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## **Research Article**

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# Experimental Data Collection for A Sphere on A Forced Oscillating Track

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#### Abstract

This work involves the experimental setup of an oscillating V-shaped trough upon which a steel sphere is subjected to a back and forth rolling motion. The trough is hinged at the center and actuated by a piston that imparts a force near one end of the track, resulting in upwards-&-downwards motion and causing the metal sphere to roll within the V-shaped trough. The real-time data collected involved the position of the sphere relative to the static equilibrium position (SEP) as a function of time as well as other corresponding data, e.g., the angle of the track. It is hoped that this pilot study can be extended to further both theoretical as well as analytical studies of such a dynamical system.

Keywords: Vibrations; Computational Modeling; Multifunctional Structures; Dynamic Loads; Testing

#### Nomenclature

dsphere: Diameter of sphere

g: Acceleration due to gravity

Ibar:	Mass moment of inertia of bar
Isphere:	Mass moment of inertia of sphere
lscrew:	Distance between each screw on disk
mbar:	Mass of bar
msphere:	Mass of sphere
rsphere:	Radius of sphere
s:	Arc length of disk
αbar:	Angular acceleration of bar
$\alpha$ disk: Angular acceleration of disk	
$\alpha$ sphere: Angular acceleration of sphere	
θ: Angle of the track relative to horizontal	
ωbar:	Angular velocity of bar
ωdisk: Angular velocity of disk	
_	

ωsphere: Angular velocity of sphere



### Introduction

Vibrations are very important in many engineering applications. Cars, machines, cellular phones, and a host of many other devices that people have come to rely upon would not be possible without this physical phenomenon. Vibration analysis allows engineers to determine the stability and effectiveness of a mechanical system. This pilot study involved an investigation of a mechanical system to evaluate the displacement and angular frequency of a solid metal sphere rolling on an oscillating V-shaped track. In this vein, an application to better understand this complex behavior can, at a first step, be viewed using the idea of objects rolling down inclined planes at various angles and speeds. It is helpful to look into similar studies that have been conducted in the past. A work that uses control theory through a Partial Integrator Derivative (PID) device to stabilize the ball on the oscillating track is presented by Jadhav et al. (2017) [1]. D'Anna et al. (2021) studied spheres of various radii rolling on tracks where the position was measured experimentally using sensors, with velocity vs. time of the response of the sphere measured as well [2]. Additional works present the results of various spheres rolling on a track at different angles [36]. Track variations were studied by Ladino (2020) using a multislotted aluminum sheet with varying widths and different angles of inclination as the surface upon which the steel sphere rolled [7].

The relevance to this pilot study of a sphere rolling on a forced oscillating track (Figure 1) to the real world and how it matters can be seen, for example, from the rocking up and down of bridge girders on elastomeric bearing pads during a seismic event (Figure 2). The focus in this paper is to experimentally collect the position of the steel sphere as it rolls along the V-shaped oscillating track, a setup that may be considered as a two degree of freedom (2DOF) system. Pedagogically, the system is rife with important concepts of engineering dynamics, e.g., particle and rigid body kinematics and kinetics [8]. The V-shape track was powered by an Arduino microcontroller which sends digital inputs to the servo-mechanism resulting in the external excitation to cause the V-shaped track to oscillate up and down in a see-saw manner (Figure 1). To carry out the experimental investigation, the sphere undergoing its described motion was videotaped and carefully analyzed for its dynamical response.



Figure 1: Experimental System Setup.



Figure 2: Girders.

## **Materials and Methods**

Some of the materials that were used during this research involved 3D printed parts; a conical shaped base that was bolted down using steel screws to a piece of rectangular plywood; the housing for the servomotor which was connected to a flywheel; and the ball in the experiment consisting of a steel sphere of mass 0.005kg and a radius of 0.5cm (Figure 3). Plywood was used to

form the V-shaped trough to serve as the track for the sphere to roll back and forth upon. Figure 4(a) shows the Arduino Uno R3 microcontroller that was used to power the mechanical system, and Figure 4(b) displays the S3305 servomotor that was connected to the Arduino Uno to provide the rotation of the flywheel, which, in turn, caused the oscillatory motion of the V-shaped track through a connecting rod (Figure 1).



## **Results and Discussion**

A top view of the experimental system used with a ruler-inset upon the V-shaped track (Figure 5) for ease of measuring the position of the steel sphere with respect to time. In order to collect measurements of the position of the steel sphere, the oscillating system was videotaped and later analyzed by starting and stopping the video at different timestamps to ascertain the position of the ball rolling on the track.

## Motion of the Sphere Through its Phases

Figure 6 is a schematic of the experimental setup showing the dimensions as well as the various symbols used in conducting the dynamical and vibrational analysis for this study.



Figure 5: Views of Experimental Setup.



During the experiment, the steel sphere's location could be characterized by its motion through its different phases. For instance, at time t=0s with the sphere positioned at the static equilibrium position (SEP) and the track in a horizontal position, the ball would begin to roll away from the center as the track begins to tilt constituting the ball in its Phase 1 motion. As the track oscillates and tilts the other way, the ball would begin rolling back towards the SEP in its Phase 2 motion. Thus, the odd numbered Phases (1,3) represent the sphere rolling away from the SEP, whereas, the even numbered Phases (2,4) represent the sphere rolling towards the SEP (Figures 7-9). The experimentally collected data of the sphere's motion through its different phases is captured and plotted in Figure 10. The actual motion of the sphere rolling through its different phases is shown in Figure 10 as generated using MATLAB with accompanying code shown in Figure 11. Arduino (Figure 12) was used to operate the flywheel that imparted simple harmonic excitation of the V-shaped track through the linkage (Figures 1,13,14).







1 %Experimental Data Collection for a Sphere on a Forced Oscillating Track A = readmatrix('graph.xlsx'); 2 3 t = A(:,1); %Defining the time vector 4 x = A(:,2); %defining the distance vector 5 % load graph.mat % t = graph.times; %Defining the time vector 6 7 % x = graph.distancex; %defining the distance vector 8 plot(t,x,'b','linewidth',5), axis([0 2.3 -0.14 0.14]) 9 hold on 10 grid on 11 xlabel('Time(s)'), ylabel('Distance(m)'), title('Experimental Results of Distance vs. Time of Sphere (d = 0.007m)') 12 x\_1 = xline(0.55, 'k', 'linewidth',5); x\_2 = xline(1.16, 'k', 'linewidth',5); x\_3 = xline(1.61, 'k', 'linewidth',5); x\_4 = xline(2.3, 'k', 'linewidth',5); set(gca, 'fontsize',50) %Setting the font size of the text 13 14 15 16 17

Figure 11: Matlab Code.



Figure 12: Arduino Code.



Figure 13: (A) Free Body Diagram (FBD) of the Track, (B) Intertial Response Diagram (IRD) of the Track.



## Conclusion

An experimental oscillating V-shaped track with a steel sphere rolling in its trough, was designed and constructed to perform measurements on the ball's position with respect to time. The motion was videotaped and used to start and stop the motion at equal intervals of time in order to collect the data. Initially, a servomotor was used to cause rotation of the flywheel that, in turn, resulted in the simple harmonic excitation of the track through a linkage, however, it this motor was found not to adequately cause full rotary (360°) motion, at which point, a stepper motor was resorted to that did solve the issue in a nice, continuous fashion. Future studies will consider an enhanced experimental setup utilizing 3D printed (Tamiya USA) parts outfitted with ultrasonic sensing capabilities for superior distance detection and the collection of measurements. Moreover, numerical and analytical characterizations will be performed to model and corroborate experimental results.

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