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**Original Research Article**

# Modelling simulation and design of smart damping cabins for transportation systems

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**ABSTRACT**
This research focuses on the dynamic modeling and simulation of a mass-spring-damper system, a common model for mechanical engineering vibration phenomena. To start, the study defines the physical system, important assumptions, and characteristics like as mass, damping coefficient, and spring stiffness. The study uses Newton's second rule of motion to derive and rewrite the system's differential equation into state-space representation. The derived mathematical model is used in MATLAB to simulate the system with a step input force. The simulation results are examined to assess the system's dynamic response, including displacement and velocity over time. Additionally, a parametric analysis examines how damping and stiffness affect system stability and dynamic performance. In addition, the material perspective of the vibration control is carried out.

## 1. Introduction

In a research, essential ideas of vibration analysis are presented, and an explanation is given on the influence that damping and stiffness have on system response. The modeling of mass-spring-damper systems makes extensive use of this reference, which is widely regarded as one of the most important references in the field of vibration engineering [1]. A contemporary introduction to vibration theory is presented in another piece of work. This introduction covers both single- and multi-degree-of-freedom systems. As a result of its emphasis on mathematical modeling and eigenvalue analysis, it is appropriate for use in simulation-based research scenarios [2]. According to a review, the evolution of vibration analysis and the contemporary issues that are faced in the field are highlighted. It highlights the significance of advanced modeling approaches and the potential routes that future research will take in the field of vibration control [3]. The reduction of vibrations is the primary focus of a research group that is working on intelligent materials and structural control systems. Adaptive damping systems have demonstrated to be capable of enhancing performance in specific technical applications [4]. An article presents a discussion on the many methods of energy dissipation that are utilized in vibration control. This paper examines the differences between passive and active damping systems and illustrates the efficiency of both types in structural applications [5]. An investigation of the effectiveness of vibration absorbers with two degrees of freedom in reducing the vibrations that occur within a system. The results demonstrate how the damping efficiency can be improved through correct tuning under a variety of excitation circumstances [6]. The use of dispersed mass absorbers allows for damping, according to an analysis. When compared to single systems, the results demonstrate that multiple dampers have the potential to accomplish a substantially greater reduction in vibration [7]. Improving the performance of absorber parameters in multi-degree systems is the primary emphasis of this research. This indicates that improved system stability and decreased vibration amplitude can be achieved through good design [8].

## 2. Experimental work

The primary objective of this research is to model and simulate a mass-spring-damper system that illustrates the vibrational characteristics in transportation cabins. The study intends to analyze the impact of system factors, such as damping and stiffness, on dynamic response, and to comprehend how intelligent damping concepts might enhance vibration control and passenger comfort. To simplify the analysis, the following assumptions are considered: In this system, linearity is demonstrated. Hooke's law is strictly followed by the spring.

The viscosity of damping is directly related to the velocity of the fluid. A single degree of freedom is exhibited by the motion, which is unidirectional. Invariance of the mass is maintained. As a step input, the external force is applied into the system. Impacts on the environment, noise, and friction are not taken into consideration.

## 3. Mathematical modelling

The system is modeled using Newton's Second Law:

$$m\,\ddot{x}(t) + c\,\dot{x}(t) + k\,x(t) = F(t)$$

where,
$m$: mass
$c$: damping coefficient
$k$: stiffness

$x(t)$: displacement
$\dot{x}(t)$: velocity
$\ddot{x}(t)$: acceleration

State-Space Representation
$x_1 = x$, $x_2 = \dot{x}$
$\dot{x}_1 = x_2$
$\dot{x}_2 = (1/m)(F - c\, x_2 - k\, x_1)$

Matrix Form
$\dot{X} = [0 \;\; 1;\;\; -k/m \;\; -c/m]\, X + [0;\, 1/m]\, F$

MATLAB Coding
Matlab coding for the above condition is as follows.

```
clc;
clear;
close all;
% Parameters
m = 1000;    % mass (kg)
c = 1500;    % damping coefficient (Ns/m)
k = 20000;   % stiffness (N/m)

% State-space matrices
A = [0 1; -k/m -c/m];
B = [0; 1/m];
C = [1 0];   % displacement output
D = [0];

% System model
sys = ss(A,B,C,D);

% Time vector
t = 0:0.01:10;

% Step input
u = ones(size(t));

% Simulation
[y,t,x] = lsim(sys,u,t);

% Plot displacement
figure;
plot(t,y,'LineWidth',2);

xlabel('Time (s)');
ylabel('Displacement (m)');
title('Displacement Response');
grid on;

% Plot velocity
figure;
plot(t,x(:,2),'LineWidth',2);
xlabel('Time (s)');
ylabel('Velocity (m/s)');
title('Velocity Response');
grid on
```

