Scilab case study project on

Optimizing Ride Quality through Damping Adjustment in Automotive Suspension Systems

Dibyani Mohanty

K J Somaiya College of Engineering

Mechanical Engineering, Control Systems, Vehicle Dynamics

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Abstract

The suspension system of a vehicle stands as a critical component in ensuring both the safety and comfort of passengers. It acts as a buffer between the vehicle's body and the road surface, absorbing shocks and vibrations to maintain stability and control during various driving conditions. This case study delves into the intricate dynamics of the car's suspension system, employing the Spring-Damper-Mass (SDM) model to dissect the multifaceted role of damping within this essential subsystem. By meticulously analysing the suspension's response under distinct damping conditions—including overdamped, critically damped, and underdamped states—the study seeks to illuminate the profound impact of damping adjustments on ride quality and handling precision. Utilizing Scilab/Xcos for simulation, the case study provides a comprehensive analysis of how adjustments in damping coefficients influence the vehicle's response to road irregularities, thereby offering insights into the design and tuning of effective suspension systems. Through this investigation, the study contributes to the broader understanding of vehicular dynamics, emphasizing the importance of balanced damping in enhancing both driver satisfaction and safety

1. Introduction

The pursuit of optimal vehicle performance and passenger comfort has been a cornerstone of automotive engineering for decades. Central to achieving these objectives lies the suspension system, a complex network of springs, dampers, and links that mediates the interaction between the vehicle's body and the road surface. This intricate system plays a pivotal role in attenuating the impacts of road irregularities, ensuring a smooth and controlled ride under a wide range of driving conditions. As such, the design and tuning of the suspension system represent critical areas of focus within the broader field of vehicle dynamics. Furthermore, this study underscores the broader implications of suspension dynamics on vehicle safety and overall performance, highlighting the necessity of balanced damping in preventing potential accidents triggered by loss of control or excessive body movements.

2. Problem Statement

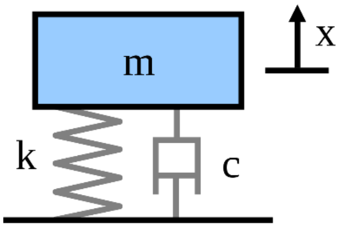
Given a car/automobile equipped with a Spring-Mass-Damper (SDM) system, the challenge is to analyse and optimize ride quality through appropriate damping adjustments. Specifically, the problem involves studying the system's response under different damping conditions.

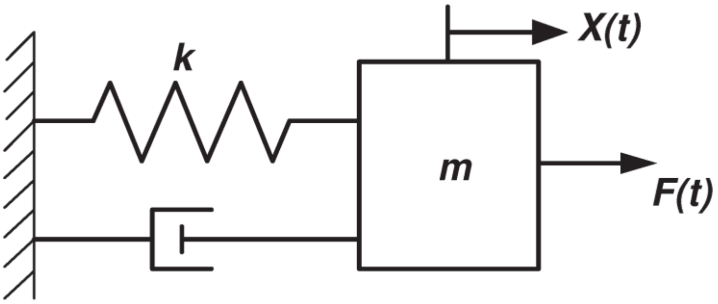
3. Basic concepts related to the topic

The mass-spring-damper model consists of discrete mass nodes distributed throughout an object and interconnected via a network of springs and dampers. This model is well-suited for modelling object with complex material properties such
as nonlinearity and viscoelasticity. Components used in mass-spring-damper model are:

1. Mass (m): The mass represents the inertial property of the system and is typically denoted by the symbol "m." It is the physical object that is subject to the forces within the system.
2. Spring (k): The spring represents the elastic property of the system and is denoted by the symbol "k." The spring exerts a force that is proportional to the displacement of the mass from its equilibrium position. This force opposes the displacement and tends to restore the mass to its equilibrium position.
3. Damper (c): The damper represents the damping property of the system and is denoted by the symbol "c." The damper exerts a force that is proportional to the velocity of the mass. This force dissipates energy from the system, damping out oscillations and reducing the amplitude of vibrations.

The dynamic behaviour of a mass-spring-damper system can be described by differential equations that govern the motion of the mass under the influence of the spring and damper forces. The solutions to these equations can be used to analyse the vibrations, resonances, and stability of the system.





Mass-spring-damper systems are commonly used in various fields, including mechanical engineering, civil engineering, control systems, and physics, to analyse and design systems that exhibit oscillatory behaviour. They provide a simplified yet effective way to understand the dynamics of complex systems and are fundamental in the study of vibration analysis and control.

