CAAP Quarterly Report

03/30/2023

Project Name: *Easy Deployed Distributed Acoustic Sensing System for Remotely Assessing Potential and Existing Risks to Pipeline Integrity*

Contract Number: *693JK3215002CAAP*

Prime University: *Colorado School of Mines*

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Reporting Period: *[01/01/2023 – 03/30/2023]*

Project Activities for Reporting Period:

During the reporting period, we effectively completed all the experimental tasks related to Task#1, and made noteworthy advancements in Task#2, 3, and 5. Our findings in Task#1 indicate the sensitivity of DAS measurement to accumulated water, particularly in the situations of high accumulation volume and fast gas flow rate. The outcomes also showcase the proficiency of slug detection, which considerably decreases the risks associated with Task#2. Furthermore, we accomplished Task#5.1, and detected modifications in vibration signals due to the elimination of one of the pipeline supports. Additional specifics regarding the completed activities throughout the reporting period are outlined below.

Activities completed during the reported period for Tasks#1&2:

- New pressure sensor was installed and interfaced to LabView DAQ system to obtain reliable pressure and flow rate measurements.
- The signal from the interrogator unit (IU) Terra 15 has been improved by splicing IU directly to the sensing cables.
- Data collection was improved by the new IU connection and a second set of data was acquired within the same day in order to have more consistent comparisons.
- The diagram in Figure 1 shows the experiment layout of Tasks#1&2. The flow direction shown in DAS data alternate for the 5 different cables as they are spliced at two separate ends, as illustrated in Figure 2 and 3.
- We conducted experimental studies for Task#1 with different stagnant accumulated water volumes, 4L, 10L, and 20L, at velocities around 2 m/s, 4 m/s, and 6 m/s. Figure 2 shows the processed DAS data recorded with around 4 m/s gas velocity with the three different water volumes. A clear low-frequency vibration can be observed by the flat cable near the V section, which is associated with wavy liquid surface and water-cable interaction.

- Figure 3 shows the spectrum analysis for the DAS data recorded at the V section on different cables. We observed that at the frequency peak around 20 Hz, the signal amplitude decreases as accumulated water volume increases. This is likely due to the accumulated water volume stabilize the pipe vibration, which can be used to determine water accumulation volume. Further data analysis and modelling will be conducted to verify this interpretation.
- In Figure 3 we also observed the spectrum amplitude is much larger for the measurements with 20L water accumulation. This is due to the slugging behavior of the flow. The slugging induced strong pipe vibration that can be clearly identified by DAS on all cables, as shown in Figure 4.

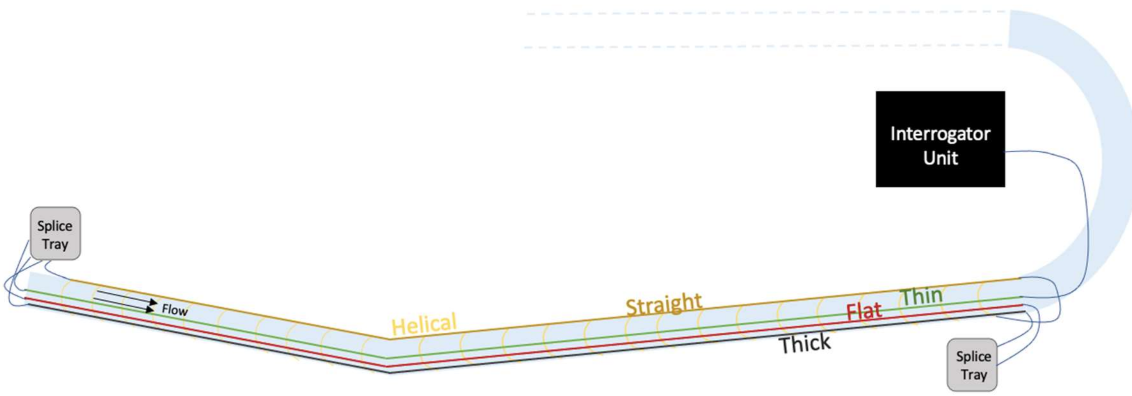

Figure 1: Diagram of Task#1&2 experiment. The interrogator unit is spliced directly to the thin cable. The thin cable is connected to the flat cable protected by the splice tray. The flat cable, thick cable, straight cable, and helical wrapped cable are connected in sequence. The two black arrows indicate the direction of the flow.

