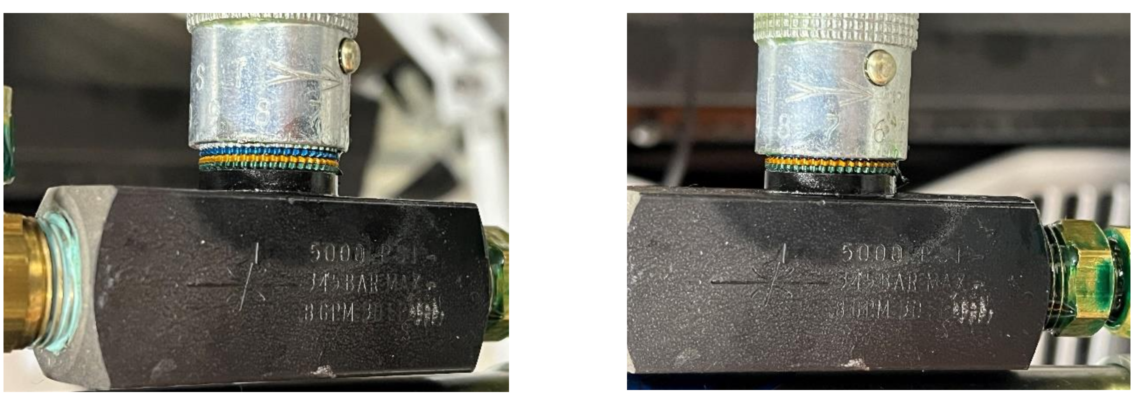
Hydraulic Cylinder Configured to Function as Viscous Damping Device

Double-acting, double-rod hydraulic cylinders can be configured either as a passive viscous damping devices or as an actuator switchable to a passive viscous damping device. In this article, the former configuration is discussed.

Hydraulic cylinders as viscous damping devices: Utilizing hydraulic cylinders as passive viscous damping devices (VDDs) involves connecting both sides of the piston in a double-acting, double-rod cylinder through an adjustable flow control needle valve, effectively transforming the cylinder into a viscous damping device. Vibrational motion prompts the fluid to transfer from one piston side to the other via the flow control valve, dissipating vibration energy due to the resulting pressure drop. Fine-tuning the damping coefficient is achievable by regulating the valve's opening. Moreover, integrating a bladder accumulator complements these damping systems, pressurized with nitrogen on one side and storing fluid on the other, ensuring compensation for any gradual fluid loss through the seals over time.

One such viscous damping device (VDD) is tested, by subjecting it to harmonic motion at 6 different frequencies with 6 different amplitudes (of motion), while measuring the force as well as the extent of motion. Appendix A presents the test procedure and the measurement device. Figure A-1, in Appendix A, shows the test set up.

The test runs were done with two different openings ‘large’ and ‘small’ of the flow control needle valve. As expected, the damping coefficient of the VDD is inversely related to the extent of opening of the flow control needle valve; i.e., the larger the opening, the lower the damping coefficient. Figure 1 depicts the two settings of the needle valve opening. Figure 1(a) showing three (green, yellow, and blue) rings corresponding to the ‘large’ opening and Figure 1(b) showing the two (green and yellow) rings corresponding to the ‘small’ opening.



(a) (b)

Figure 1 The ‘large’ opening (a) and the ‘small’ opening (b) of the flow control needle valve

Test Results

By following the outlined steps in Appendix A, Figures 2(a) and 2(b) exhibit the force vs. displacement hysteresis loops corresponding to a large and a small openings of the flow control valve. This analysis involves plotting a single cycle of force against its corresponding displacement cycle at frequencies of 2 Hz and 3 Hz, depicted by the red trace. As detailed in Appendix A, the hysteresis loop's area serves as an estimation for the VDD's equivalent linear damping coefficient, while the loop's tilt aids in determining the associated stiffness. These estimations are visually presented in Figures 2(a) and 2(b).

