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FPGA BASED VIBRATION CONTROL OF A MASS VARYING TWO-DEGREE OF FREEDOM SYSTEM

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Abstract- Controlling of vibration in any system is very challenging problem. In the present work design, fabrication and testing of a variable mass 2-DoF system was presented. The system has been designed to be used as tool to demonstrate the capability of mass variable tuned vibration damper for wide frequency application. All valves and pumps were controlled by a cRIO with onboard FPGA. cRIO with FPGA enable the designer to implement different control algorithms that can be used for real time wide spectrum vibration control. LabVIEW with real time suite was used for algorithm implementation and device control. To avoid sloshing in tanks at different water height a floating roof was used. Its effect on damping was also studied.

Index terms: FPGA (Field Programmable Gate Array); Reconfigurable Input Output device (cRIO); Vibration control, Real time control; TMD (Tuned Mass Damper); LabVIEW.

I. INTRODUCTION

The problem of reducing the level of vibration in constructions and structures arises in various areas of engineering, technology, and industry. In most of today's mechatronic systems, a number of possible devices such as reaction or momentum wheels, rotating devices, and electric motors are essential to the system's operation and performance. These devices, however, can also be sources of detrimental vibrations that may significantly influence the mission performance, effectiveness, and accuracy of operation. Therefore, there is a need for vibration control. Several techniques are utilized either to limit or alter the vibration response characteristics of such systems. During recent years, there has been considerable interest in the practical implementation of these vibration control systems. In the design of a vibration-control system, it often occurs that the system is required to operate over a wideband load and frequency range that is impossible to meet with a single choice of required stiffness and damping. If the desired response characteristics cannot be obtained, an active vibration-control system may provide an attractive alternative vibration control for such broadband disturbances. However, active vibration control systems suffer from control-induced instability in addition to the large control effort requirement. This is a serious concern, which prevents them from the common usage in most industrial applications. On the other hand, passive systems are often hampered by a phenomenon known as "detuning." Detuning implies that the passive system is no longer effective in suppressing the vibration it was designed for. But semi-active vibration control system provides wide range of vibration control. Semi active control can be achieved by using variable rate damper or by using variable stiffness spring damper. In both the control it was tried that operating frequency should not be equal to system's natural frequency to avoid resonance. For semi active control system, a control method is required which should be efficient and real time.Frahm, 1911 described about the dynamic vibration absorber and he also described that how it can be a useful device for vibration control. Since then there are lot of practical applications where dynamic absorbers are useful to control the vibration. Inman, 1994 defined that how the vibration of a primary system can be minimized by selecting properly absorber mass, stiffness, and damping. TLDs were proposed in the late 1800s where the frequency of motion in two interconnected tanks tuned to the fundamental rolling frequency of a ship was successfully utilized to reduce this component of motion, Den Hartog, 1956. In Li S.J.et al., 2002 it was presented and proved that shallow rectangular tuned liquid damper are better compare to deep liquid water damper. M. A. Goudarzi et al, 2009 described an analytical model for damping measurement in tanks with or without baffles. He discussed that how damping changes with the change in the height by width ratio of liquid and find out the experimental results also, which was acceptable. Carroll Dase et al., 2009, did a motorcycle control prototyping using an FPGA-based embedded control system to develop a research engine control unit (ECU) that would be suitable for prototyping engine control algorithms as well as sensor and actuator design. The development and use of a research ECU allow engine researchers to set up a control system with baseline performance equal to the factory ECU and then investigate methods for improving control performance.

In the current research, a mass variable 2-DoF system was modeled and various experiments were performed on this system. In order to vary the mass, water was used as a controlling mass of the secondary system and accordingly the FPGA based embedded real time controller was used to effectively control the various entities.

II. INSTRUMENTATION FOR SYSTEM SETUP

The system setup consists of the following:

- CompactRIO 9012
- NI C Series module (NI 9505,NI 9477,NI 9215)
- Laser pick-up (L-GAGE model LG10 series)
- Universal motor(either AC or DC power)
- Two Solenoid Valves
- Two Small Submersible pumps

Sensors and data acquisition are very much important for feedback and measurement in control. Actuators are used to regulate the process according to feedback from the sensors. In this project two solenoid valves and two small submersible pumps were used to control water flow in tanks. A universal motor was used to produce disturbance at primary system. Control of valves and pumps was done by NI CompactRIO 9012, with different NI C series modules. NI 9505 was used for motor speed control by PWM generation, NI 9477 is used for digital output to control pumps and solenoid valves and NI 9215 is used for analog input from the laser pickup. Experimental setup is shown in Figure 1.

