Team 14 Restated Project Scope and Project Plan

Noise Mitigation in an Organic Rankine Cycle (ORC) Turbine Bypass Line

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Abstract

Sustainable and clean energy is emerging and becoming a more viable choice in the current industrial atmosphere. Energy recollection systems are becoming commonplace in industrial processes that produce byproduct waste, such systems increase efficiency while lowering waste and environmental impact. These systems produce grid level electricity from otherwise wasted thermal energy. In this way, an ORC system generates cost savings and efficiency but like all concepts there is a unwanted byproduct of the ORC process, excessive noise generation. When the working fluid of the ORC is not operating the turbine, the flow is passing through a bypass line which is a narrow and congested segment of piping in the system. This in turn produces an undesirable amount of noise which poses health issues to employees and an annoyance to residents in the vicinity. Team 14's objectives are to conduct multiple measurements on site during steady-state and bypass, determine the noise characteristics and define the generated noise from the time to frequency domain. Early results from testing show a steady-state noise level of 81dB to 88dB from the bypass line. From this a passive noise dampening solution localized to the bypass line is to be devised and implemented.

Acknowledgments

Team 14 would like to extend our deep appreciation to the FAMU-FSU College of engineering and the Mechanical engineering department for their time and devotion to organizing this year's senior design projects. We also want to personally thank Verdicorp, our sponsor Corey Nelson, and our advisor Dr. Cattafesta for their time, consideration, and experience in their fields

1. Problem Statement

When operating in bypass, the ORC system generates an unacceptably loud amount of noise. A solution needs to be found to mitigate the bypass line noise while not impeding the performance of the system nor requiring significant modifications of existing components.

2. Restated Project Scope/Goals

The project scope/goals for this project have not been modified from the initial scope of the project stated in the fall semester. The overall goal for the project is to design and test a prototype that will lower the noise level when the refrigerant is passing through the turbine bypass line to the levels seen when the refrigerant is flowing through the turbine and the ORC system is in steady-state operation generating electricity.

The goals and objectives/constraints for the project have remained constant from what was stated in the fall semester. It has been reiterated by our sponsor that the prototype is to be designed to stay on the outside of the ORC system (no modifications allowed within the piping system). In addition, the environment of the ORC system is to play no role in the type of noise mitigation used (e.g. the ORC system currently resides within a shipping container, however this is not always the case).

2.1 Scope

- Create a reasonably cost effective solution to dampen the noise.
- The prototype must not impede the performance of the system.
- Lower bypass line noise levels to levels seen during steady-state operation.
- Have prototype manufactured in Verdicorp's machine shop.

2.2 Objectives

To successfully create a well-researched working prototype to dampen the turbine bypass line noise level, its necessary to properly complete several smaller objectives. These include but are not limited to:

- Find the source of the noise in the turbine bypass system
  - This requires properly measuring and analyzing the noise levels given off during ORC system – specifically analyzing the decibel levels seen at specific frequencies.

  - It is necessary to compare the frequency and decibel footprints in both the steady-state and bypass line operations to determine which frequencies are most affected.
- Create a working prototype for the ORC bypass line system
  - The type of noise mitigation method will depend on the desired frequencies to dampen.
  - Material choice and location of prototype will be aimed specifically to address necessary frequencies.

2.3 Goals

- **Initial goal**: Create a working prototype that can be tested.
  - Document new noise levels of the ORC system while operating in bypass.
  - Address any prototype issues that may arise such as correct fitting and sealing.
- **Final goal**: Have a working prototype that will lower the noise level of the ORC system when operating in bypass mode to the noise levels seen during steady-state operation.

3. Approach

To properly characterize the noise given off by the ORC system, proper measurement procedures need to be followed to provide accurate and reliable data for concept generation. The locations within a closed body chosen for measurements must be further than one meter from any wall or surface that can cause noise to rebound back to the testing equipment, changing the pressure levels and frequency of the original sound. The same hold for the ground, where the microphone used for measurements should be supported 1.2 meters off the floor.

