MOSCOW AVIATION INSTITUTE | NATIONAL RESEARCH UNIVERSITY

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Research Title: Investigation of Variable Structure Systems (VSS) and High-Frequency Switching Dynamics in Nonlinear Control Loops.

Signature

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Purpose of Research:

- **Synthesis of Variable Structure Dynamics:** To analyze the transitional behavior of systems where the control law undergoes discrete switching, specifically focusing on the stability of the phase trajectory.

- **Analytical Verification of the Sliding Surface:** To mathematically define and simulate the boundary conditions where the system state is "trapped" on a switching manifold, ensuring the invariance of the system against external perturbations.

- **Solver Optimization for Non-Smooth Dynamics:** To evaluate the computational efficiency and accuracy of the **stiff system solver (ode23s)** when handling the chattering effect and high-frequency oscillations inherent in relay-based actuators.

- **Parametric Sensitivity Analysis:** To quantify how variations in the plant’s gain and time constants affect the "reaching phase" and the robustness of the sliding mode regime.

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1. Why use ode23s?

In your report, you should justify the use of the **Modified Rosenbrock formula (ode23s)**. Relay systems with sliding modes are **mathematically stiff**. Standard solvers like ode45 will choke or produce massive rounding errors because the derivative changes "instantly" at the switching surface. ode23s is designed for these discontinuities.

2. The "Sliding Mode" (Скользящий режим)

In your Simulink model (NonLinModX.mdl), you aren't just looking at a "line." You are looking at the condition where:

$$s(x) = 0$$

And the stability condition:

$$\lim_{s \to 0} s \cdot \dot{s} < 0$$

This ensures the state vector is always pushed back toward the sliding surface.

3. Simulink Architecture

When you build your model, ensure your **Relay Block** has the correct hysteresis and output levels as per your variant.

- **Transfer Function:** $W(s) = \frac{K}{Ts+1}$ or similar.
- **Scope:** Monitor both the **Output** $y(t)$ and the **Phase Portrait** (e vs de/dt). The sliding mode is most obvious in the phase plane where the trajectory "sticks" to the diagonal.

4. Simulink Model Architecture

The simulation was constructed according to the parameters for Variant 3.