Figure 1. System setup

Pumps used here were AC pumps to control it digitally digital output from NI 9477 is taken, and given to DC driven relays which in turn control AC pumps Figure 2. There was some delay in control system which was due to use of separate relays and due to time taken by water to reach into tank. These delays were added in program, so pump's 'ON' time was increased to compensate this delay.

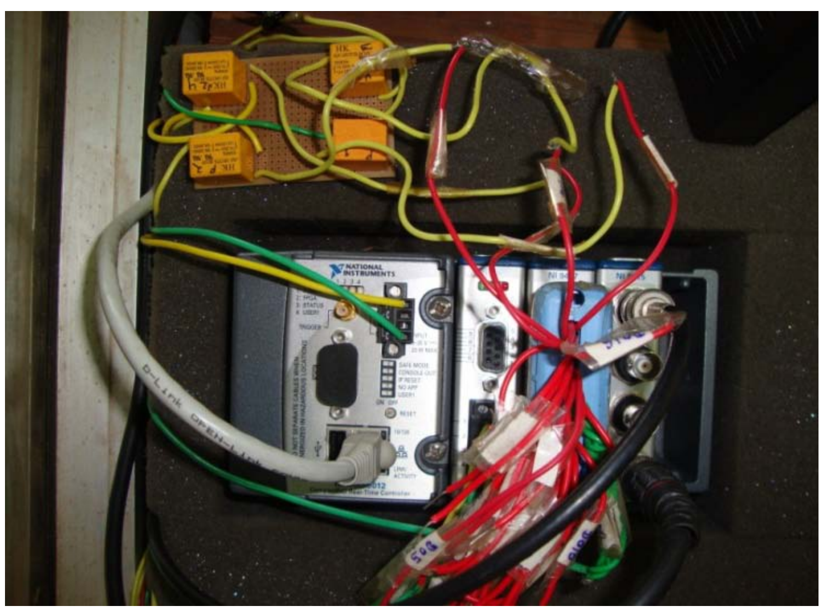

Figure 2. cRIO 9012 With NI C Series module (NI 9505, NI 9477, NI 9215).

III. FPGA PROGRAMMING IN LABVIEW FOR SYSTEM CONTROL

An FPGA is a silicon chip that consists of many configurable logic blocks. Unlike the fixed, vendor-defined functionality of an Application-Specific Integrated Circuit (ASIC) chip, an FPGA can be configured and reconfigured for different applications [Richard Wain et al., 2006]. FPGAs are used in applications where the cost of developing and fabricating an ASIC is prohibitive, or the hardware must be reconfigured after being placed into service.

1. Use of LabVIEW FPGA with LabVIEW Simulation Module

A simple analog input and analog output operation written with LabVIEW FPGA is shown in Figure 3. The analog I/O will run at the maximum rate allowed by the FPGA since a timing VI has not been added to the program. The timing is then limited only by the conversion rate for I/O on the FPGA-based device.

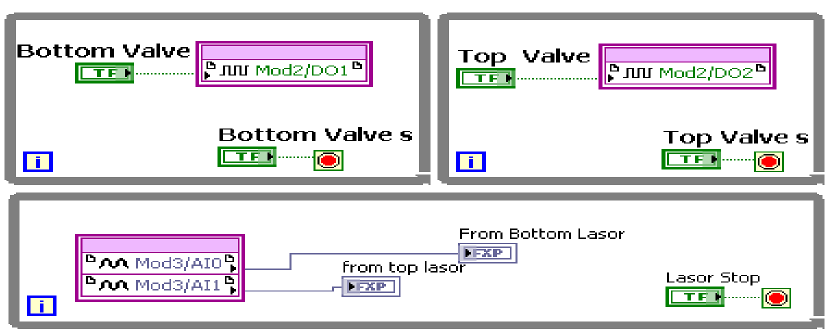

Figure 3. AI/DO output VI in LabVIEW FPGA for I/O.