Damping in a Spring-Mass-Damper (SDM) system refers to the phenomenon where energy is dissipated within the system, typically through the action of a damper or dashpot. This energy dissipation occurs as the system oscillates or vibrates, gradually reducing the amplitude of these oscillations over time until the system comes to rest. The primary purpose of damping is to prevent excessive oscillation, which can lead to instability or damage to the system, and to control the speed at which the system returns to its equilibrium position after being disturbed.

For an SDM system, the transfer function is derived from the system's differential equation, which models the interaction between the mass, spring, and damper.

$$\frac{X(s)}{F(s)} = \frac{1}{Ms^2 + f_v s + k}$$

(X(s)): The Laplace Transform of the displacement of the mass from its equilibrium position. It represents the output of the system in the frequency domain.

(F(s)): The Laplace Transform of the external force applied to the mass. It represents the input to the system in the frequency domain.

(M): The mass of the object. It is a measure of the inertia of the system.

(s): The complex frequency variable in the Laplace domain, which extends the concept of frequency to include complex numbers, allowing for analysis of both magnitude and phase of the system's response.

(fv): Represents the damping force, where (f) is the damping coefficient and (v) is the velocity of the mass.

(k): The spring constant, which measures the stiffness of the spring. It determines the restoring force exerted by the spring.

The same equation can be expressed in time domain like this:

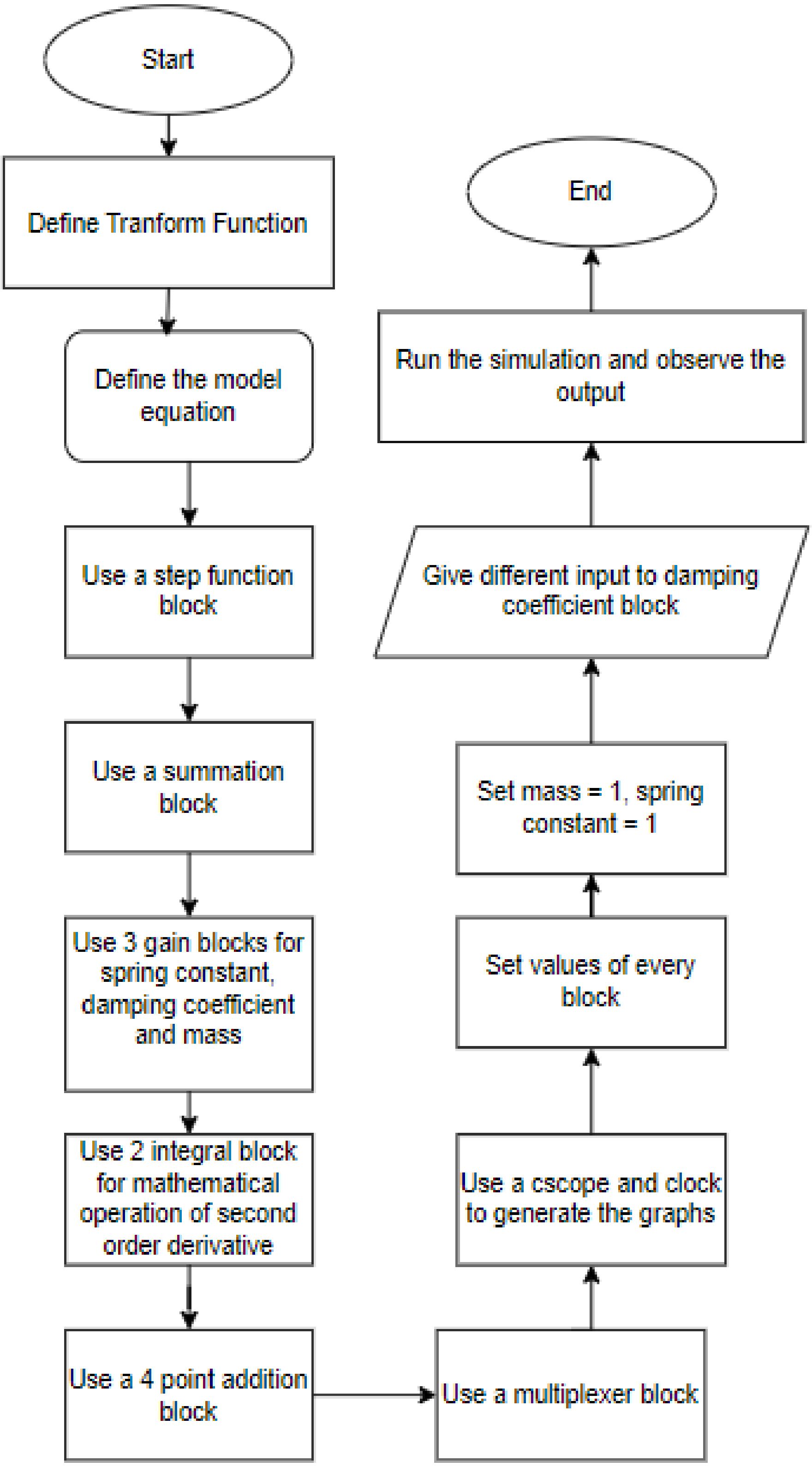
$$M\frac{d^2x(t)}{dt^2} + f_v\frac{dx(t)}{dt} + kx(t) = F(t)$$

