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Project Number: P19310

TUNED VIBRATION ABSORBER DISPLAY

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ABSTRACT

This project is a continuation of project P18310. Project P18310's purpose was to build two vibrating mass systems to demonstrate the effectiveness of a TVA (Tuned Vibration Absorber) using LORD's vibration isolator technology at trade shows and academic presentations. Project P19310's goal is to take the existing unit and refine the design and software to create a more effective and portable solution.

> *History from P18310: A Tuned Vibration Absorber (TVA) is a device used within a system to reduce the severity of vibrations of a specific frequency in order to improve the robustness of the system. LORD is a company that sells TVA's for industrial use, but is unable to demonstrate the technology at trade shows, as no equipment currently exists for this purpose. Ideally, a system could be created that allows for the direct comparison of the two vibration systems, while at the same time providing data to support the demonstration in a manner conducive to table top displays.*

The key objectives of this project are: de-couple the two vibrating masses, rewrite existing QT (C++ code package) code into MATLAB, reduce packaging size and weight of system, maintain system ruggedness, and to be designed to be operated by a nontechnical person.

Our project upon completion has significantly reduced the coupling between the units. It has also been lightened substantively. The new MATLAB code however has bugs and does not fully met the requirements from the customer.

BACKGROUND

Last year, team P18310 was assigned with using LORD's vibration isolators to construct a Tuned Vibration Absorbers (TVAs) system for demonstration. Overall their final product was functional, but needed refinements in several areas. The main issues were the vibrating systems would couple during use. This would either reduce or inflate the vibration reduction values. The system was also overweight, preventing it from being brought with LORD personal on flights to tradeshows. Finally, due to QT being used, LORD engineers were required to learn a new language in order to troubleshoot any issues, or make improvements. Working with LORD we developed a list of needed improvements, itemized in Figure 1, and converted those to our engineering requirements. Our team decided that using the original designs and hardware with tweaks would be the most efficient way to accomplish the requirements.

Our team also identified our stakeholders, being LORD personal, RIT, the Senior Design Program, our guide Gary Werth, and the team members themselves.

Customer Rqmt. #	Importance	Description	Addressed by
Rugged			
R02	3	Handle 8-10hr days 5 days/week cont. usage	CS01
R03	1	Work continuously for 10hr day w/o maint	ER14
R04	3	Setup/Teardown by unfamiliar person (non-engineer)	ER15
R05	3	Laptop must fit in pelican case with display	CS19
Operation			
O02	1	Easy Troubleshooting <1hr by operator with eng. Background	CS06, CS07, CS16
O03	3	Standalone Unit	CS03?
Additional			
A01	9	Communicate Uses of TVA Technology	ER01, ER02, ER06
A02	3	Attract Customers to the Lord Booth	ER01, ER02, CS04, CS12
A03	9	Be Safe to Operate	CS12, CS20
A04	3	Instructions are clear and concise	ER15, CS06
Software			
S01	3	Fully Commented Code so changes can be made during downtime	CS16
S02	9	Display a SDOF System Near Resonance	ER02, ER03
S03	9	Display Second SDOF System with TVA	ER02, ER03, ER13
S04	9	Clearly show vibration reduction numverical number (very large)	CS02, CS04, CS12
S05	3	Display transmissability plots on separate pop-up screen	CS15, CS17
S06	1	Software Operable/debuggable onsite	CS16
S07	9	Measure/Display Vibration Readings via graphs	CS04, CS13
S08	3	Scale amplitude graphs (y-axis) to make graph more pronounced (possibly ove	CS04, CS13
Electronics			
E01	1	Change electrical connectors	CS04, CS20
E02	1	Use cleaner cable wrapping	CS04, CS20
E03	3	Reduce size of electonics box	ER16, ER18
E04	3	Color coded wiring diagram	CS06

Figure 1 – Customer & Engineering Requirements

SYSTEM REVISION - MECHANICAL

In order to meet the engineering requirements, the mechanical team developed three top priority goals: minimize the coupling of vibrations between the two vibrating units, reduce the weight of the system, as it is shipped, to be under 50 lbs., and maximize the vibration absorbed by the TVA. These three goals drove the majority of changed to the mechanical system.