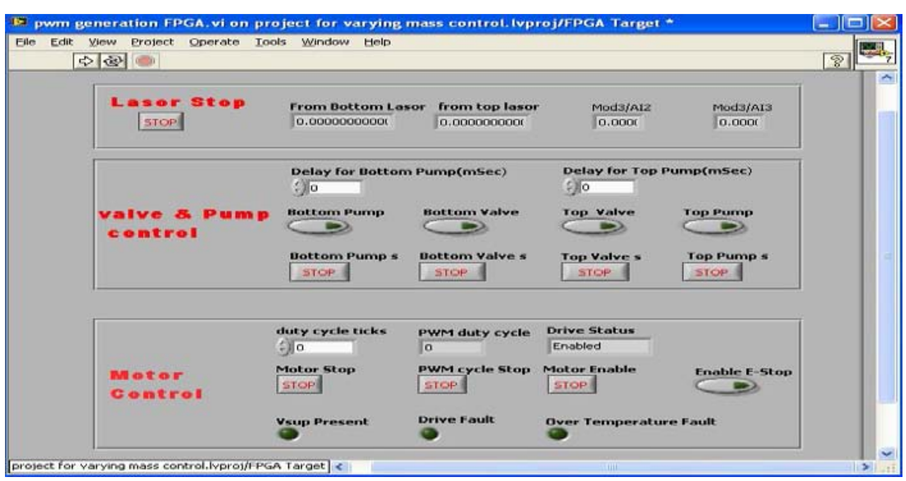

Figure 4. Front panel of Analog input and Digital output VI in LabVIEW FPGA.

The front panel for block diagram is shown in Figure 4. The analog output is taken from laser pickups by using NI 9215 module. The user can adjust the switches to give the digital output to the motor and pumps and stop buttons are given to stop the operation instantaneously. Once the basic entities have been specified in the FPGA target, the next task is to create a host controller as it gives more flexibility (more features) in the architecture of LabVIEW program using FPGA interface method.

2. Mass control of the system

In this system water was used as a variable mass. For controlling the water mass, water height has to be controlled in the tank. After collecting all the data from valve's output and pump's input an open loop system was used for controlling water height.

For adding mass to the system water was pumped in the tanks. For this purpose mass flow rate of the pump was calculated. The programming was done in such a manner that it gives synchronism between the varying mass and on time of pump. The scenario is different in the case of outflow. The water outflow depends on the height of the water and there is no linear relationship. Hence the outflow rate was measured at every 5 mm reduction in height and the results were tabulated in 1-D lookup table using LabVIEW. Block diagram of code is given in Figure 5. For this system a 2-D lookup table was made, after collecting all the data, some qualified data has been feed into control table. When this program will run the output data was chosen according to the motor speed (on X-Axis) and bottom water height (on Y-Axis).

3. Control and data representation in front panel

A front panel of the tank control and acquires data from laser pickup is shown in Figure 6. Motor control was done by a slider on front panel; speed of the motor varies according to the slider movement. The first tab is used to see time domain data of primary system acquired by laser pickup and bottom graph represents time domain data of absorber system. Primary system mass can be fixed by fixing height of water in primary system and absorber water height changes according to the required value at that instant for controlling the vibration. In the last tab frequency domain data from the sensors are presented with different control and indicators to monitor the control process.