$$M\ddot{x} + f_v\dot{x} + kx = F$$

$$\ddot{x} = \frac{1}{M}\{F - f_v\dot{x} - kx\}$$

The above equation is used to implement the model in xcos.

4. Flowchart


Start
Define Tranform Function
Define the model equation
Use a step function block
Use a summation block
Use 3 gain blocks for spring constant, damping coefficient and mass
Use 2 integral block for mathematical operation of second order derivative
Use a 4 point addition block
Use a multiplexer block
Use a cscope and clock to generate the graphs
Set values of every block
Set mass = 1, spring constant = 1
Give different input to damping coefficient block
Run the simulation and observe the output
End

5. Software/Hardware used

Operating System: Windows 11

Toolbox: None

Hardware: Personal Computer with Intel Core i7 Processor and 8GB RAM

Software: Scilab Version: 6.1.1 - Xcos

6. Procedure of execution

Step 1: Launch the Scilab software on your computer.

Step 2: Open the provided Xcos file named "SDM.zcos".

Step 3: Set the value of damping coefficient constant block to 0

Step 4: Run the simulation by navigating to the "Simulation" menu and selecting "Run".

Step 5: Observe the graph displayed as the output.

Step 6: Set the value of damping coefficient constant block to 2

Step 7: Run the simulation by navigating to the "Simulation" menu and selecting "Run".

Step 8: Observe the graph displayed as the output.

Step 9: Set the value of damping coefficient constant block to 4

Step 10: Run the simulation by navigating to the "Simulation" menu and selecting "Run".

Step 11: Observe the graph displayed as the output.

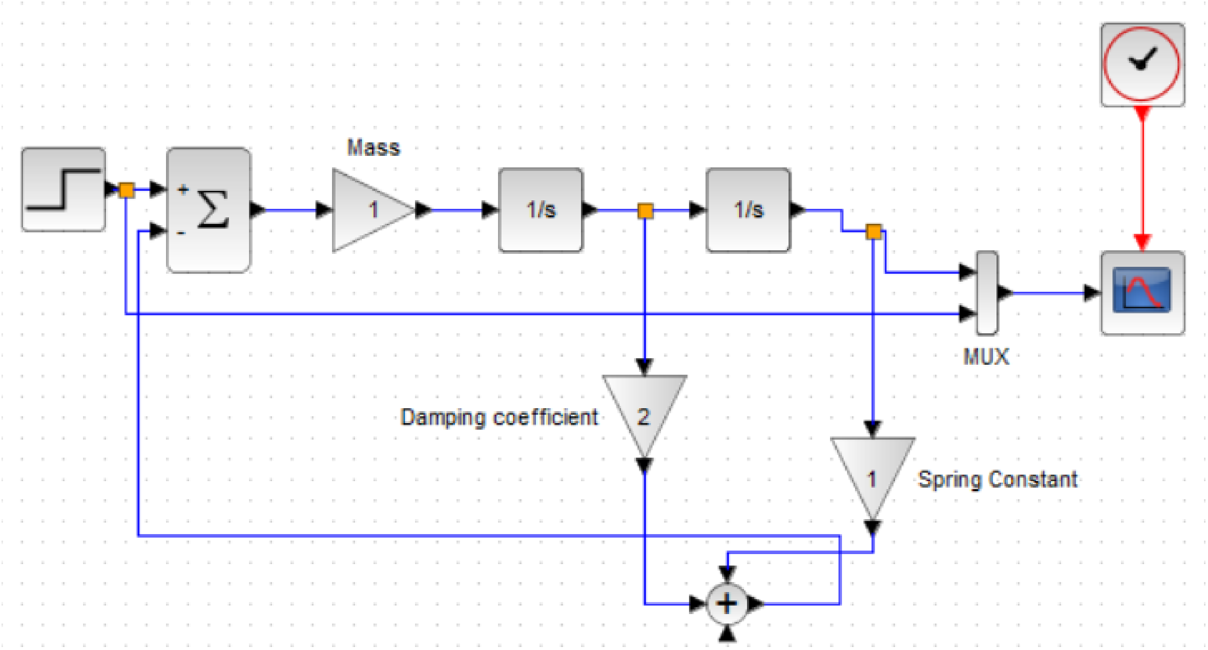
Step 12: Set the value of damping coefficient constant block to 0.2