To decouple the two vibrating units, the large baseplate was swapped out for two smaller base-plates so the two units could be physically separated. With the two units separated, the coupling between the two was significantly reduced. Some new issues were introduced, however. Since the smaller base-plates were much lighter, the vibrations were enough to slide the baseplates around on the table surface. This was combated by adhering four Command Strips to the bottom of each baseplate, firmly sticking it to the table. With these changes, the coupling between the two vibrating units was significantly reduced. When both units are on the same table, a drop in vibration reduction of approximately 6% is observed compared to the units being on separate tables.

The final major change made to the mechanical system was the re-tuning of the TVA mass. To accomplish this, the team used a modified version of the MATLAB code used by P18310. The input parameters were re-measured and updated to reflect last minute changes to the design that had occurred the year before. The modified code allowed the team to collect additional data from the simulation and identify a target frequency that would better comply with the input parameters and allow for consistent, visible vibrating motion. The team selected 11.4 Hz as the target operating frequency and redesigned the TVA mass to be the necessary weight for this frequency. The new mass, along with updates to the electronic system and operating code, was able to perform more consistently and absorb more vibration.

Additional minor changes were made to the mechanical system to achieve other requirements and constraints. New flywheels were machined, with a single hole instead of a slot, to eliminate some variability in the vibrating motion and make the two units more consistent. A locking pin to hold the TVA mass in place during shipping was added at the customer's request. The pin acts to restrict all TVA motion when in place, preventing unwanted strain and possible damage to the micro mounts. New mounts for the accelerometers were fitted to each unit to ensure the accelerometers were properly aligned and sturdy. Additionally, new acrylic covers were added to protect the vibrating units and function as safety guards during operation. Finally, the wiring harness change (described further below) added a new mounting location to the base-plate and allowed the cable to exit the enclosure from the side. This mount was added and a slot was added to the cover to allow the connector for the wiring harness to be reached.

SYSTEM REVISION - ELECTRICAL

The original electrical system needed a full overhaul. The wiring diagram was inaccurate, wires were nicked or exposed, and the switch to two base plates made the original cable obsolete. Needing new cables, the team decided to switch from the automotive connectors to Amphenol connectors due to their ruggedness and wide versatility. The new connectors allowed to cleaner cables that are easier to reproduce if needed. During testing, it was discovered that with an additional attachment to the Arduino Mega board already in use, the system could be simplified down to a single Arduino. This switch simplified the wiring, diagrams, and troubleshooting by removing an entire sub-system. This additionally allowed for cleaner and more direct wiring paths in the electronics box. Removing several points of possible error. An added feature of the new box was to have all wires be a dedicated color, continuously through its path. The prior system, had several mismatched, which created difficulties in troubleshooting. Due to the smaller system size requirements after the switch to one Arduino, and a different tool storage location, the original electronics box/system base was replaced by a separate electronics box that did not function as system base. During this shift, it was decided that the LED LORD display would no longer be a meaningful addition to the box, as it will now be placed out of sight. The removal of the LED light all\so allowed for further space saving.

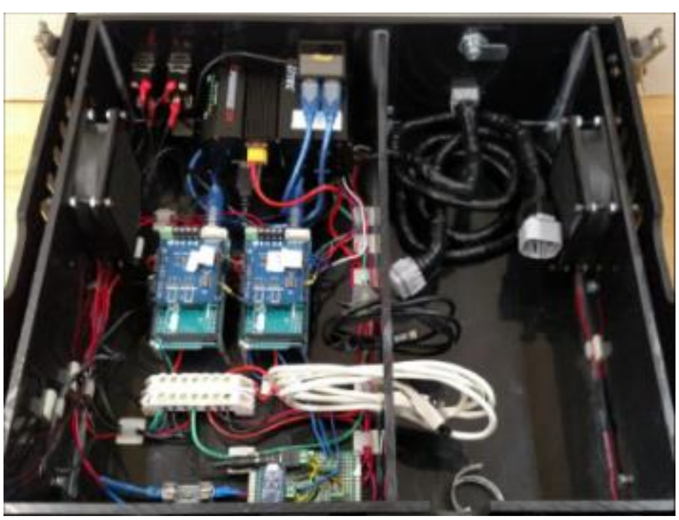

Figure 2 – Old Electronics box 18 x 18 x 6 (inch)