In Figure 3, the blue traces represent the modeled hysteresis loop of a comparable linear damper. This model is built using the equivalent linear damping coefficient and stiffness of the viscous damping device. The close alignment between the modeled and measured hysteresis loops indicates the reasonably accurate predictions of the VDD's equivalent linear damping coefficient and stiffness. For a deeper understanding of the hysteresis loop, its connection to energy dissipation, and the assessment of the damping coefficient, consult Appendix A.

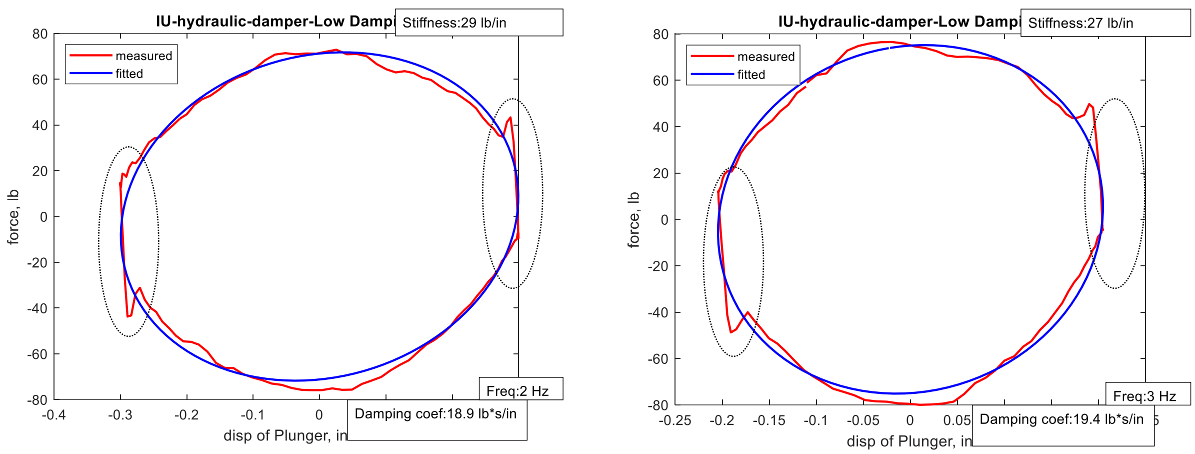


Figure 2(a) Measured (red traces) and estimated (blue traces) hysteresis loops accompanied by the estimated dynamic parameters of the test VDD, at two frequencies, with the large opening of the flow control valve