## 4. Results and discussions

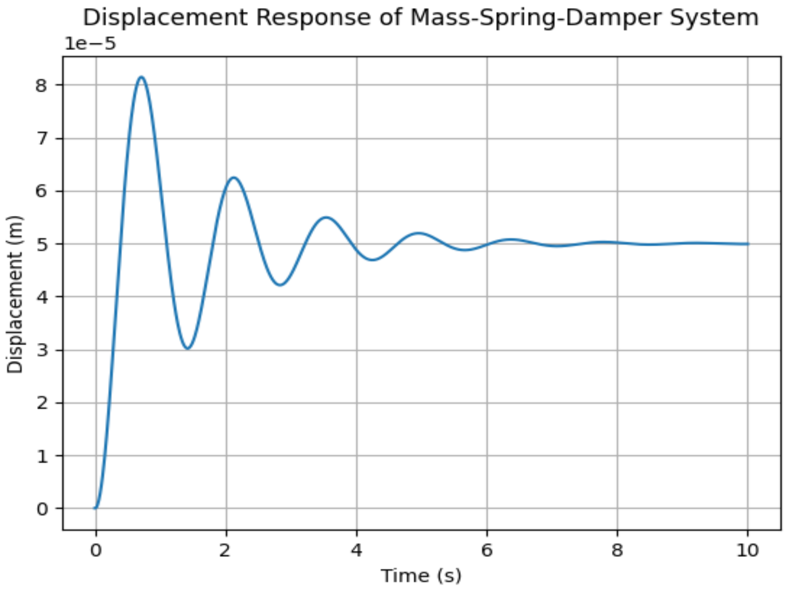


**Figure 1:** Displacement response of the system under step input.

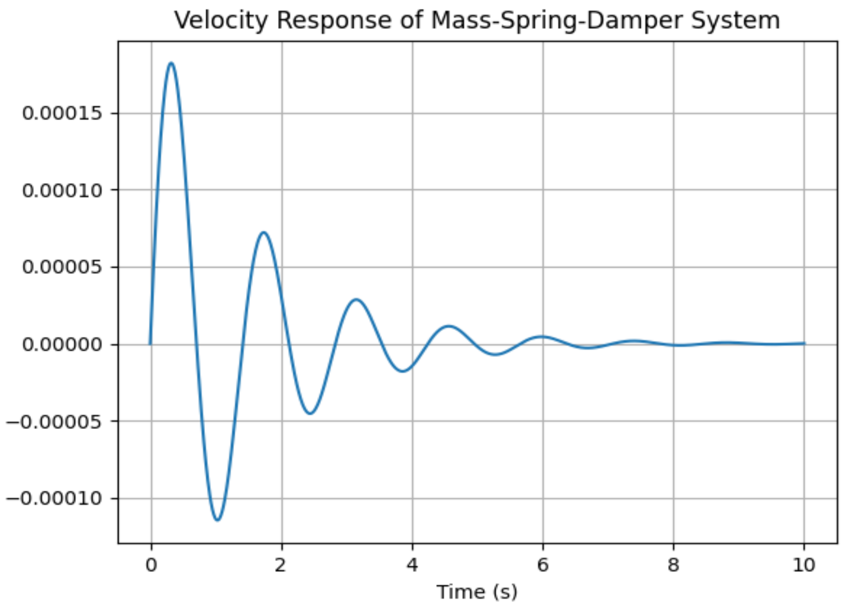


**Figure 2:** Velocity response of the system showing damping effect over time.

Fig. 1 and 2 show the graphs as output of matlab programing. It is possible to make the following observations based on the MATLAB simulation: When the step input is applied, the system's initial response is characterized by oscillations. As time passes, the damping effect brings about a reduction in the amplitude of oscillations. Over time, the system will eventually arrive at a condition of steady-state. The displacement curve illustrates the manner in which the system becomes stable. The velocity response provides evidence that motion is slowing down. Accelerating the reduction of oscillations can be accomplished by increasing damping, whereas increasing stiffness can reduce displacement but may also increase system rigidity. Having a design that is balanced provides greater comfort and stability.

## 5. Conclusions

According to the findings, the mass-spring-damper system is an efficient method for depicting vibration behavior. Furthermore, the results indicate that the correct tuning of parameters is an essential component in enhancing the performance of the system. The implementation of intelligent dampening devices in contemporary transportation cabins is bolstered by this work.

## Authors' contributions

All authors contributed equally to the conception, design, data analysis, interpretation of results, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

## Conflicts of interest

The author declares no conflict of interest.

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## Data availability

No new data were created.

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