CAAP Quarterly Report

Date of Report: *April 15, 2019*

Contract Number: 693JK31850012CAAP

Prepared for: *USDOT Pipeline and Hazardous Materials Safety Administration (PHMSA)*

Project Title: *Magnet-assisted Fiber Optic Sensing for Internal and External Corrosion-induced Mass losses of Metal Pipelines under Operation Conditions*

Prepared by: *Missouri University of Science and Technology (Missouri S&T)*

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For quarterly period ending: *March 31, 2019*

Business and Activity Section

(a) Generated Commitments – Dr. Genda Chen directed the entire project and coordinated various project activities.

Mr. Liang Fan and Mr. Chuanrui Guo, two Ph.D. candidates in civil engineering at Missouri S&T, were on board since the beginning of this project. They are responsible for the fabrication and characterization test of sensors under Dr. Chen's supervision.

(b) Status Update of Past Quarter Activities – Detailed updates are provided below by task.

Task 1 Optimization of a magnet-assisted hybrid FBG/EFPI sensor enclosed in a plexiglass container for simultaneous measurement of temperature and pipe wall thickness

In this study, a hybrid extrinsic Fabry-Perot interferometric (EFPI) and fiber Bragg grating (FBG) sensor is designed to measure the change in thickness and surrounding temperature of a steel plate. The hybrid EFPI-FBG sensor is assembled in four steps as displayed in Figures 1-3. First, a gold-coated glass sheet is placed on top of the steel plate in center area, as illustrated in Figure 1. Second, 17 springs are distributed and glued to the surface of six Neodymium magnets, as shown in Figure 2(a), which are symmetrically arranged in a packaged chrome-plated steel case with an unthreaded hole in its center. The self weight of the magnet case ensures that all springs are in contact with the bottom steel plate. Each magnet is 67 mm in outer diameter and 10 mm tall with a maximum pull force of 220 lbs up to 80 °C in operation temperature. Third, one optic fiber is inserted into a small-diameter glass tube and its fiber end is guided to move in the direction of an EFPI. A FBG sensor is then attached to the outside surface of the small-diameter glass tube, which is protected by an outer large-diameter glass tube, as illustrated in Figure 2(b). Fourth and lastly, the steel case with six magnets as shown in Figure 2(a) is turned upside down and placed on top of the steel plate, as shown in Figure 3. The glass tubes are then inserted through the center hole of the steel case. After necessary adjustments, super glue is used to firmly attach the outer glass tube on the magnet case and fix the optic fibers to the two glass tubes. The final assembled device is presented in Figure 3.

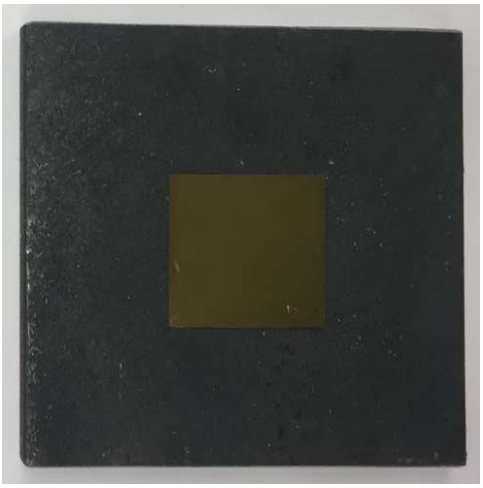

Figure 1. Gold-coated glass attached to the surface of a steel plate.

Figure 2. (a) Springs glued to the surface of six magnets and (b) optic fibers glued to two glass tubes.

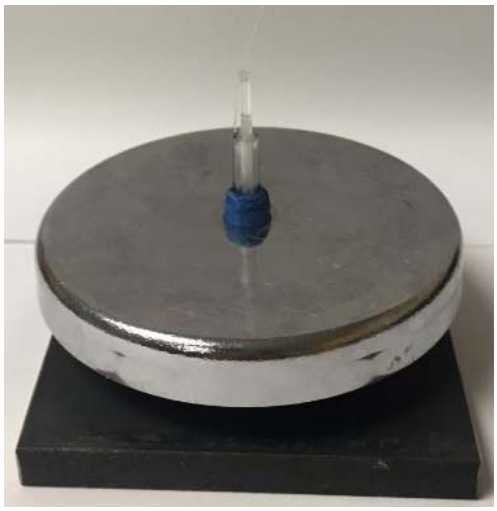

Figure 3. Assembling of a hybrid EFPI/FBG sensor.