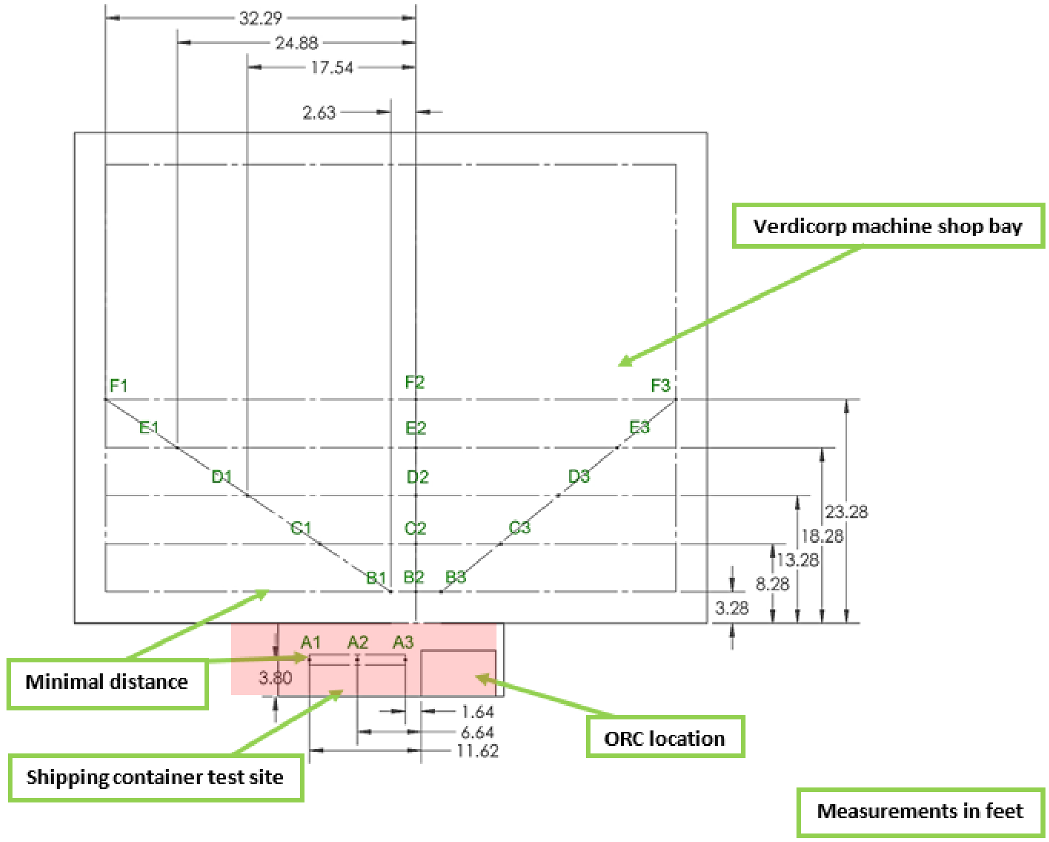

Figure 1. Layout of the Verdicorp Machine Shop

To abide by these measurement methods, a measurement template was created. From Figure 1 the measurement layout was developed with the safety of the Verdicorp employees both inside and outside of the steel shipping container as shown in the red highlighted zone. The measurements are taken at six different zones with three measurements taken along each zone to provide enough measurements to generate an acoustic contour plot when enough data is collected from measurements. At each measurement point, the startup transient and steady state noise levels will be recorded three times each to get a more accurate idea of the average dB level.

Figure 2. View from inside the ORC shipping container

Figure 3. View from Verdicorp machine shop

Figure 2 shows a view from inside the shipping container where the ORC is located. Points A1, A2, and A3 are placed inside the container equidistant from the ORC and far wall. Figure 3 is a view from the Verdicorp machine shop looking at the opening to the shipping container. The B and C region markers are shown emanating from the container door.

4. Progress Made

Raw Data Matlab Processing

With the data files ready for processing, we used the edited and reviewed code from Dr. Cattafesta with a few adjustments to compare data across the different Zones and points for analysis. The sine test script was also properly tested and confirmed the frequency and spectrum power accuracy of the pwelch function for use with the on-site data.

Table 1. Plot Configurations

Steady-State (SS)	Zone A points 1-3	Zone B points 1-3	Zone C points 1-3
Transient State(T)	Zone A points 1-3	Zone B points 1-3	Zone C points 1-3
Comparison (T vs SS)	Zone A2	Zone B2	Zone C2