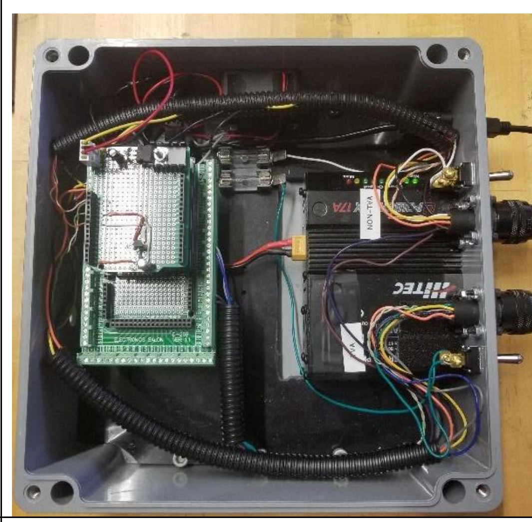

Figure 3 - New Electronics box 10 x 10 x 5 (inch)

SYSTEM REVISION - SOFTWARE

A LORD requirement with the project revision was to convert the QT software over to MATLAB to allow easier troubleshooting and improvements after the project's completion. This task was accomplished by writing two new software sets.

In the first iteration of the new software under the constraint that the software be written using MATLAB, the original setup was developed using Simulink. The motor control and accelerometer functionality was developed at which point it was discovered that sampling in real time was more difficult than previously thought. This method was abandoned due to the inability determine how to ensure the conversion of MATLAB sampling time to real time.

In the second iteration of the new software, all the development was completed within the MATLAB environment. Using the Arduino support packages for MATLAB made the programming easier when connecting to the Arduino, reading data and sending commands. This version was fully functioning and even included additional features such as temperature monitoring. Only after developing the software and merging it with the Graphical User Interface (GUI) was it discovered that the sampling rate of the Arduino support packages and GUI slowed down the processing of data to a rate equal to or less than the rate of operation. This causes aliasing and didn't allow for a usable interface or vibration data. The standard requirement for sampling a signal is for that sampling to be twice the highest frequency also known as the Nyquist rate. It was determined at this stage that using the Arduino support packages was not an option but that the GUI might still be usable.

The third and final iteration of the software was written using a combination of Arduino IDE to run both motors and read both accelerometers and MATLAB to display the vibration reduction data. This method still allowed for the system to be operated using one Arduino Mega with one motor shield. This method ran 20 times faster than the second iteration of the software but presented its' own problems. The GUI in MATLAB was still slowing the collection and display of data to a rate that cause aliasing. It was determined that plotting the data live was to root cause of the slow down. This cause a last minute decision to remove the graph from the display to ensure that the vibration reduction number was displayed at a rate that did not result in aliasing of the signal. Another issue using this method is that while the motor control functionality was built into the software for the Arduino getting the functionality for the changing of the frequency on the GUI could not be overcome.

SYSTEM REVISION - PACKAGING ALTERATIONS

A major issue of the system built by P18310 was weight. The total system was too heavy to be brought on commercial airlines, even with the maximum amount paid for oversized baggage. The solution P19310 choose was to separate the packaging into two separate Pelican cases. Pelican cases were chosen for their strength and low weight to ensure the system arrives safely. The two vibrating units and their covers were placed in one case. While the electronics box, laptop, cables, and spare parts were placed in a second case. The final weights of the cases were 45 lbs and 27 lbs, respectively. This guarantees that the cases will be able to fly on all major airlines without issue.