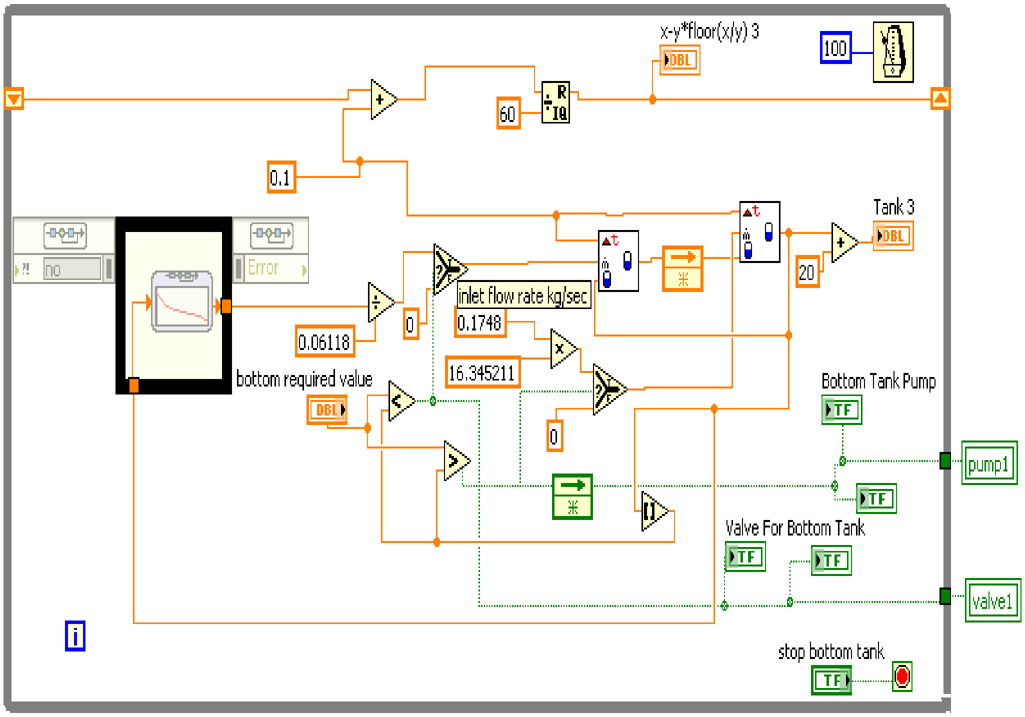

Figure 5. Water height control or mass control VI

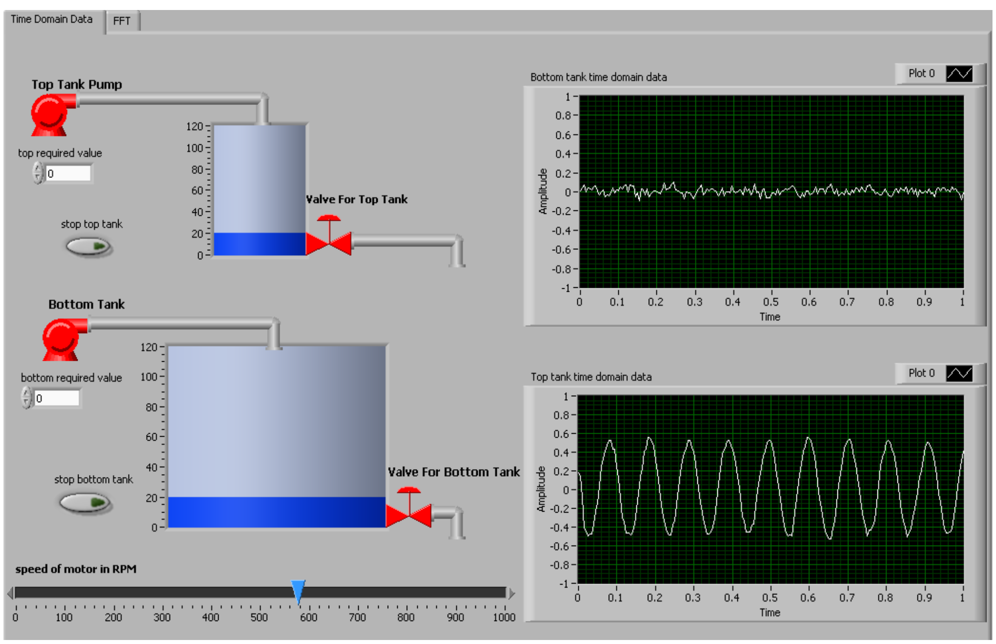

Figure 6. Front panel with time domain data and tank level control.

IV. RESULTS AND DISCUSSION

To achieve the objective of this instrumentation, experiments were done on the system and results were obtained in order to validate system and system control. For this purpose, different data was recorded at different masses of the primary system or secondary system with varying frequency from the modeled system. These experiments were conducted when surface of water was free for sloshing or when there was a floating roof kept on the surface of the water to avoid sloshing.

Case I: Water surface was free for sloshing: In both the systems initially there was some water (due to design constraints this water was always present in tanks) Different graphs were plotted for different water height in absorber system as in Figure 7. In absorber system or top tank water height was changing from 15 mm to 70 mm to change its weight from 1.65 kg to 3.65 kg and for bottom or primary system 15 mm to 100 mm to change its weight from 5.71 kg to 10.6225 kg.

Case II: Floating roof used for sloshing suppression: In the last experiment it was observed that analytical values were differed from the experimental values. So, it was required to make system more compact. The floating roof arrangement was placed on the top of water and the experiments were done to analyze the behavior of the system. When floating roof was placed on the top of the water, the vibration amplitude was decreasing at every position. It can be observed from Figure 8.