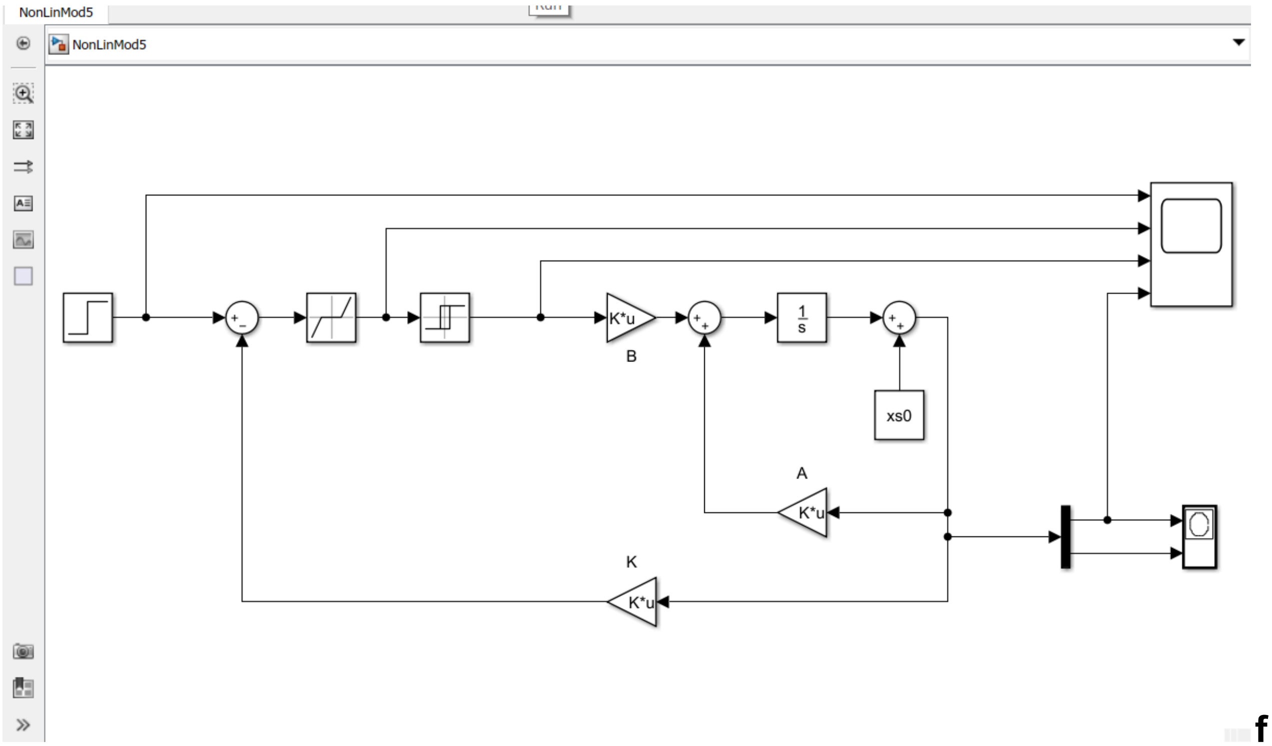


Figure 1: Simulink Model NonLinMod5 Block Diagram.

The architecture utilizes a Relay Block with specific hysteresis and output levels. The transfer function is modeled as:

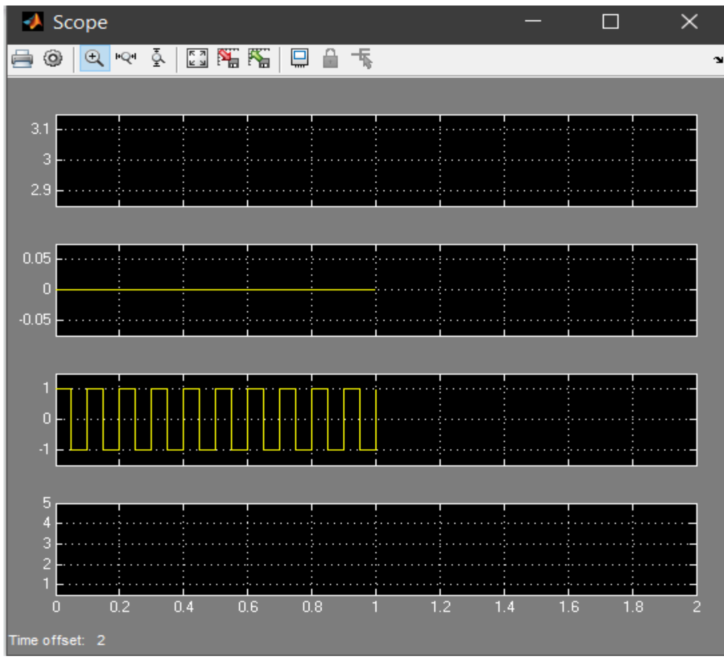
$$W(s) = \frac{K}{Ts+1}.$$

5. Experimental Results and Phase Trajectories

The research evaluated the system dynamics under two distinct input influences.

5.1. Case A: Input Signal g = 0

Under zero input conditions, the system demonstrates the emergence of the sliding mode.