Figure 4 – Vibrating unit box (45 lbs)

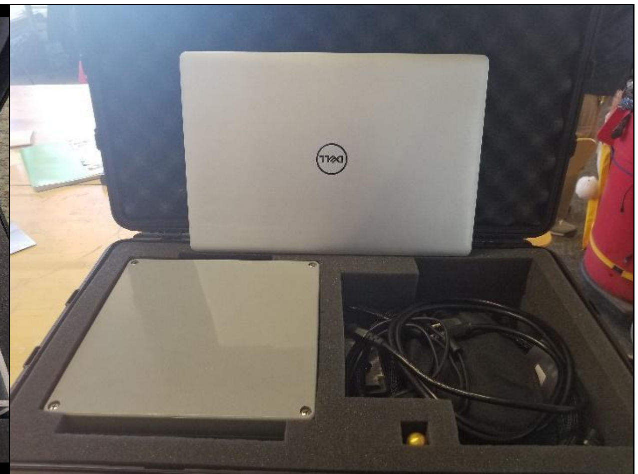

Figure 5 – Electronics (27 lbs)

Other addition changes were made for shipping as well. With the TVA being re-machined to correct the optimization issues, LORD suggested adding a shipping pin to immobilized the TVA during shipping to prevent damage to the micro-mounts. A 3D printed puck was designed to fit under the TVA to relieve downward pressure, while a bolt held the TVA in place for lateral movement.

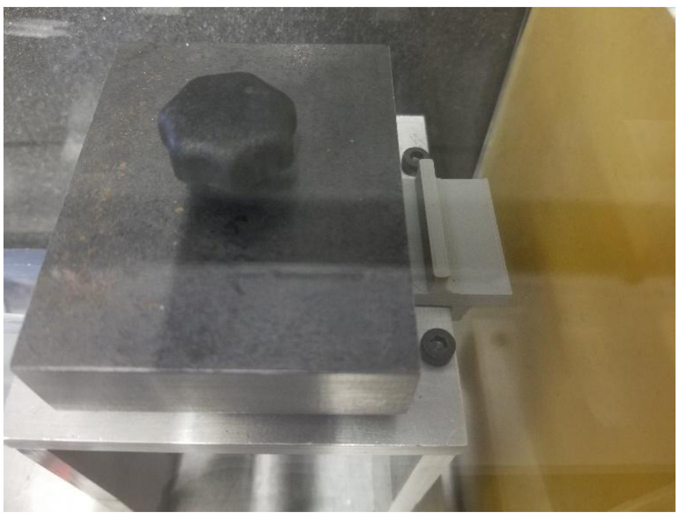

Figure 6 – TVA shipping mount

Another shipping alteration was to fix the piston in place during shipping as well. This was accomplished by placing a foam block in the guide tube for the piston, creating enough tension to hold it in place. This block is easily removable once on location and is light enough that if it mistaken left in while the machine is run it will not cause immediate damage.

ENGINEERING TESTS

RQMT. #	Function	Engr. Requirement (metric)	Verification Test Results	Marginal Value	Ideal Value	Unit of Measure	Comments/Status	Test Number
ER01	Two Separate Systems (No Coupling)	Vibration Amplitude	7.0%	10.0%	0.0%	% red.	marginal changed from 5% to 10%	TP01
ER02	Low Frequency Sine Wave Operation	Vibration Frequency	+/-0.24	+/-1	+/-0	Hz		TP02
ER03	Single DOF Systems	Vibration Amplitude (in y/z directions)	0.2	0.2	0	g's	unchanged from P18130 data	see P18310 T03
ER06	Accurate Vibration Measurement	Vibration Amplitude	0.1	0.1	0.01	g's	unchanged from P18130 data	see P18310 T05
ER13	Minimal vibration in mitigated unit	Vibration Reduction %	61.7%	50.0%	80.0%	% red.	marginal changed from 70% to 50%	TP04
ER14	Maximize time of operation	Operational time	8+	8	inf.	hrs.	limiting factor- micromount life	TP05
ER15	Minimize set-up time	Set-up time	5	15	5	min.		TP06
ER16	Small footprint	Footprint	100	150	100	in.^2		Measured
ER18	Minimize weight of entire system and packaging	Weight	45/27	50/50	40/40	lbs		Measured

