impact, cyclic wetting, and chloride ingress. Unlike conventional cathodic protection studies that evaluate static, pre-defined defects, real operational conditions involve dynamic, progressive coating failure; a scenario that demands adaptive protection strategies. This study experimentally investigated the response of a closed-loop Impressed Current Cathodic Protection (ICCP) system to real-time, flow-induced coating degradation under controlled laboratory conditions. Intact 5 mm and 10 mm concrete-coated steel specimens were subjected to sequential pressure loading (100, 200, 400, and 600 kPa), simulating escalating marine flow impact. A deliberate hairline crack was introduced in one 5 mm specimen to enable comparison between intentional and flow-induced degradation. Throughout testing, the adaptive ICCP system continuously monitored electrochemical conditions and autonomously adjusted protection current in response to evolving damage states. Computational Fluid Dynamics (CFD) validation confirmed that laboratory flow velocities accurately replicated marine splash zone conditions. The closed-loop system demonstrated effective real-time adaptation across all damage stages, from intact coatings through partial erosion to complete disbondment at 400 kPa. Measured settling currents ranged from 0.012 mA for minor hairline cracks to 0.810 mA under significant coating erosion. Extended 6.5-hour exposure at 100 kPa resulted in a 179% current increase, confirming the system's sensitivity to cumulative damage accumulation even at moderate flow pressures. These findings demonstrate that closed-loop ICCP can reliably protect marine infrastructure throughout progressive coating failure, offering faster adaptive response, prevention of hydrogen embrittlement risk, and significantly greater reliability compared to conventional ICCP systems under dynamic marine conditions.

Keywords: *Cathodic protection, Marine corrosion, Concrete-coated steel pipelines, Coating degradation, Closed-loop ICCP, Flow-induced damage*