BALANCE PAN DAMPING USING TUNED SLOSHING LIQUIDS

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Abstract

This paper describes a new method to damp out balance pan oscillations even when the balance is operated in vacuum. The key is to tune the wavelength of the damping liquid, which resides in a sealed container attached above the pan, to the natural frequencies expected in the pan operation. Both NIST and LNE are investigating the practical application of this damping approach in our respective watt balance experiments [1,2].

Introduction

Sloshing tuned dampers have been studied both experimentally and theoretically for application of damping out skyscraper oscillations caused by wind or earth movements [3,4]. The basic idea is that the energy of oscillations can be transferred to energy loss within the liquid. By adjusting the depth of the liquid and its container length, one can get dramatic improvement in the damping efficiency. These techniques were also used in the damping of unwanted motions in early satellites [5]. This paper looks at the damping when applied to simple and double pendulum motion of pans on a balance.

Design Considerations

A simple equation can be used to approximate when the frequency, \( f_i \), of the pan motion equals that of a liquid [3,4].

\[
\frac{1}{2\pi} \sqrt{\frac{\pi g}{L} \tanh \left( \frac{\pi h_i}{L} \right)} \approx \frac{1}{2L} \sqrt{gh_i} \quad (1)
\]

Where \( h_i \) is the liquid depth, \( L \) the channel length and \( g \) the gravitational acceleration. This equation is used to estimate the best depth for the container, and then empirically adjust the liquid level to optimize the damping of the pans. The range of frequencies common in mass pans is a good match to this technique. For example, a pan with a center of mass 25 cm below the flexure (a 1 Hz pendulum frequency) takes 4 mm of liquid in a 10 cm long channel to get maximum damping. Positioning the dampers is also critical. If the center of mass of all the weight on the pan is at the location of the liquid, then there is no motion of the liquid and thus no damping. Also, if the damper is far above the flexure point, the liquid may be in an unstable equilibrium where all the liquid shifts to one side. In a watt balance experiment it is common to make one weighing without any mass in the pan, and in this condition, the mass of the damper is likely to dominate the center of mass. We therefore use two dampers, each at a different height, to ensure damping in all the situations. The two dampers can be tuned to different frequencies.

Initial Results

A double pendulum with two dampers, both attached to rods in the upper pendulum section, was used to show the damping capabilities of tuned liquid systems. Figure 1 shows four plots of the damping for each of four modes. The double pendulum has two Eigen frequencies, and these two frequencies are different, depending whether the mass is on or off the pan. A horizontal impulse is applied to the pan to excite the mode which we call the pendulum frequency. A horizontal impulse to the middle flexure assembly excites the second mode that we call the wobble frequency. The graphs show that all the modes can be damped. The liquid levels were adjusted for maximum damping in the two pendulum modes. The last graph shows the least damping, because most of the mass is in the damper and the liquid moves less. However, the wobble mode is the least likely to get excited when putting masses on and off the pan. Also, because this wobble mode with mass off has the least amount of mass, it will likely have the smallest effect on the balance. Without the liquid there was very little damping in this 25 sec time period.
Application

The passive properties of the tuned damper system can be tuned for optimum performance in applications like damping balance pans. Active damping of the induction coil, which is turned off during the weighings, is very effective in the NIST watt balance experiment, but this tuned passive damper system is an attractive candidate to improve the damping of the mass pans used in this experiment. A combination of active and passive damping is also being investigated at the LNE with tuned sloshing dampers a strong candidate for the passive component. Because the liquid is sealed in a tight container, we avoid heating it and a pressure relief system is being considered.

References


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