Figure 7 - Completed Test Plans and Results

Engineering tests shown in Figure 7 are developed to ensure the project meets the engineering requirements shown in Figure 1. Each test has set ideal limits for testing to reach and accomplish. Engineering requirements are color coded to easily understand. Green indicates that the test was passed satisfactorily, yellow signifies that the test marginally passed and is acceptable, red shows that the test failed. Status shows the current position of the test. Red text shows a value that was changed by the customer to allow our current results to pass.

BILL OF MATERIALS

With team P19310 taking over where P18310 left off, we inherited a large quantity of parts. In addition to the spares, we received the original unit as well. This required our team to have a very well laid out Bill of Materials (BOM) to ensure items we already have are not reordered or double counted on our budget. The BOM recorded all parts purchases, with their date ordered, shipping time, and final cost. Figure 7 below shows the summary of our budget upon completion of our project.

Team #:	P19310	Team Name:	LORDs Work	Budget:	$4,000.00
Date:	2/26/19	Document Owner:	Greg Felker	Total Spent:	$1,920.80
Revision #:	6			Remaining:	$2,079.20

Phase	Team Part #	Allocated Budget	Allocated Used	Spent Budget	Unallocated Budget
Feasibility	1	$500.00	$223.68	$223.73	$276.32
Build	2	$2,950.00	$1,697.07	$1,697.07	$1,252.93
Imagine	3	$50.00	$0.00	$0.00	$50.00
Misc	4	$500.00	$0.00	$0.00	$500.00
Total		$4,000.00	$1,920.75	$1,920.80	$2,079.25

Figure 8 - BOM

We came in $2,079.25 under budget due to careful planning of materials needed and ensuring the part being ordered was correct and fits the requirements it is meant for. Eliminating the need to reorder parts for one solution.

SYSTEM RESULTS

The system has been significantly improved from last year's iteration. Vibration reduction has improved from 37% to 61%. The overall weight has decreased from 110 lbs to 72 lbs, while also being split into two cases for easier transport. The electronics box was reduced by 25% and simplified by removing redundant components while color coding all wires. The mechanical systems were split into two separate units, giving several benefits. This allowed most of the coupling to be removed from the system, allow different display options, reduce the weight of each component. The individual unit are shielded with acrylic enclosures to protect the operators and public from moving components. The new MATLAB code displays the reduction in vibration in the TVA system, in addition to having a tab to show transmissibility plots. The MATLAB code is fully commented to allow easy alterations and fixes to the software if needed.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion the system performs excellent. The vibration in the TVA system is reduced by 61% of the non-TVA system. The vibration difference between the systems is visible from a distance of 4-5 feet away. The system was designed to capture the audience and draw them in, with moving parts and noise exemplifying this.

For future renditions, a method to attach the cover to the base-plate would be a nice feature. This was done on the original project but was unable to be added to the new version due to time and machining constraints. This issue is only apparent during set-up as the covers remain stable during use. Code that is able to process data live, instead of only showing data after the fact would be preferable. MATLAB scripts are included that have these features, but were unable to be used in a single executable due to sampling frequency limitations.

Lessons learned from this project would include: It would be recommended to ensure documentation is kept up to date when it is created, and not all at once. Starting processes before their deadlines and allowing ample time for completion would assist in ensure other sections of the project are not delayed. Planning was crucial in keeping the project on track and ensuring we were prepared if things didn't work out. The senior design program was beneficial in preparing us for real work environments. The program helped us learn time management, how to quantify customer requirements into measurable factors, and how to manage risks and issues as they arise.

REFERENCES

A very special thanks to LORD Corporation, Keith Ptak, Zach Fuhrer, Zack Leicht, Gary Werth Kathleen Lamkin-Kennard, and the RIT ME machine shop staff for without their support the project would not have been possible.