Steady-State

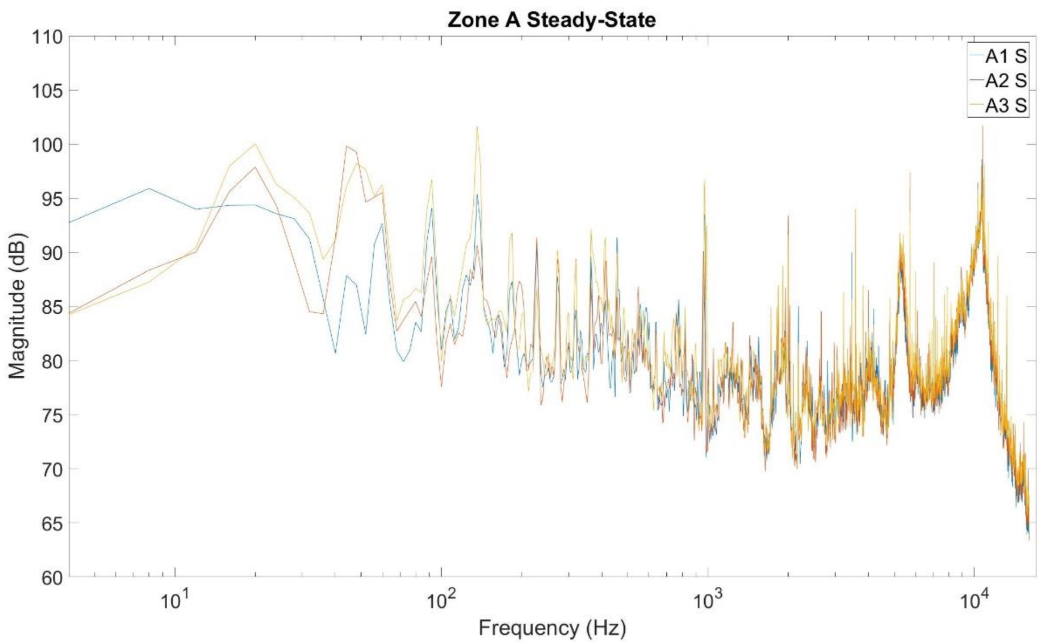

Figure 4. A1, A2 and A3 Steady-State dB vs frequency domain plot

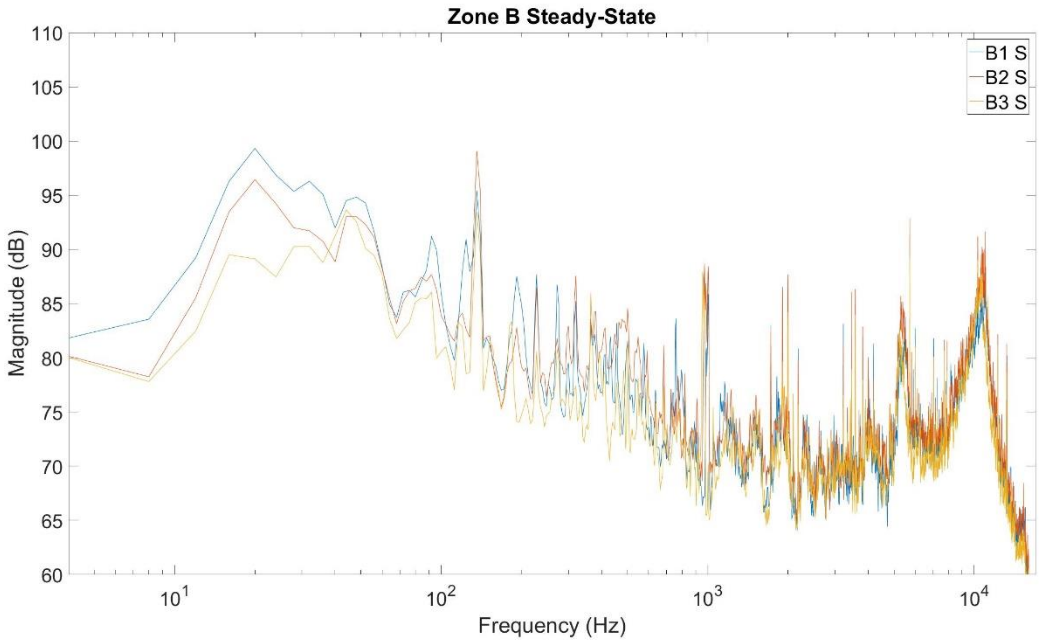

Figure 5. B1, B2 and B3 Steady-State dB vs frequency domain plot

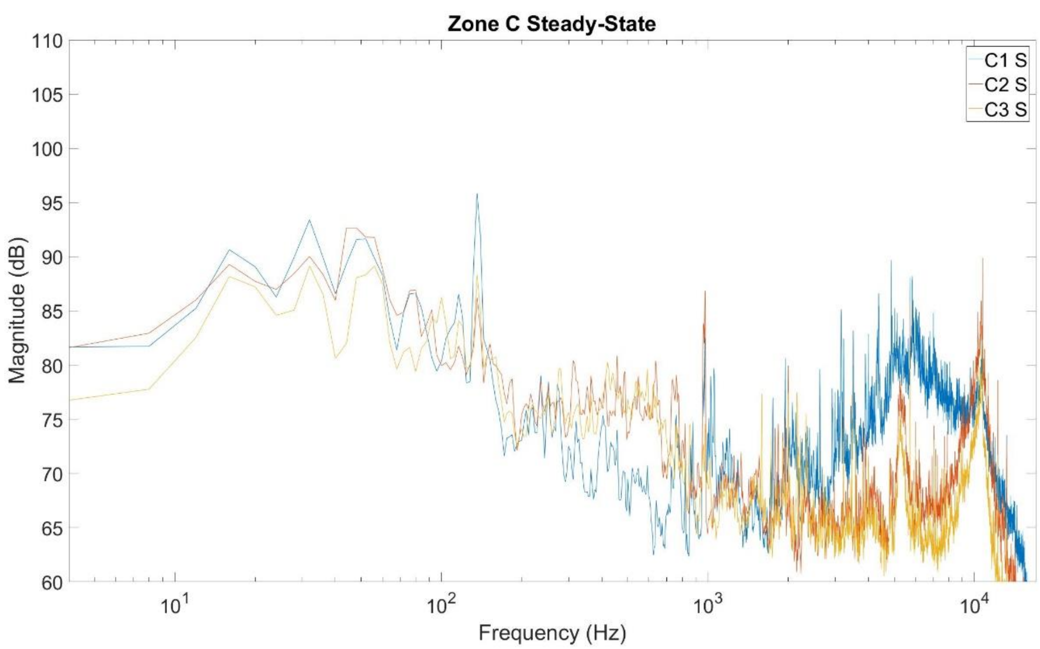

Figure 6. C1, C2 and C3 Steady-State dB vs frequency domain plot

For figures 4-6 the steady-state measurements are shown for the three positions within each zone from the measurement methodology. For figures one and two the results are about as expected within reason. The noise profile and dB levels in zone A are all about the same, which follows the principle of the shipping container acting as a reverberation chamber and the noise level being about average throughout. In figure 6 there is a variation between zone C1 from C2 and C3 with a spike round 8 kHz. More analysis will be required but this may be a geometric factor based on the location of C3 from the noise source. but this may be a geometric factor based on the location of C3 from the noise source. Moving forward with data verification, the sampling rate will be increased to inspect the impact on the measurements and if the higher end frequencies have been aliased.