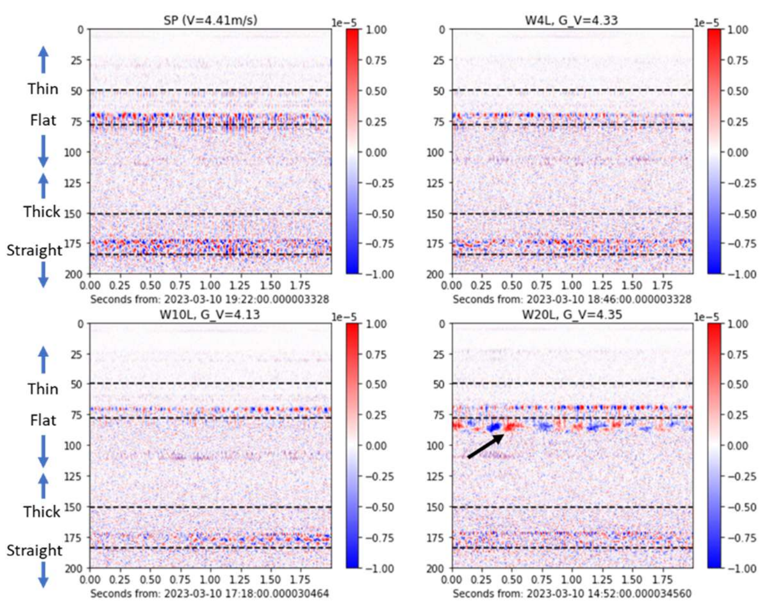

Figure 2 Waterfall plots for DAS raw data all observed at around 4 m/s gas velocity with different volumes of water accumulated at the v section. Vertical axis is distance along the fiber in meter, and horizontal axis is time. Top row: no water accumulation (left), 4L water accumulation (right). Bottom row: 10L water accumulation (left), 20L water accumulation (right). The location of V section is indicated by black dashed lines. From top to bottom, the dashed lines mark the V section location for thin, flat, thick, and straight cables. Blue arrows indicate flow direction in each fiber section. Black arrow highlights the vibration of flat cable associated with the wavy liquid surface.

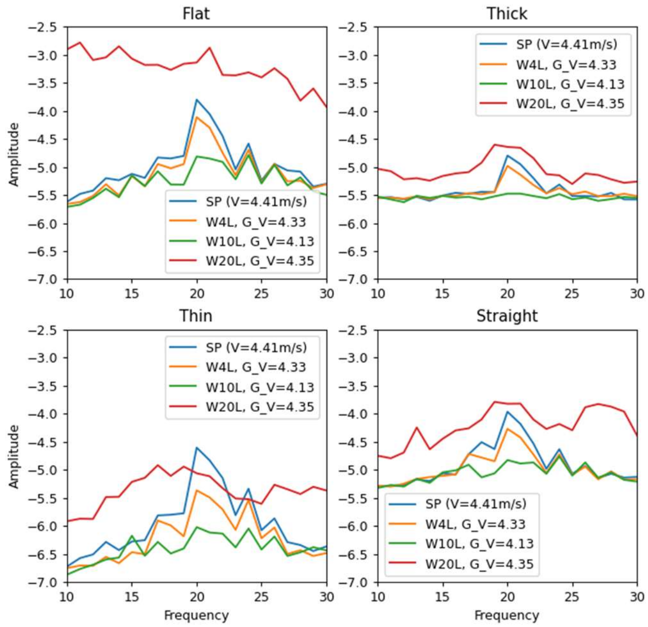

Figure 3: Frequency spectrum of the DAS measurements near the V section recorded on different cables, at the gas velocity around 4 m/s. SP (Single Phase): no water accumulation. W4L, W10L, W20L: 4L, 20L, 20L of water accumulation, respectively. The amplitude is in log scale. The amplitude of the peak around 20 Hz is clearly associated with accumulated water volume.

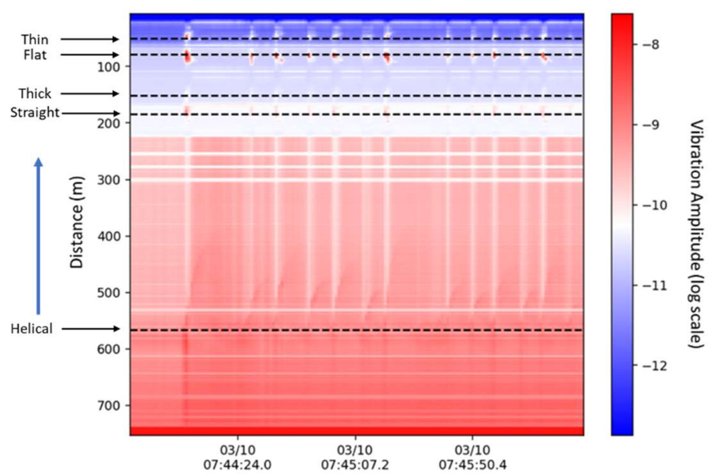

Figure 4: DAS measured vibration amplitude over time. The measurement was taken during 20L water accumulation with gas flow rate of 4 m/s. Black dashed lines indicate the V section location of each cable.