Step 13: Run the simulation by navigating to the "Simulation" menu and selecting "Run".

Step 14: Observe the graph displayed as the output.

7. Result

After implementing the SDM model in Xcos and conducting simulations with various damping factors, we observed distinct behaviours that have significant implications for optimizing ride quality in automotive suspension systems. The damping factor directly influences the system's response to road irregularities, affecting both ride comfort and handling.



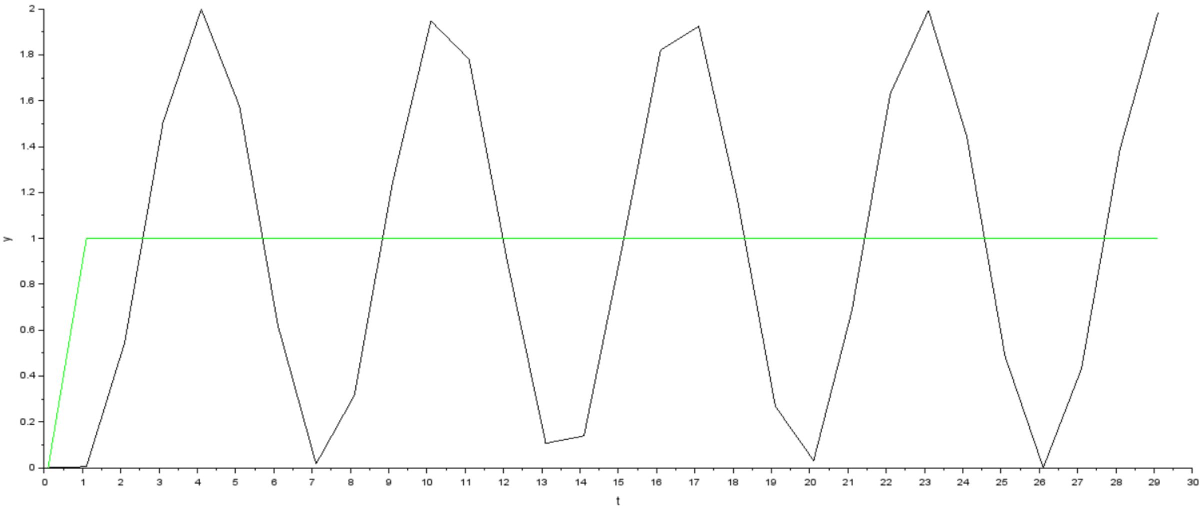
- **Undamped**

  i. Scenario Description: When the damping factor is set to 0, the system behaves as purely elastic, with no energy dissipation due to damping. This corresponds to an undamped system.

  ii. Graphical Output: The simulation showed pronounced oscillations following a step input, indicating that the system continues to oscillate around the equilibrium position without dissipating energy.

  iii. Time to Equilibrium: Due to the lack of damping, the system never truly settles to equilibrium; it continues to oscillate. This indefinite oscillation means there is no practical time to equilibrium in this scenario.

  iv. Implications for Ride Quality: An undamped suspension system is highly undesirable in real-world applications because it fails to provide a comfortable ride. The continuous oscillations translate into a rough and unstable ride for passengers, compromising safety and comfort.