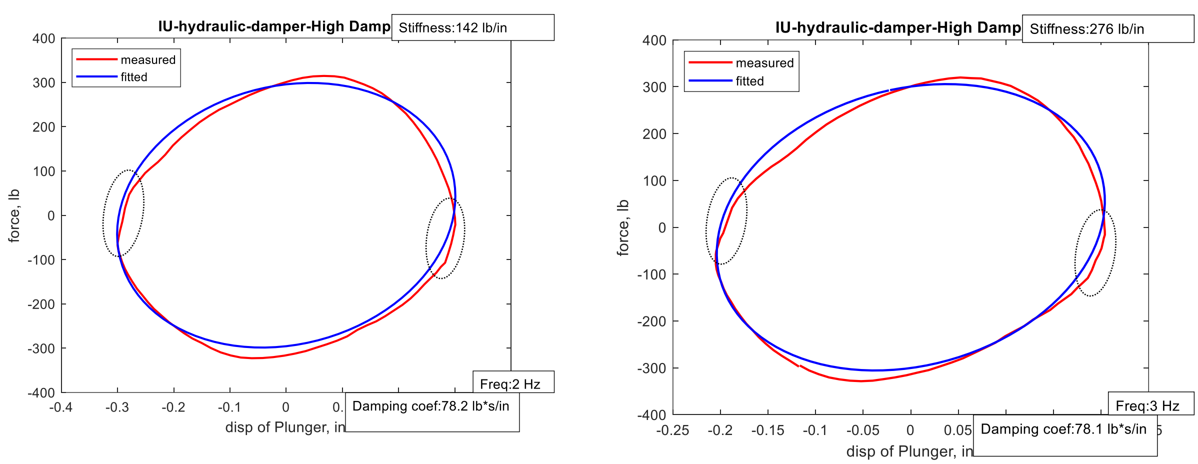
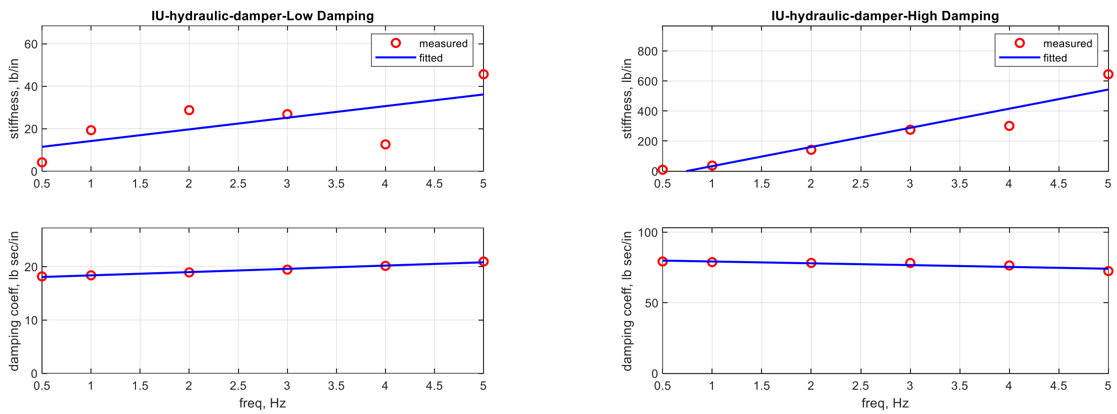


Figure 2(b) Measured (red traces) and estimated (blue traces) hysteresis loops accompanied by the estimated dynamic parameters of the test VDD, at two frequencies, with the small opening of the flow control valve

The straight-line portions of the measured hysteresis loops, circled in Figures 2(a) and 2(b), point to the presence of friction (which is a nonlinear damping phenomenon) in the test VDD. As the opening of the flow control valve becomes smaller, resulting in higher viscous damping, the presence of friction becomes less pronounced.

Contrary to viscous dampers which allow for the internal passage of liquid from one side of their piston to the other side, hydraulic cylinders made for fluid power applications, have elaborate seals placed on their piston preventing fluid from flowing across the piston. Rubbing of piston seals against the cylinder bore, cause a hydraulic cylinder configured as a viscous damping device exhibit more friction than a comparable genuine viscous damper.

Examining its frequency dependency, Figures 3(a) and 3(b) depict the equivalent linear damping coefficient and stiffness of the tested VDD across a spectrum of frequencies from 0.5 to 5 Hz. These figures also include a linear regression fit applied to the collected data. Notably, it becomes evident from these visual representations that the test VDD maintains a relatively consistent damping coefficient across the measured frequency range, regardless of whether it's set to a 'large' or 'small' opening of the flow control valve.



(a) (b)

Figure 3 Damping coefficient and stiffness of the test VDD measured at 6 frequencies with large opening (a) and small opening (b) of the flow control needle valve

Appendix A

Damping Measurement Apparatus and Test Procedure

Figure A.1 shows the set-up used to evaluate the test VDD. The apparatus is made up of an Aluminum frame to which one side of the VDD (the pivot at the end of the piston rod) is pinned. The other side of the damping device is attached to a hydraulic actuator, thru a force sensor. The hydraulic actuator itself is also secured to the Aluminum frame. An LVDT, built into the make-up of the hydraulic actuator, measures the stroke of the piston.