Transient State

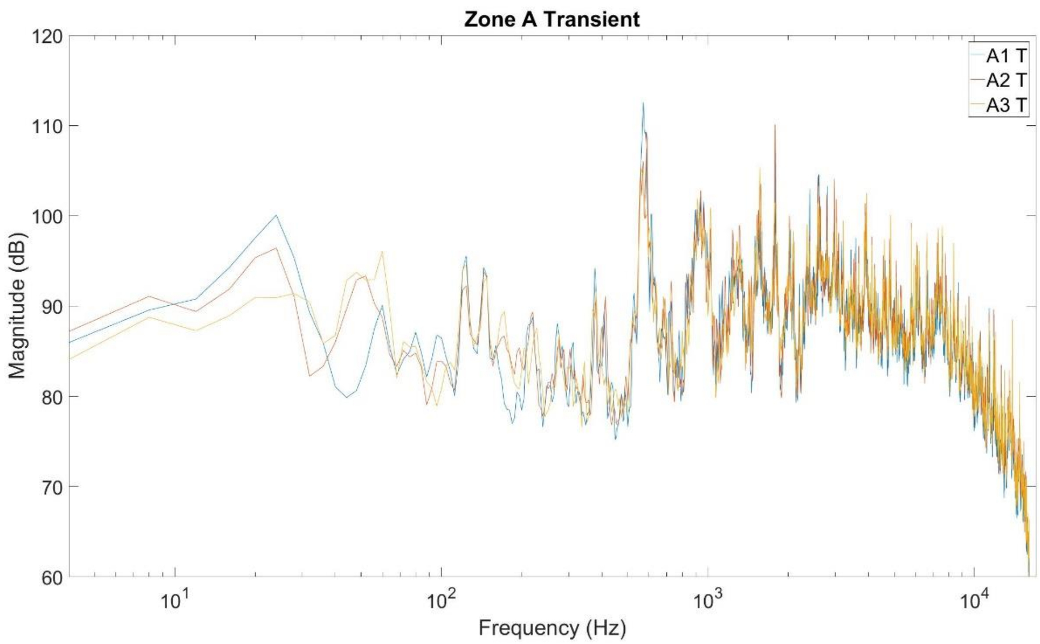

Figure 7. A1, A2 and A3 Transient dB vs frequency domain plot

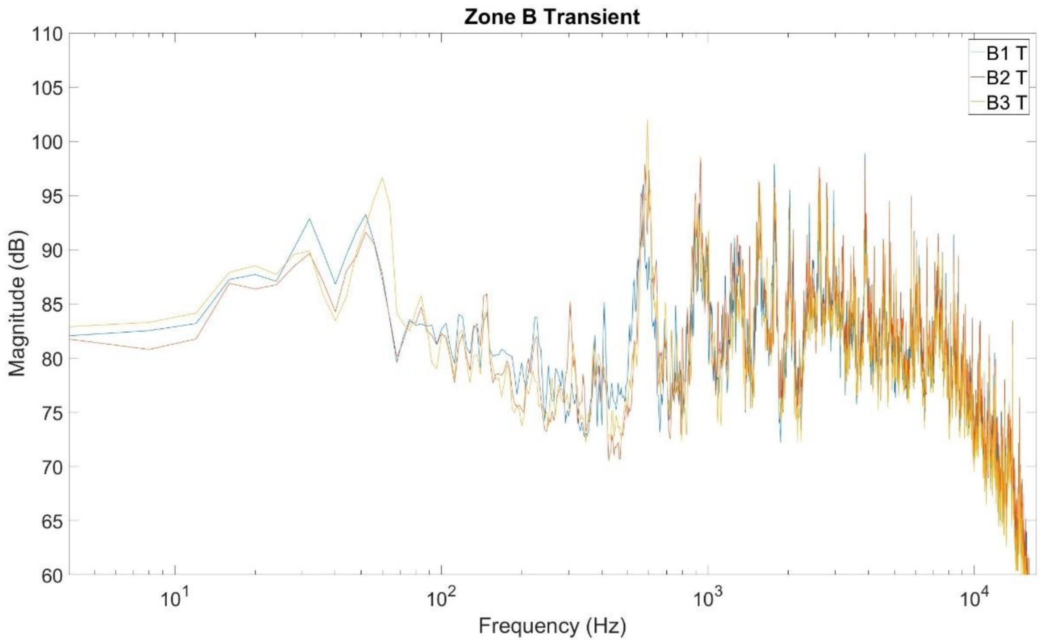

Figure 8. B1, B2 and B3 Transient dB vs frequency domain plot

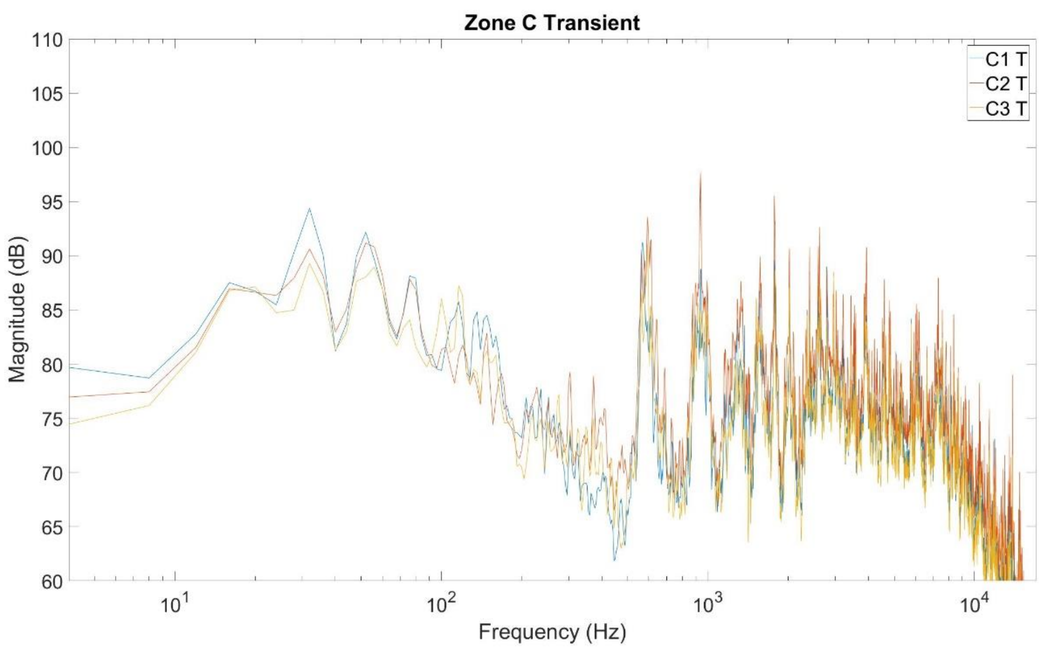

Figure 9. C1, C2 and C3 Transient dB vs frequency domain plot

For figures 7-9 the transient plots show about the same trend as the steady-state measurements with a constant low frequency response but with larger dB measurements at the higher frequencies as expected from the working fluid passing through the bypass line. At 1.7 kHz at all zones we can observe the largest dB spike across the frequency range at 110 dB, which occurs at each location of our measurements showing consistency across the various testing zones. As recommended for our next set of measurements we will proceed and record at higher sampling rat, from 32 to 40kHz to improve upon the sampling range and prevent potential aliasing of the data points.