Activities completed during the reported period for Tasks#3-6:

- Benefiting from the extended processing and analysis of the data in Tasks #1&2, we have noticed that the internal flat cable provided better quality data. Hence, the fiber optics deployment in the steel pipe was revised and re-designed. An internal flat cable was added.
- As planned, the steel pipeline is complete and equipped with all five different fiber optic cables. The fiber cables deployed in the steel pipeline are consecutively spliced with each other in the following order: straight external yellow cable with the black cable, followed by the flat cable, and then succeeded by the thick cable and then connected to the external helically wrapped cable coming in last to facilitate the change of the 1 m middle section as explained in the previous report.
- The splicing of all five cables was tested with a visible light source successfully showing laser light at the end of the connection. The splicing integrity was further tested with the Terra 15 interrogator indicating a robust signal strength.
- Two rubber-sealed inlets were created to introduce the internal cables (thick, black, and flat), as shown in Figure 5. The rubber-sealed fittings are assembled in a flexible manner to allow the easy movement of the internal cables, and the change of the 1m test section situated in the middle of the steel pipeline with the least re-splicing needed.
- We used a flexible hydraulic hose to connect the steel pipeline with the main air supply from the Mine air compressor. A PVC valve was added to divert the airflow from the PVC flow loop into the steel pipeline.
- As planned, we have successfully conducted the base case experiments with non-defects in the 1m test section. As part of Task#5, we tested single-phase air with two different setups. In the first setup, six tripods were used to support the steel pipeline. While in the second setup, one of the supports (the tripod at the beginning of the 1-m test section) was removed to simulate the condition when one of the supports is nonfunctional or damaged. This is shown in Figure 6. Figure 7 shows the waterfall plot of recorded DAS data with a gas flow rate around 10 m/s for the two different setups. Strong pipe and cable vibration can be observed in all types of cables. Further spectrum analysis identified the resonant frequencies of the pipe vibration modes. The measurements illustrate the amplitudes and frequencies of the vibration modes change after the support removal (Figure 8).
- For Task#3, the 1m test section was corroded internally at the 6 o'clock position (2 ft. long corroded internal surface with a depth of 3 mm reflecting the pipe wall thinning). The 1m steel pipe is ready for the upcoming experiments. Our next step is to change the current non-defected 1m section in the middle with the steel pipeline to the corroded 1m section. Figure 9 shows an internally corroded steel pipe surface vs a non-corroded surface.
- For Tasks#4&6, we have discussed the possibility of handling the creation of the dent and leakage spots on the 1m test section on campus at the physics machine shop. Our next step is to make the model of the targeted design for both experiments to be executed by the machine shop experts.

Figure 5: Photograph of the rubber-sealed inlets used to deploy the internal cables.

Figure 6: Photograph of the removed tripod at 1m test section.

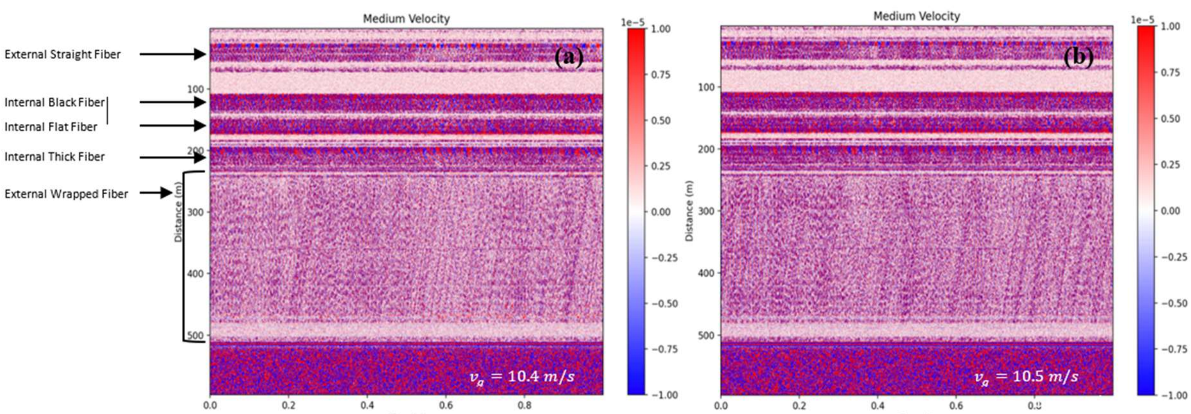

Figure 7: Waterfall plots of processed DAS data for all 5 cables with the gas flow rate around 10 m/s. (a) 6 supports (b) 5 supports to simulate the condition when one of the supports is damaged.