When it is corroded, a steel plate becomes thinner. This process reduces the attraction force between the steel plate and the magnets, increasing the extension of springs or the cavity between the optic fiber and the gold-coated glass. Therefore, the EFPI data can be used to determine the change in steel pipe thickness. In this study, five steel plates with a thicknesses of 9.5 mm, 7.9 mm, 6.4 mm, 4.8 mm, and 3.2 mm are used to simulate the corrosion-induced thinning process of steel plates and study the cavity length change accordingly.

The cavity length (L) in the EFPI can be determined from phase change and calculated by:

$$L = \frac{\lambda_1 \lambda_2}{2(\lambda_1 - \lambda_2)} \tag{3}$$

where λ_1 and λ_2 represent the wavelengths of two adjacent valleys in an interference spectrum as shown in Figure 4. Figure 5 shows the relationship between the cavity length and the steel plate thickness. The cavity length increases linearly with the decrease of steel plate thickness until the thickness reaches to 4.77 mm. When the steel plate thickness is further reduced to 3.18 mm, the cavity length changes little. There seem a threshold value of steel plate thickness or pull force of the magnets to make the change in thickness of the steel plate detectable. The threshold value depends on the number of springs or the overall spring constants. To detect a minor change in steel plate thickness, a smaller number of springs or more flexible springs should be used in order to increase the change in spring elongation under the magnetic force and thus the sensitivity of the EFPI sensor.

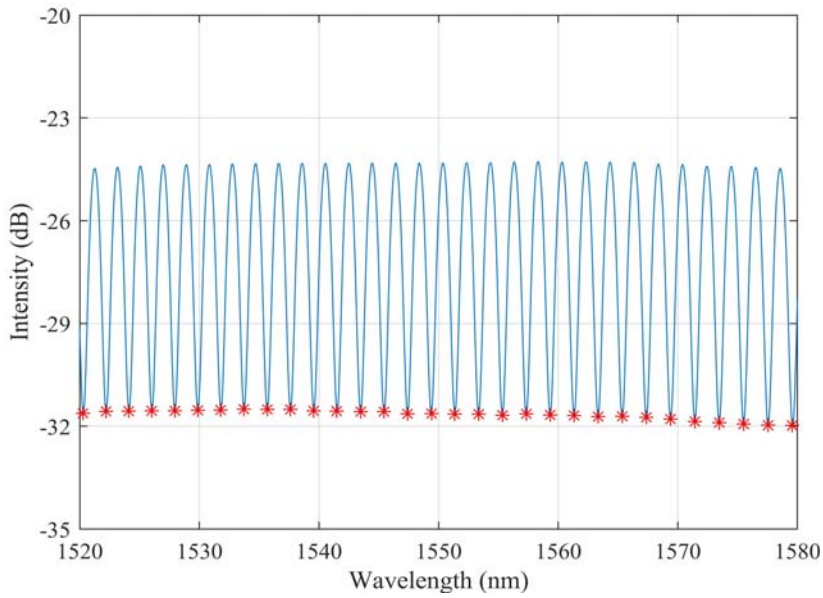

Figure 4. Interference spectrum of the EFPI.

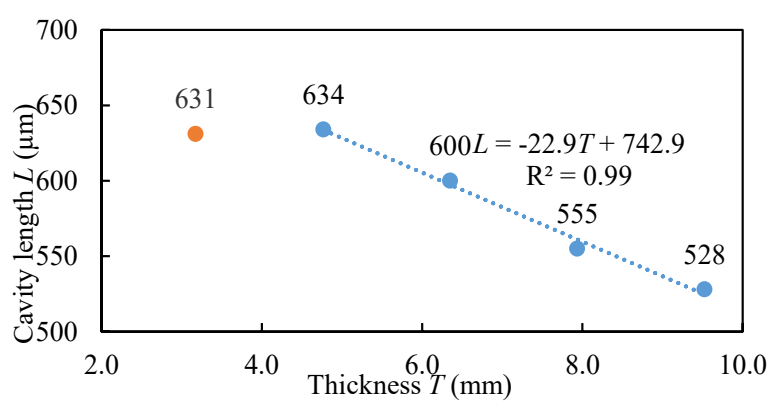

Figure 5. Relationship between the cavity length and the steel plate thickness.

In field applications, as a pipe wall gets thinner, it may potentially leak oil or gas, which changes local temperature. Depending on the type of substances transported through the pipeline, the pipe may become locally warmer (crude oil, brine, heating systems) or cooler (gas pipeline). In this case, the FBG can help monitor the surrounding pipeline temperature to detect the leakages. Its temperature measurement can also be used to compensate the thermal effect on the change in cavity of the EFPI. In this study, the entire magnet-assisted hybrid FBG/EFPI sensor with a steel plate was put into a furnace for test. The temperature was increased from 20 °C to 80°C. The wavelength at the peak of the reflection spectrum in Figure 6 is measured for every 10 °C increment of temperature. The wavelength is shown in Figure 7 to increase linearly with the increase of the temperature.

