# THE CONCEPT OF LINEARIZATION

LAB EXPERIMENT 6


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***Abstract*—This experiment explores the concept of linearization by analyzing the behavior of a nonlinear spring-mass-damper system through simulations. Using Python, we modeled a system with a nonlinear stiffness component and derived its linear approximation around the equilibrium point. We then compared the time-domain responses of both systems and quantified the approximation error. Results show that the linearized system closely matches the nonlinear behavior near equilibrium, validating the effectiveness of linearization in simplifying system analysis for small perturbations.**


## I. RATIONALE

Linearization is used to simplify the analysis of nonlinear systems by approximating them as linear systems near an equilibrium point. This experiment demonstrates the process of Linearization.

## II. OBJECTIVES

- Linearize a nonlinear system (e.g., a spring-mass-damper system) around an equilibrium point.
- Quantify the approximation error between the linearized system and the original non-linear system.
- Verify that the linearized system's response matches the nonlinear system near the equilibrium point.

## III. MATERIALS AND SOFTWARE

- Software: Python (with control, matplotlib, and scipy)

## IV. PROCEDURES

1) Set up a nonlinear system, such as a spring-mass-damper system with nonlinear stiffness.
2) Identify the equilibrium point of the system.
3) Linearize the system around the equilibrium point by approximating the nonlinear terms with linear models.
4) Simulate the system response using the linearized model and compare it to the nonlinear system's behavior near the equilibrium point.
5) Calculate the error between the linearized and nonlinear responses.
6) Discuss the validity and limitations of the linearization.

## V. OBSERVATION AND DATA COLLECTION

DATA COLLECTION:

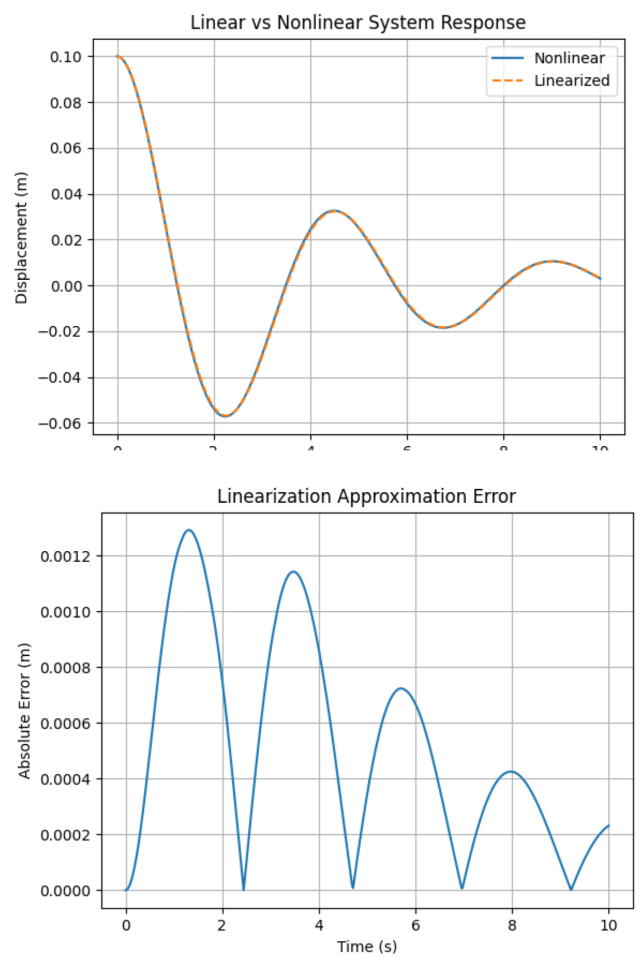


Fig. 1. Linear vs Nonlinear system response and Linearization Approximation Error

## VI. DATA ANALYSIS

To evaluate the validity of linearization, we simulated both the nonlinear and linearized versions of a spring-mass-damper system. The nonlinear system included a cubic stiffness term $k_2 x^3$, while the linearized version excluded this component, assuming small displacements.

- **Figure 1 (Top)** shows the displacement-time responses of both systems. The trajectories are almost identical for an initial displacement of 0.1 meters.
- **Figure 1 (Bottom)** plots the absolute error between the two responses. The maximum error was less than 0.0013 meters, indicating close alignment.
- The error appears to oscillate and decay over time, consistent with damped harmonic motion.
  The small error values validate the assumption that the linear approximation holds well near the equilibrium point.

## VII. DISCUSSION AND INTERPRETATIONS

The simulation highlights how linearization simplifies the analysis of nonlinear systems with minimal loss in accuracy under small perturbations. Because the nonlinear term $k_2 x^3$ has a negligible effect near equilibrium, the linearized model captures the dominant behavior.

The oscillatory nature of the error suggests that the linear model slightly underestimates or overestimates the displacement at different points in the cycle, but these differences remain minor. As expected, the deviation becomes most noticeable at the displacement peaks, where the nonlinear effects are greatest.

This validates the practical engineering approach of linearizing systems for control and analysis, especially in small-signal conditions. However, for larger displacements or highly nonlinear dynamics, the error would likely grow and the linear model would no longer be reliable.

## VIII. CONCLUSION

The simulation confirms that linearization is a valid and effective method for simplifying nonlinear systems near equilibrium. The linearized model closely replicates the nonlinear system's response when initial displacements are small, with only a minimal approximation error. However, this method has limitations and becomes less accurate for large displacements or strongly nonlinear systems. Linearization remains a fundamental tool in system modeling, analysis, and control design, especially in engineering contexts where small deviations are assumed.