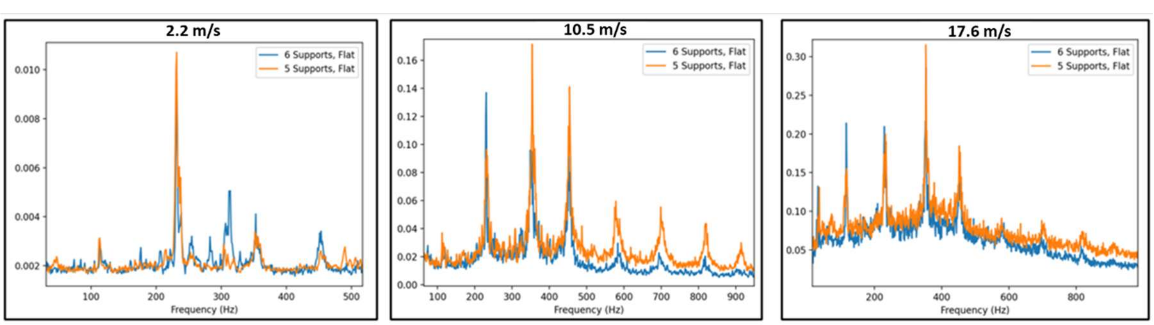

Figure 8: Steel pipe vibration spectrum comparison for 6 & 5 supports. The data were measured by the flat cable.

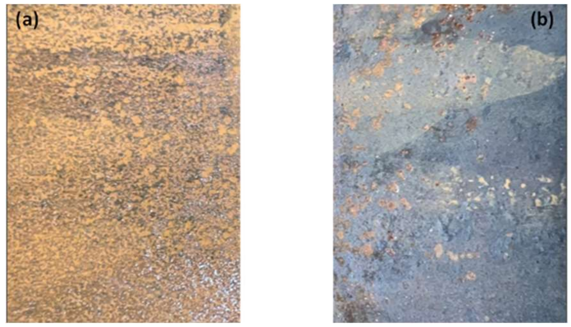

Figure 9: (a) corroded vs. (b) non-corroded internal pipe surface.

Project Financial Activities Incurred during the Reporting Period:

The following table summarizes the financial activities and the corresponding expenses during the reporting period. Also shown are the budget for the 2nd year and the total expenses in the 2nd year so far. Please note that the actual amount for the expenses might be slightly different from the numbers in the final financial report, since some of the expenses occurring in late of the quarter may not be included in the university's financial system that we use for managing the funds and expenses by the time the report is submitted. Normally, it takes several days for an expense to be shown in the system after its occurrence.

Items\Budget and Expenses		Budget for Year 2	Total Expenses in Year 2 So Far	Expenses During Reporting Period
1	Faculty Salaries and Wages including Fringe Benefits	$28,510	$0	$0
2	Graduate Student Salaries	$65,920	$25,230	$13,050
3	Graduate Student Tuition	$46,260	$23,006	$23,006
4	Experimental Expenses (experimental work supplies, services, maintenance, cables, etc.)	$27,000	$5,119	$2,158
5	Travel	$3,000	$0	$0
6	Indirect Costs (51.5%)	$64,703	$15,630	$7,832
Total		**$235,392**	**$68,985**	**$46,047**

Project Activities with Cost Share Partners:

The cost shares are the AY efforts of the PI and co-PIs. Activities are the same as above.

Project Activities with External Partners:

No external partners.

Potential Project Risks:

PI Fan is on maternity leave and co-PI Jin is taking the lead of this project during this period. One PhD student will take an internship during summer 2023, and the other PhD student is still recovering from her ankle injury. We plan to hire a summer intern to support the experiments during the summer months. These risk factors may potentially delay the project timeline.

Future Project Work:

In the next 30 days, we will:

1. Start Tasks#2.1 as planned
2. Continue Task#5.1 as planned
3. Start and finish Task#5.2 as planned
4. Continue the data analysis from previous experiments

In the next 60-90 days, we will:

1. Continue Task#3.5 as planned
2. Start Task#4.2 as planned
3. Start Task#6.2 as planned
4. Continue the data analysis from previous experiments

Potential Impacts to Pipeline Safety:

Tasks#1 and #2 can potentially help identify and characterize the possible liquid accumulation in a gas gathering or transmission pipeline using DAS, while Tasks#3-6 will potentially help detect the internally corroded surface, deformation, infrastructure damage, and leakage in a gas pipeline.