CAAP Quarterly Report

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Project Title: Probabilistic Performance Evaluation of Cathodically Protected Pipeline Considering AC Corrosion

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Business and Activity Section

(a) Contract Activity

The subcontract for Marquette University was approved and the paperwork is processing during this quarterly period.

No materials were purchased during this quarterly period.

(b) Status Update of Past Quarter Activities

In the past quarter, we continued making progress in Task 1 on the comprehensive literature review. The influencing factors, testing methods, and criteria in AC-induced (alternating current, AC) corrosion for cathodic protection (CP) were reviewed and summarized.

Besides, several pipeline companies contacted us as they are interested in this research project, such as Burns & McDonell. We had two virtual meetings with the Pipeline Engineers in the Pipeline & Facilities Engineering Department at Burns & McDonell on 12/17/2020 and 2/5/2021. They were very interested in our proposed research and are willing to provide us professional support on this project and may also provide us some field-testing data on our request. We are looking forward to collaborating with them on this project in the future quarters.

(c) Cost Share Activity

No cost share was used during this quarterly period.

(d) Technical Approach

The goal of this proposed study is to probabilistically evaluate the performance of cathodically protected pipelines under AC-induced corrosion. This study will utilize experimental testing and numerical analysis

to examine AC-induced corrosion, which will be used for identifying key influencing factors and understanding the AC corrosion mechanism. Meanwhile, the monitored defect profile will be used for the probabilistic defect time-evolution model development, which is crucial for the reliability evaluation of pipeline performance. Knowing how the influencing factors and different CP designs impact the pipeline performance, optimal CP design can be determined. Specific technical objectives are proposed as follows:

- Determine critical influencing factors on AC corrosion;
- Better understand AC corrosion mechanisms with systematical consideration of different combinations of influencing factors;
- Probabilistically model time evolution of AC corrosion profile;
- Assess pipeline performance under CP and AC corrosion based on the probability of failure;
- Optimize CP design under different combinations of influencing factors;
- Investigate the impact of various physical quantities and uncertainty sources on pipeline reliability.

To achieve the proposed research objectives, four tasks are developed.

- Task 1. Identify key influencing factors in AC corrosion (Drs. Huang & Zhou)
- Task 2. Generate realistic AC corrosion profile (Dr. Zhou)

  Task 2a. Corrosion profile configuration in AC corrosion

  Task 2b. Systemically investigation on AC corrosion with CP
- Task 3. Numerical simulation of AC corrosion behavior and CP system (Dr. Wang)
- Task 4. Probabilistic prediction model of AC-induced corrosion and reliability assessment (Dr. Huang)

1. Task 1. Identify key influencing factors in AC corrosion

1.1 Background and Objectives in the 2nd Quarter

AC interference can affect adversely the effectiveness of CP on pipelines by shifting the applied CP potential from the design value. The objective of this task in the 2nd quarter is to seek answers to the following questions through a comprehensive literature review: 1) What are the key influencing factors in AC corrosion on the pipeline under CP? 2) What are the testing methods involved in the past studies of AC corrosion under CP? 3) How is the AC corrosion behavior/risk quantified? 4) What are the criteria that have been suggested to ensure the effectiveness of CP?

1.2 Research Progress in the 2nd Quarter

The literature used in this Task is mainly based on the research work from four research groups at (1) University of Calgary in Canada (Chen et al., 2013; Kuang & Cheng, 2017; Xu et al., 2012), (2) University of Science and Technology Beijing in China (Du et al., 2017; D. Tang et al., 2016; D. Z. Tang et al., 2015; H. Wang et al., 2017), (3) China University of Petroleum in China (Guo et al., 2015; Guo et al., 2016), (4) Politecnico di Milano- Dipartimento di Chimica in Italy (Brenna et al., 2014; Goidanich et al., 2010; Ormellese et al., 2015; Ormellese et al., 2010), and other researches from all over the world (Markus Büchler, 2020; He et al., 2012; Olesen et al., 2019; Shabangu et al., 2017; L. Wang et al., 2018).