A 10 hp hydraulic power supply with a 20-gal tank powers the hydraulic actuator, under the control of a dedicated computer. In addition to controlling the hydraulic system, the computer acquires the force and displacement data measured by the aforementioned force sensor and LVDT.

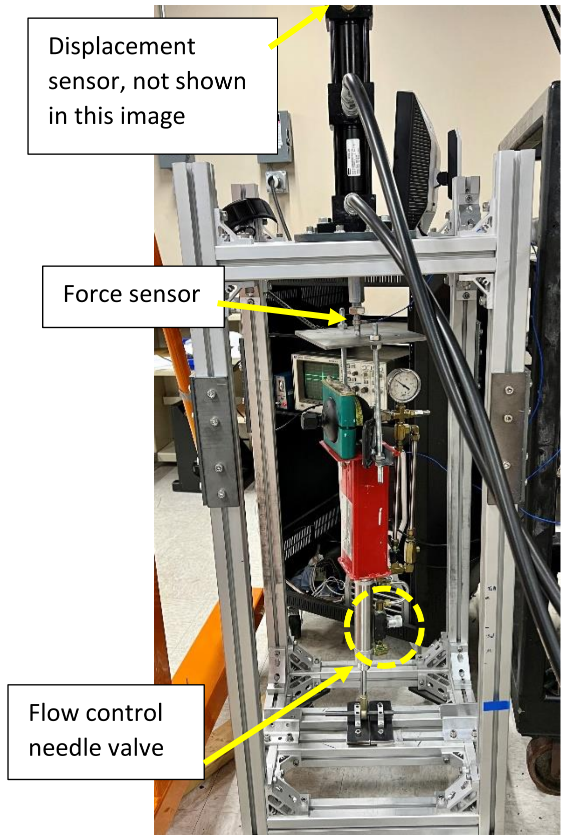


Figure A-1: The test set-up

With the hydraulic actuator under position control, using a PI controller, the body of the VDD is harmonically moved. The reference input to the controller is a sinusoid with known amplitude and frequency. The actuation runs long enough so that at least 10 cycles of oscillation are realized. The force experienced by the force sensor and the motion measured by the LVDT are simultaneously acquired by the control computer, during each run.

To examine the dependence of damping parameters on frequency, experiments were done at 6 different frequencies. To avoid exceeding the limitations of the hydraulic power supply, the runs at higher frequencies were done with smaller amplitudes of harmonic motion.

With each run complete, the collected data are exported to MATLAB for processing, using the following steps:

1. select one complete cycle of measured force and the corresponding complete cycle of measured displacement,
2. plot the measured force vs. measured displacement and construct the hysteresis closed loop of force versus displacement,

3. calculate the area (presenting the dissipated energy in one cycle of motion) and tilt (presenting possible stiffness of the damping device) of the hysteresis loop, and
4. find the experimentally evaluated equivalent linear[1] damping coefficient and stiffness of the VDD at that run.

Figures 2(a) and 2(b) in the body of this article show the measured (red trace) hysteresis loop constructed by plotting a single cycle of force vs the corresponding single cycle of displacement at two frequencies of 2 Hz and 3 Hz. As stated earlier, the area of the hysteresis loop is used to estimate the equivalent linear damping coefficient of the damping device and the tilt of the hysteresis loop is used to find the corresponding stiffness. The blue traces in Figure 3 are the fitted hysteresis loop of an equivalent linear damper constructed using the estimates of equivalent linear damping coefficient and stiffness of the VDD.

[1] Due to the presence of friction caused by rubbing the piston seals against the cylinder and gland seals against the piston rod of the Bimba, as well as other small nonlinearities, the VDD does not quite exhibit linear damping. As such, equivalent linear damping coefficient is evaluated by comparing the measured dissipated energy in one cycle of motion (the area of the hysteresis loop and find the damping coefficient of a linear damper that would have had the same area.