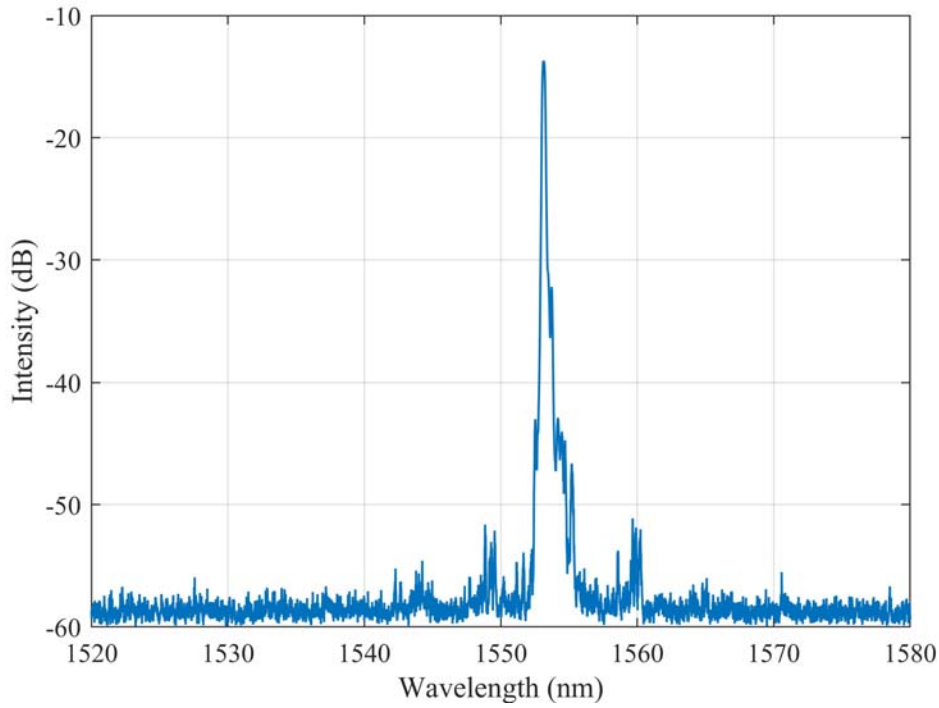

Figure 6. Reflection spectrum from the FBG sensor.

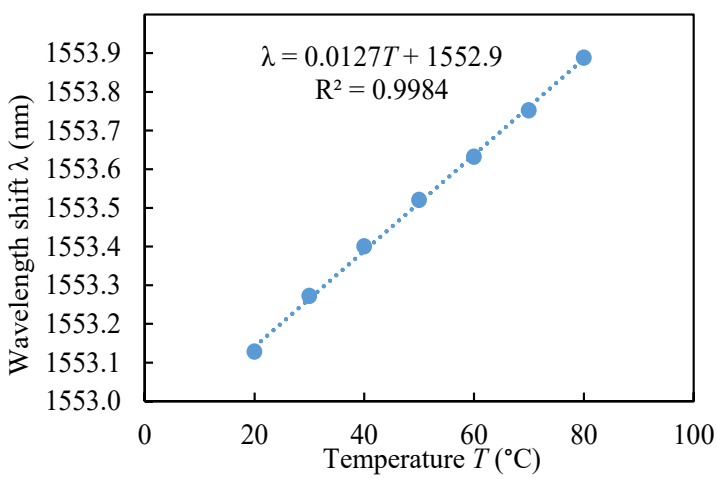

Figure 7. The relationship between the wavelength shift and the temperature.

Task 2 Development and validation of a graphene-based LPFG sensor with Fe-C coating for improved sensitivity in mass loss measurement in varying temperature environment

This task will not start till the 4st quarter in 2019.

Task 3 Integration and field validation of multiple FBG/EFPI and multiplexed LPFG sensors for internal and external corrosion monitoring of a pipeline with temperature compensation.

This task will not start till the 2st quarter in 2020.

***(c)* Planned Activities for the Next Quarter** - The following activities in Task 1 will be executed during the next reporting quarter.

Task 1 Optimization of a magnet-assisted hybrid FBG/EFPI sensor enclosed in a plexiglass container for simultaneous measurement of temperature and pipe wall thickness

In the next quarter report, the sensitivity of the EFPI sensor will be increased by adjusting the number of springs or by using springs with more flexible constants. To assess the magnetic force generated in the magnet-spring-steel plate system and the distance between the magnet and the steel plate, a finite element model will be built and run for different cases of plate thickness, separation distance, and number of springs. Finally, the magnet-assisted hybrid FBG/EFPI sensor will be used to test the thickness loss of a steel plate due to corrosion.