Based on the literature review and our conversation with pipeline engineers from Burns & McDonell, the following is the summary of the answers to the above four questions.

(1) The parameters that influence AC corrosion have been intensively studied in the past, including AC voltage, AC current density, AC frequency, CP potential, DC current density, soil composition and

resistivity, and coating defects. The most interesting finding when studying the influence factors is the fact that no matter if the direct current potential of the steel is shifted negatively or positively upon application of AC, the steel suffers from increased corrosion (Kuang & Cheng, 2017). This indicates that the criteria used for ensuring the effectiveness of CP without AC cannot be used in the CP application when AC exists. In summary, given the soil environment and metal composition, it is believed that the key influencing factors in AC corrosion that contribute to the CP effectiveness are AC current density, DC current density, and CP potential.

(2) We had also compared the testing setup, the ranges of design factors used in the testing including metal composition and soil properties (e.g., soil composition, pH, and conductivity) where soil solution is typically adopted. The studied metal is typically sealed with epoxy leaving a 100~400 mm^2 working area, immerged in the soil solution. The typical controlling factors used in the test are: AC voltage, AC current density, CP potential, and DC current density. Those comparisons will guide the experimental design in Task 2 for the next quarter. In our study, we are planning to expand the metal type and soil type such that we could complement our testing data with the existing data from the literature to draw conclusions that are not limited to a certain metal and soil.

(3) In the past study, AC corrosion behavior is typically measured through corrosion rate which is calculated by weight loss, or electrochemical parameters measured by linear polarization or electrochemical impedance spectroscopy. Sometimes, a surface examination is also conducted (such as scanning electron microscopy and X-Ray diffraction) to study AC corrosion mechanism. The unaccepted risk generally refers to AC corrosion rate of less than 0.01 mm/year. However, we believe this definition of "unaccepted risk" may not be accurate, as the influencing factors such as AC current density may fluctuate through time, which means the AC corrosion rate fluctuates through time. On the other hand, the pipeline failure is directly related to corrosion geometry profile not just corrosion rate. Thus, in the study, we may redefine "unaccepted risk" when we establish criteria for CP effectiveness.

(4) To understand the correlations of the influencing factors, different criteria for cathodic protection under AC corrosion were reviewed and compared. Unfortunately, there are no generalized criteria or threshold values for cathodic protection effectiveness under AC interference. Some criteria are based on the ratio of AC current density to DC current density (M. Büchler, 2012), and others are according to the absolute values of AC current density or DC current density (He et al., 2012; Ormellese et al., 2015). In addition, these threshold values are different for each study due to different testing metals or testing conditions. Therefore, it may be necessary to combine different study conclusions through combining similar metal composition or soil conditions to generate more generalized criteria which cover these key influencing factors and can be applied appropriately. Another solution that will be studied in this work is to utilize the corrosion data extracted from the past study and obtained the proposed study in Tasks 2 and 3 to generate a comprehensive database, which then can be used to re-establish more generalized criteria for risk measurement. The data extraction and analysis of these published criteria will be started in the next quarter.

1.3 Conclusions

The work done in this Task has well prepared us for the next task. With the identified the influencing factors in AC corrosion that contribute to the CP effectiveness (i.e., AC current density, DC current density, and CP potential), we will start working on the lab setup. A review paper is on the preparation to summarize the results from this Task and will elaborate all the comparisons and observations from the literature. This review paper will work as the delivery of Task 1 of this project.

1.4 Future work (next quarter)

More literature will be further reviewed for the testing methods and experimental setups for AC corrosion

in the next quarter. Besides that, the corrosion behavior data will be extracted and used as a part of the database for the risk assessment and establishing the CP effectiveness criteria.

2. Task 2: Generate realistic AC corrosion profile

This task will start in the 3rd quarter of this project.

3. Task 3: Numerical simulation of AC corrosion behavior and CP system

This task will start in the 5th quarter of this project.

4. Task 4: Probabilistic prediction model of AC-induced corrosion and reliability assessment

This task will start in the 7th quarter of this project.

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