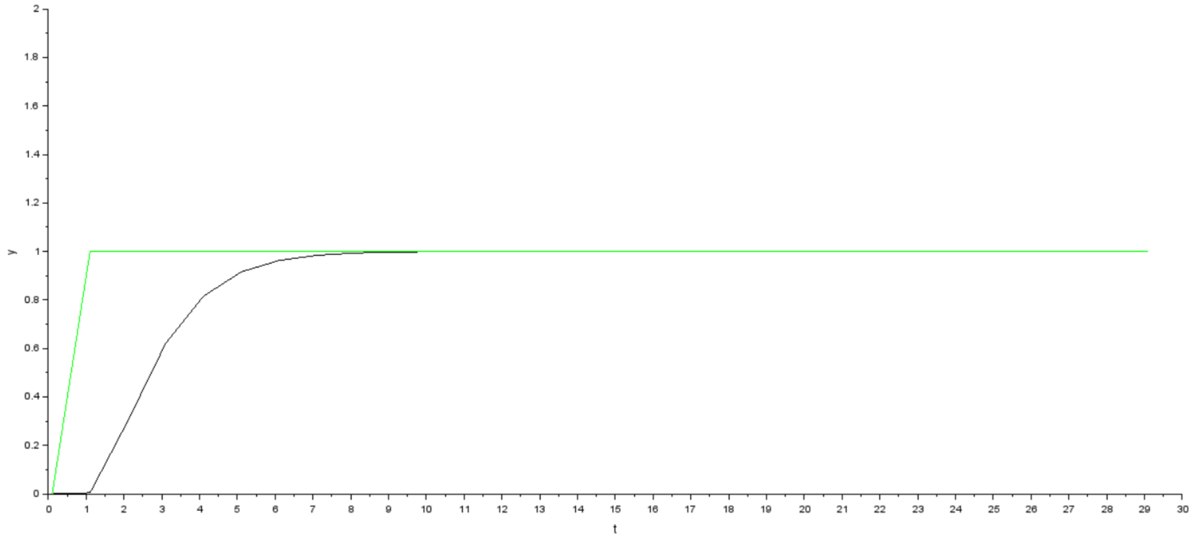
➢ Critically Damped

i. Scenario Description: Setting the damping factor to 2 resulted in a critically damped system, where the system returns to equilibrium as quickly as possible without oscillating.

ii. Graphical Output: The system demonstrated a rapid return to equilibrium with no oscillations, indicating that the suspension system efficiently absorbs shocks and minimizes bounce.

iii. Time to Equilibrium: This is the fastest return to equilibrium among the damping scenarios. The system responds immediately to disturbances, making it ideal for situations requiring quick stabilization, such as sudden road changes or avoiding obstacles. This characteristic enhances both ride comfort and handling.

iv. Implications for Ride Quality: A critically damped suspension system is ideal for optimizing ride quality. It provides excellent handling and stability by minimizing body roll and bounce, ensuring a smooth and controlled ride. This configuration is particularly beneficial for aggressive driving conditions, where maintaining control and stability is paramount.



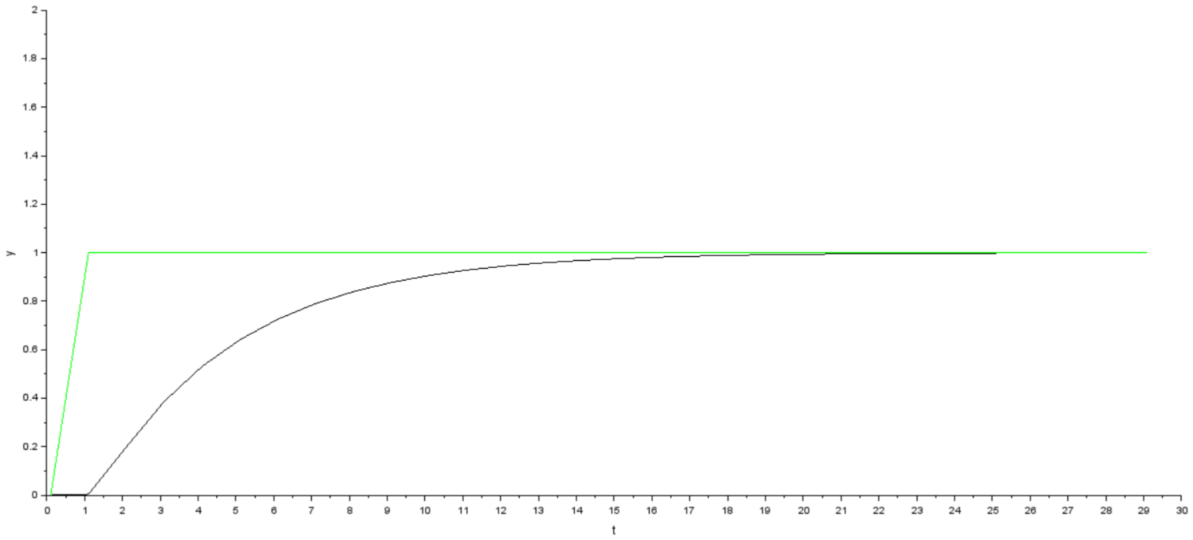
➢ Overdamped

i. Scenario Description: With a damping factor of 4, the system is overdamped, characterized by a slow return to equilibrium with negligible oscillations.