Comparison

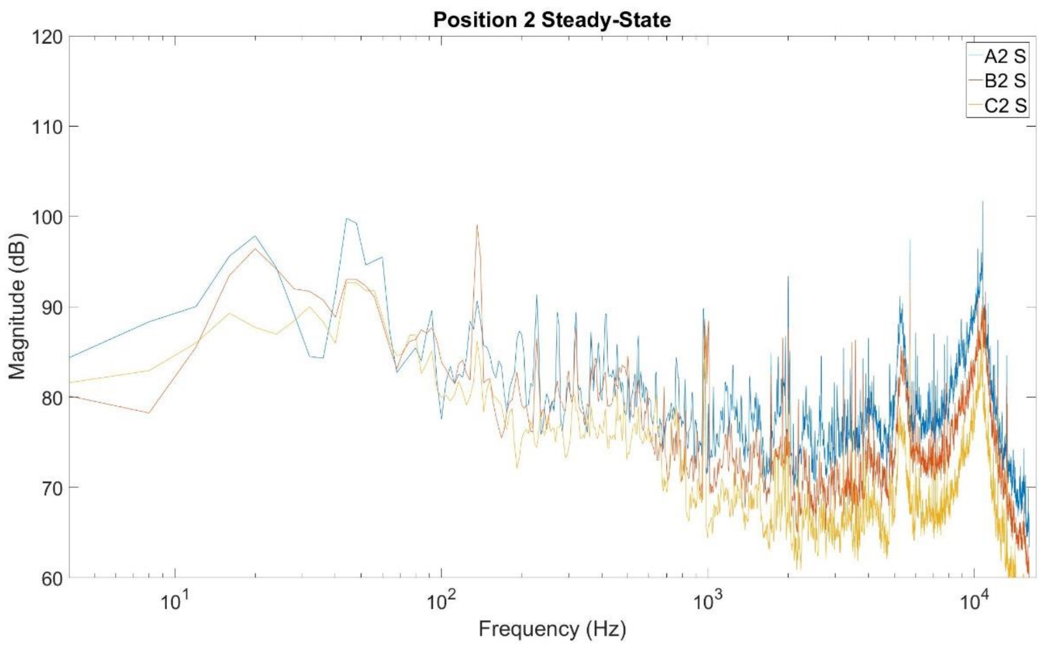

Figure 10. A2, B2 and C2 Steady-State dB vs frequency domain plot

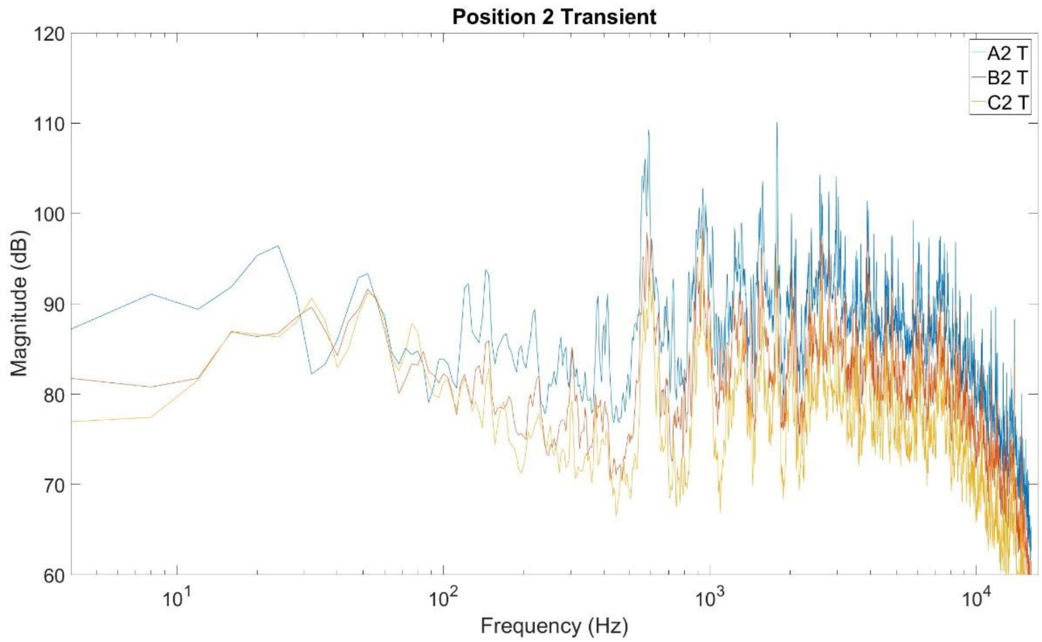

Figure 11. A2, B2 and C2 Transient dB vs frequency domain plot

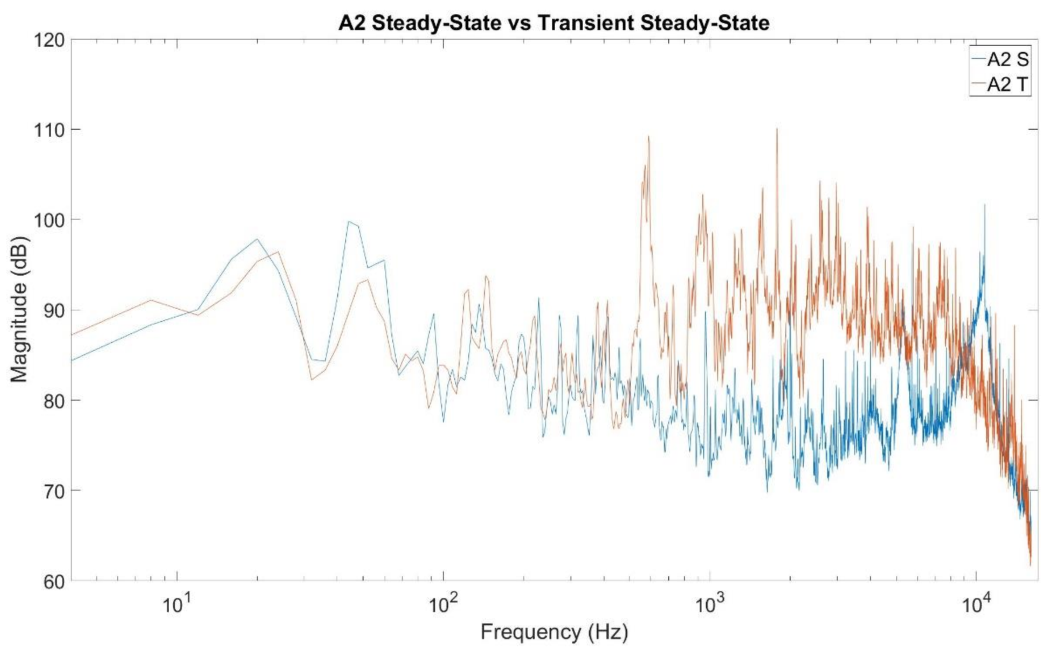

Figure 12. A2 Steady-State vs Transient in dB vs frequency domain plot

Plot Data Extraction

To better analyze the plots the generated Matlab figures were further broken down using the built-in brush and clipboard features as shown in the next image.

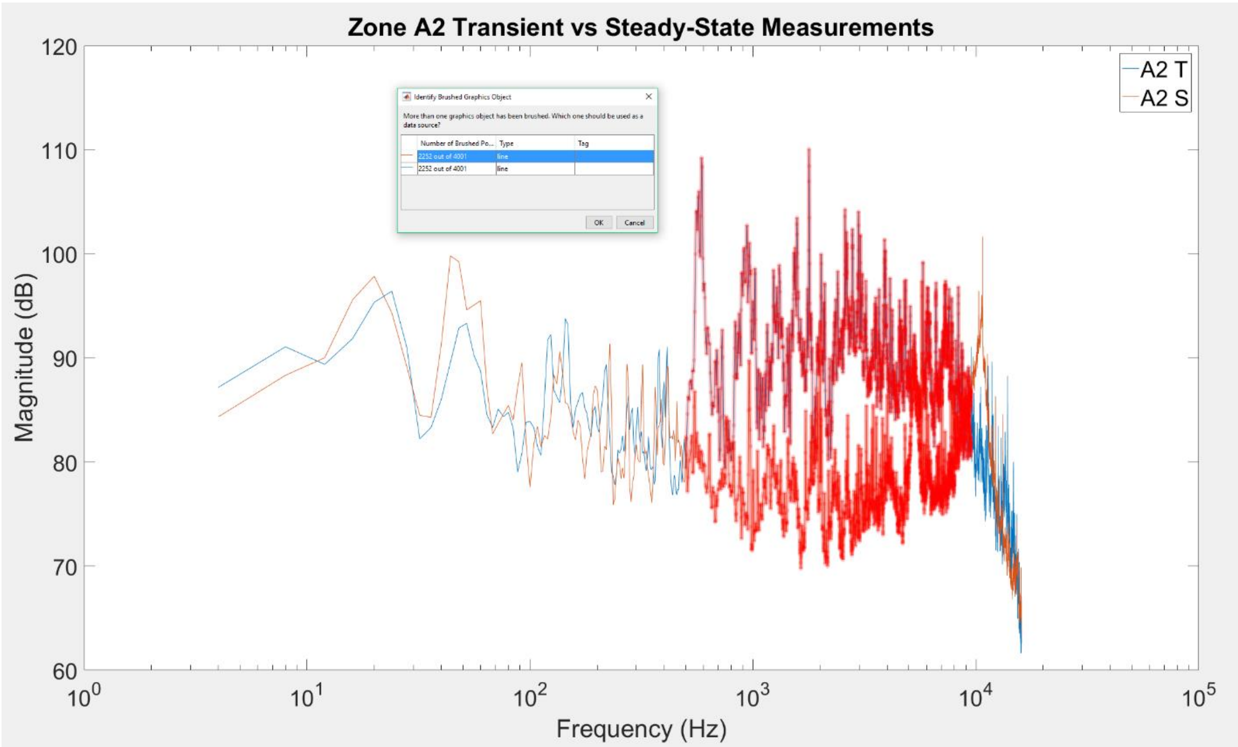

Figure 13. A2 Steady-State vs Transient frequency range refinement plot

This enabled us to only include the frequency range were the dB values changed significantly in intensity between steady-state and transient state. The data could then be saved for each state and was transferred back into excel for further refinement which will be described in detail in the discussion section of the write-up

Discussion

First up for discussion is the noise characteristics that first become apparent in figures 4-6. In these steady-state plots for zones A, B, and C, there are two principle ranges of the plots were the dB response is distinctively different. The first occurs from about 50 Hz to 500 Hz, and the second from 500 Hz up to 10,000 Hz. This becomes even more distinctive when looking at the comparison plots in figures 12.