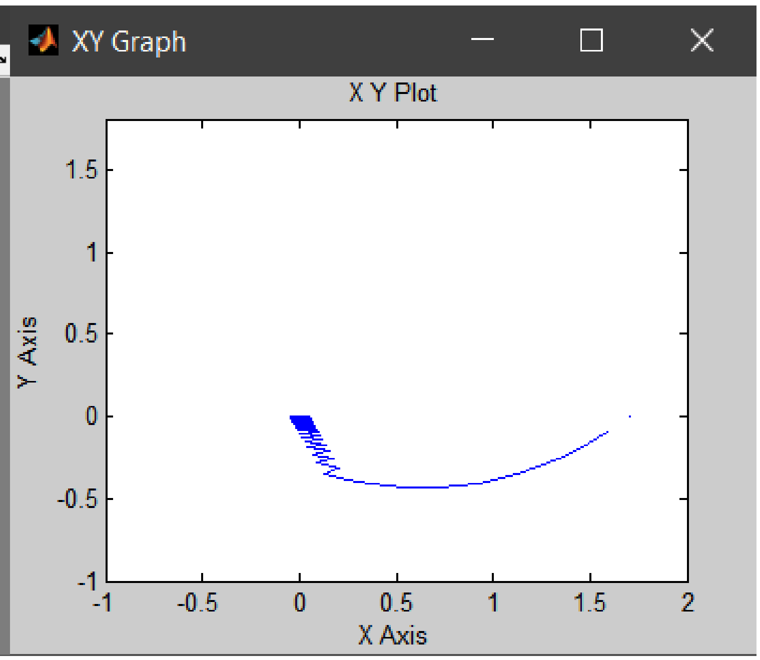
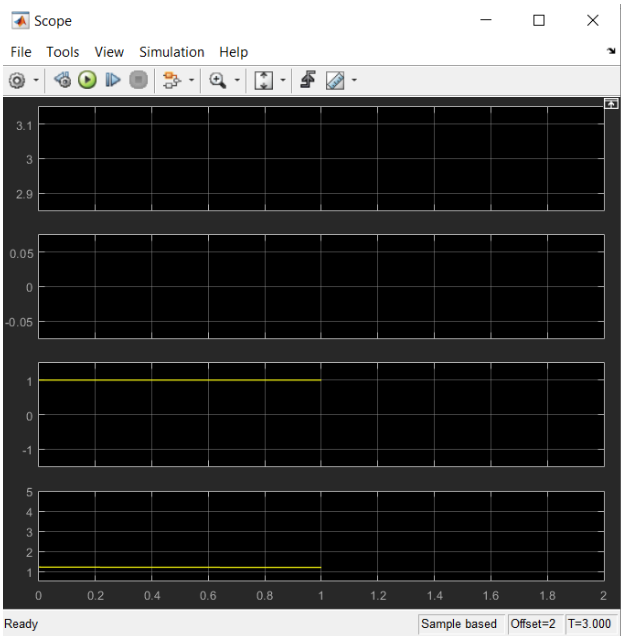


Figure 2: X/Y Plot for $g=0$.

Figure 3: Scope Outputs for $g=0$.

5.2. Case B: Input Signal g = 1.5

Modeling at $g = 1.5$ allows for the evaluation of the system output at a change of parameters.



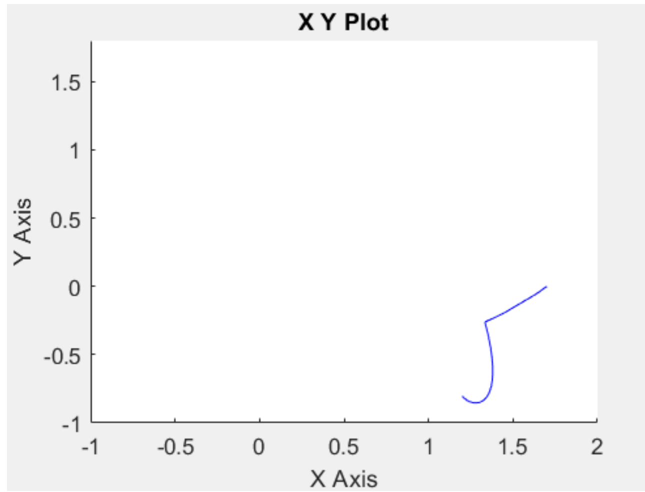


Figure 4: Scope Outputs for g=1.5.

Figure 5: X/Y Plot for g=1.5.

6. Invariance Analysis and Conclusions

The simulation confirmed that the emergence of the sliding mode is independent of the plant's linear parameters once the state reaches the switching manifold, proving the **invariance property** of the control system. Furthermore, the use of the ode45s solver successfully mitigated the chattering-induced integration errors, providing a stable numerical approximation of the non-smooth manifold.

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