ii. Graphical Output: The system took a longer time to return to equilibrium, with almost no observable oscillations. This behaviour suggests that the suspension system is very effective at absorbing shocks but may feel sluggish in responding to sudden changes.

iii. Time to Equilibrium: Although the system eventually reaches equilibrium, it does so very slowly. This slow response can be perceived as a lack of responsiveness, especially in situations requiring immediate reaction to changes in the road surface or driving manoeuvres. However, it provides a very stable and smooth ride by minimizing bouncing and rolling.

iv. Implications for Ride Quality: An overdamped suspension system sacrifices some responsiveness for improved stability and comfort. While it provides a smooth ride by effectively absorbing most road imperfections, it may not offer the best handling in situations requiring quick adjustments, such as sharp turns or sudden obstacles.



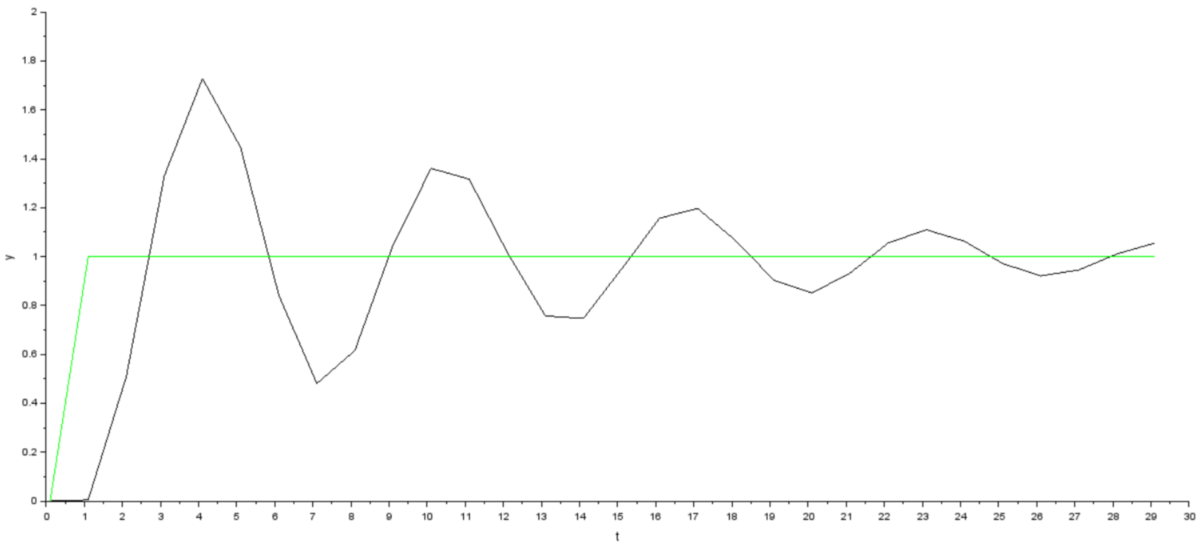
➢ Underdamped

i. Scenario Description: With a damping factor of 0.2, the system is underdamped, meaning there is some energy dissipation but not enough to prevent oscillations.

ii. Graphical Output: The system exhibited damped oscillations, with the amplitude of oscillations gradually decreasing over time. However, the oscillations were still present, indicating that the suspension system can absorb some of the shock but not completely.

iii. Time to Equilibrium: The system eventually returns to equilibrium, but it takes significantly longer than in an overdamped or critically damped system. The exact time depends on the damping coefficient and the system's natural frequency. Despite the eventual return to equilibrium, the prolonged oscillations can lead to a perception of a rougher ride.

iv. Implications for Ride Quality: An underdamped suspension system offers improved ride comfort compared to an undamped system. The damping ensures that the system does not oscillate indefinitely, providing a smoother ride. However, the presence of oscillations suggests that the suspension system could still benefit from increased damping to further reduce road noise and vibrations.



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