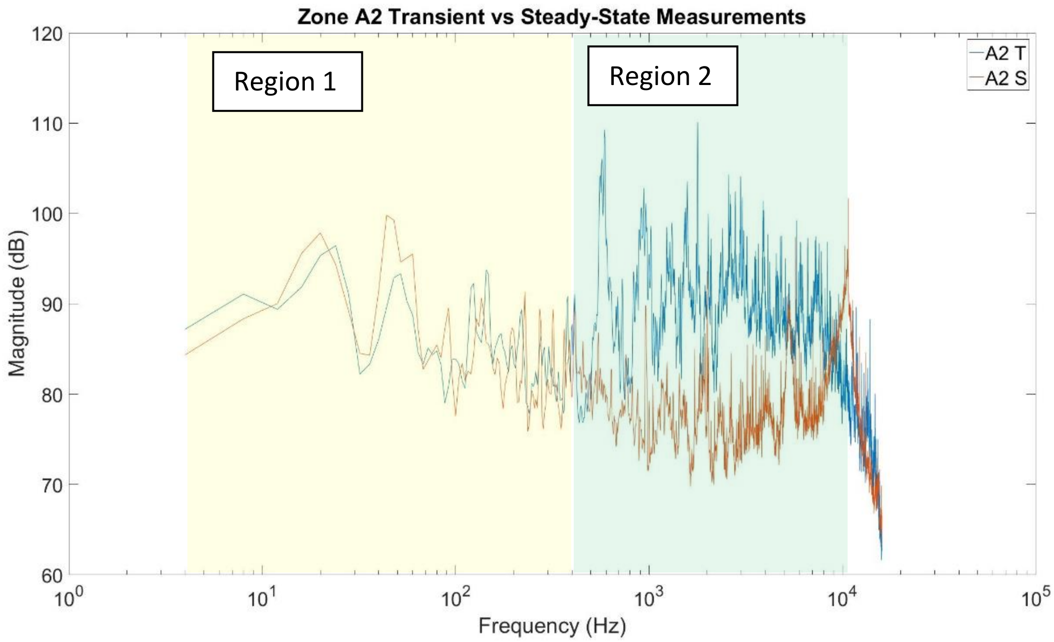

Figure 14. A2 transient vs steady-state frequency range comparison

As shown in figure 14 region 2 highlights were the distinctive variance in the frequency vs dB varies for the steady-state and transient stages of the ORC's operation. The higher frequencies in region 2 support the higher intensity of the noise we experienced firsthand at the test bed, and it also occurs in the frequency range in human hearing where the threshold of pain is lower. This behavior is repeated across all three zones will overall lower dB values as expected from drop-off due to distancing from the noise source. With region 2's distinctive variance between steady-state and transient state due to the nature of the ORC system, region 1 does not experience any significant changes in its profile whether it is in steady-state or transient. One possible reason this may be the case is that this region may be the result of some constant noise source within the ORC system that is apparent at all operating states of the system. This may be the pump or possibly the transformers within the shipping container. The profiles for each zone and their according position are similar except for the case of figure 6 in Zone C1 where the dB is larger in the higher frequency range similarly to the transient levels. This may be a result of geometric factors within the work bay or measurement error on behalf of human error, this is to be noted as the only major disturbance from the similarity among the data sets.

Zone C2 Steady-State Values	
Hz (604-16,000)	dB(A)
Average dB	67.73

Zone B2 Steady-State Values	
Hz (604-16,000)	dB(A)
Average dB	73.58

Zone A2 Steady-State Values	
Hz (604-16,000)	dB(A)
Average dB	78.23

Figure 15. Position 2 Steady-State Average dB Assessment

Focusing on the values obtained from the data analysis, for all the steady-state testing the average dB recording in position 2 is as listed in figure 15 above. From our proposed rough steady-state value of 80 dB provided to Dr. Gupta by Verdicorp, our recorded value of 78.23 dB is both within acceptable ranges and establishes our target sound pressure level that we want to dampen to during the transient stage.

Zone C2 Transient Values			Zone B2 Transient Values			Zone A2 Transient Values	
Hz (500-9,956)	dB(A)		Hz (500-9,956)	dB(A)		Hz (500-9,956)	dB(A)
Average dB	76.92		Average dB	82.47		Average dB	88.66

Figure 16. Position 2 Transient Average dB Assessment

Moving from steady-state, the average dB in the transient stage at Zone A2 is 88.66 dB as shown in figure 16. This is a large increase in the dB level due to the logarithmic nature of the dB scale, which further backs the higher perceived sound intensity experienced at the test site during the transient state compared to steady-state. For both figures 15 and 16 the dB levels drop off as one moves outward from the noise source at zone A to C, sticking to the definition of noise cutoff for the sake of the reliability of the testing rather than for use in finding noise mitigation techniques.

Zone A2 Steady-State Values			Zone A2 Transient Values		
Hz (504-11,184)	dB(A)		Hz (504-11,184)	dB(A)	
Average dB	80.57	At 872 Hz	Average dB	87.66	At 1784 Hz
Max dB	101.69		Max dB	110.10	
Min dB	69.75		Min dB	74.29	

Figure 17. Position 2 Zone A Comparison Data

The final numerical results follow the same process at figure 17 but the range is slightly broader and we look specifically at the higher and lower strengths of dBs that were measured (slight differences between these and the past average dB level are a result of the broader frequency range). For the transient stage the highest recorded dB level was 110 at a frequency of 1784 Hz, and for steady-state 101 dB at 10.7 kHz.

What we took overall from these measurements is that our target goal for the transient dB is around 78 dB as recorded from the steady-state. The current dB level at transient is 88, over a 10dB increase from steady-state. With our current noise levels known and our target range set, we can now use that data showing were most of the offending noise is occurring at higher frequencies and target those frequency regions with specific materials and techniques to mitigate the overall noise level down during the transient stage of the ORC's operation.