Case III. Single-DoF system with variable base excitation: For this experiment, water was not filled in the containers. An excitation was given to the primary system, due to this excitation there will be some vibration also in the secondary system.

Case IV: Two-DoF system with variable frequency excitation: This experiment was done without adding water to both of the system. As speed of the motor increases vibration amplitude increases on both of the system (primary or secondary). After reaching to a certain limit it starts decreasing and it can be seen that on primary system, it becomes minimum at certain frequency. Here forced frequency is equal to the natural frequency of the absorber or secondary system this is the point of maximum displacement transmissibility.

Case V: Both of the systems damping value was measured with and without floating roof and then comparison was done between both damping values. From Figure 9 it has been observed that when water surface was free then damping was increasing. There was no description found in literature survey done by authors about damping measurement when a floating roof is used to avoid sloshing in containers or damping measurement of a fully filled container.

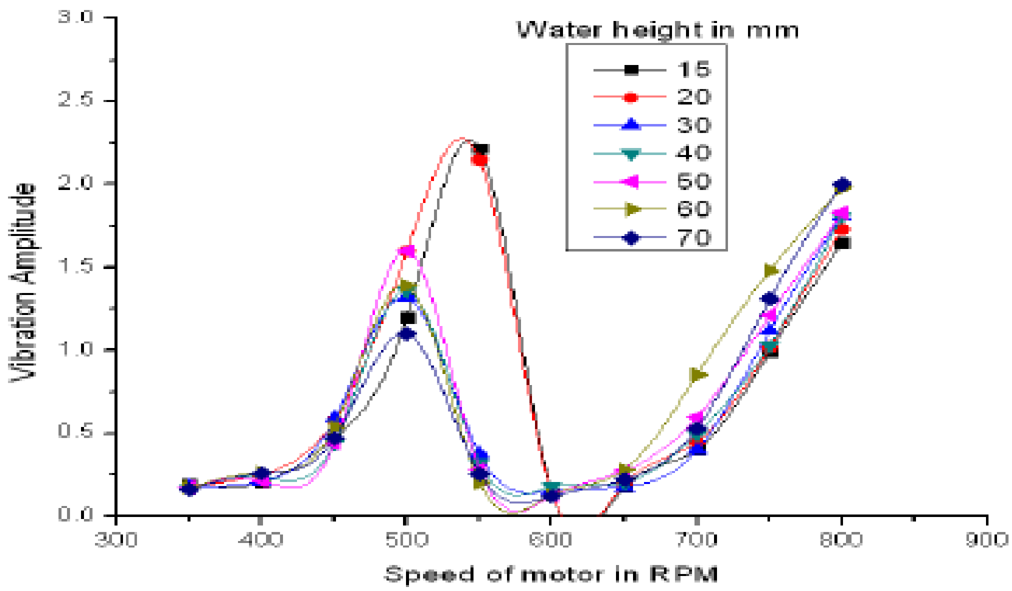

Figure 7. : Bottom 100, top varying (Without Floating Roof)

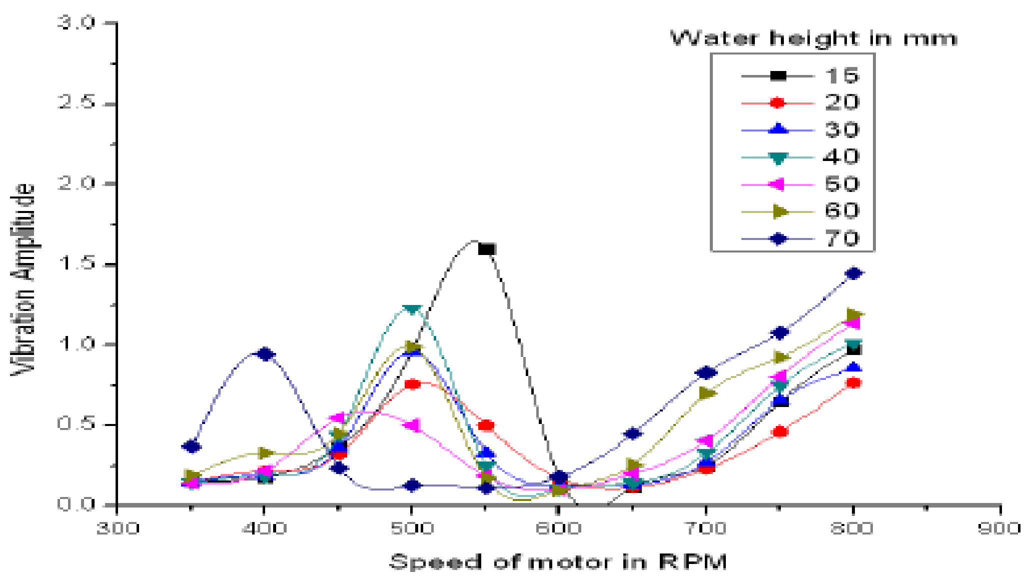

Figure 8. : Bottom 100, top varying (With Floating Roof)

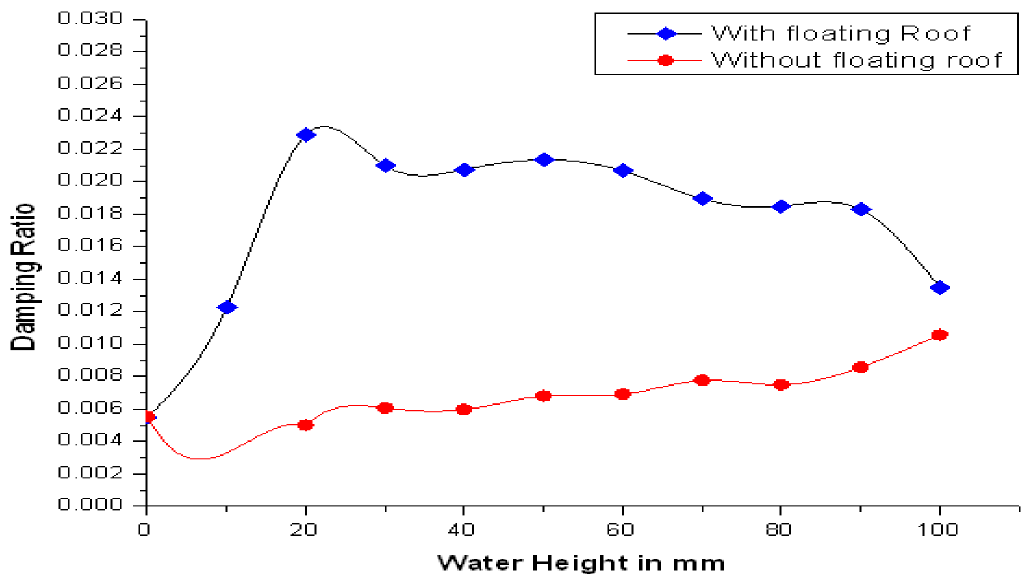

Figure 9. Damping comparison with or without liquid in containers

V. CONCLUSIONS

Mass variation is possible, to control the vibration. When water was used for mass variation, it shows the effect of mass variation on system but its properties are not same as solid. This system can be used at offshore applications to control the vibration. It can also be used in structures where time delay is permitted to control the vibration. This time delay is due to inlet and outlet flow rate constraints of the system. When liquid surface was free for sloshing, vibration amplitude was very high at first combined frequency of 2-DoF system. When primary mass is kept constant and absorber mass was increased then its amplitude reduces and when absorber mass is kept constant or primary system mass was increases again vibration amplitude decreases slowly. When a floating roof was used in both the cases, either primary mass or secondary mass was changing, vibration amplitude decreases but when a little water was added to the absorber system to increase its mass, there was a sudden decrement in vibration amplitude. So if in the place of a solid absorber system a closed system filled with small amount of liquid will suppress more vibration. Control table in place of control algorithm was used to decide control gain for the system. For this all the data were recorded and then some qualified data was selected. This qualified data was given to lookup table. As water height in the tanks increases damping of the system increases. But at the same time damping increases suddenly when small amount of water was added to the containers with floating roof and then decreases continuously as more and more water was added. In the case of tuned liquid damper when water height was very less, then it provides better vibration suppression. As water height increases in the system, vibration suppression decreases and when water height reaches to a certain limit then at that time there is no vibration suppression on the top. A single-DoF system has more amplitude of vibration at higher frequencies when a floating roof is kept on the top of the water. The setup is kept prepared for remotely use for SOLVE (student online laboratory through virtual instrumentation), so students can perform real time experimentation through internet.

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