5. Challenges

Throughout the semester, the team is going to confront different challenges to accomplish the goal of the project. One of them is the environment and location of the system. As can be seen in Figure 18 the system is located at the corner inside a shipping container, therefore reverberation is going to be a problem. The sound will repeatedly bounce off reflective surfaces such as the ceiling, walls, floor, or tables. Particularly, too much reverberation has a negative impact on any possible noise measurements that could be taken inside the container due to an averaging of the sound intensity within the container.

Figure 18. ORC system positioned in shipping container

A reverberation time measurement is used to calculate the time required for a sound to fade way or to decrease by 60 dB. RT60 is the standard reverberation time measurement and is used to determined how high the reverberation is within a room. Using the equation for RT60 a simple calculation was performed to determine the reverberation inside the container where the ORC is located. As can be seen in Equation 1 below, the resultant time for the reverberation is equal to 2.2 seconds. This means that if the sound generated by the ORC is abruptly stopped, the reflections will linger in the room for 2.2s until it dissipates. On this equation V is the volume, S is the surface area, and a is the average absorption coefficient of room surfaces. Another point to make is that the container opening is factored into the reverberation time and an absorption coefficient of 1 is given due to the noise leaving the shipping container. Table 2 shows a comparison of the RT60 for different rooms. Comparing the result of the reverberation inside the container with the other different rooms, it can be say that the room where the ORC is located is very echoic. After speaking with our sponsor additional dampening of the container or implementing an enclosure is not desired and a localized concept will need to be utilized [1].

$$RT_{60} = \frac{0.161\frac{m}{s} * V}{Sa} = 2.2s \text{ [2]} \qquad \text{Equation 1}$$

Table 2. RT60 for different rooms[1]

Location	Volume	Critical Distance D_c	Recommended RT60
Recording Studio	< 50 m^3	1.5 m	0.3 s
Classroom	< 200 m^3	2 m	0.4 - 0.6 s
Office	< 1'000 m^3	3.5 m	0.5 - 1.1 s
Lecture Hall	< 5'000 m^3	6 m	1.0 - 1.5 s
Concert Hall, Opera	< 20'000 m^3	11 m	1.4 - 2.0 s
Church			2 - 10 s

Another challenge that the team is going to meet is characterizing the noise source. As can be seen in figure 19, the ORC has different components and each one of those components contributes to the total noise recorded on site. Therefore, dampening those individual components of the bypass line with varying acoustic traits is going to be a challenge. In addition, another challenge that needs to be addressed is the availability conflict with Verdicorp. Currently there is only one boiler on Verdicorp, therefore they can only have one ORC functionating at a time. As it was last semester this is going to be an issue because the time of the ORC is divided between Verdicorp's clients, projects and our team. Currently we are working with our sponsor to fit additional verification testing and future prototype testing into our schedules.

Figure 19. View of the ORC Components

6. Deliverables and Schedule

Task Name	Duration	Start	Finish
Team 14 Spring 2017	**71 days**	**Mon 1/9/17**	**Mon 4/17/17**
Conclude Data Analysis	14 days	Mon 1/9/17	Thu 1/26/17
Concept Development	14 days	Mon 1/16/17	Thu 2/2/17
Measurement Confirmation	28 days	Thu 2/2/17	Mon 3/13/17
Procurement of Materials	28 days	Thu 2/2/17	Mon 3/13/17
Prototype Manufacturing	14 days	Mon 3/13/17	Thu 3/30/17
Prototype Measurements	7 days	Thu 3/30/17	Fri 4/7/17
Prototype Comparison	7 days	Fri 4/7/17	Mon 4/17/17

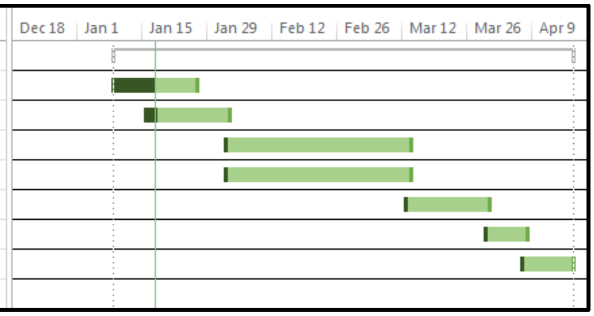

Figure 20. Semester 2 project timeline and plan

As shown in figure 20 our time will primarily be spent on measurements and the procurement of the materials necessary to construct the acoustic dampening concept. Being that our solution will be passive and that we have the assistance of Verdicorp's machinist, construction and attachment of the passive dampening system should not take much time. The measurements prior and after the prototype has been applied will be the most important aspect of our design process. If the results of our measurements after the dampening are close to the desired levels, we can continue to tweak the design to reach the desired levels.

7. Summary

After collecting and analyzing the noise measurements our initially provided steady-state sound pressure level of 80 dB was confirmed, providing us with a strong target to fix our proposed dampening solutions on. Reducing the peak and average dB levels during the transient stage of operation from 110 dB and 88dB respectively to steady-state levels is still our primary concern. After consulting with our advisor on potential concepts we are limited to a localized noise dampening technique, as we are unable to use the walls or an enclosure within the shipping container. Looking forward we have concept refinement and material selection procurement. We must work closely with our sponsor to find times around their current projects to confirm our measurements and to test the prototypes we will have completed and installed by then.

References

1) "Total yearly running cost € 0," Atlas Copco - Energy recovery. [Online]. Available: http://ctenergyrecovery.atlascopco.com/en/. [Accessed: 17-Jan-2017].

2) N. T. Audio, "Reverberation Time RT60," Reverberation Time RT60. [Online]. Available: http://www.nti-audio.com/en/functions/reverberation-time-rt60.aspx. [Accessed: 17-Jan-2017].