

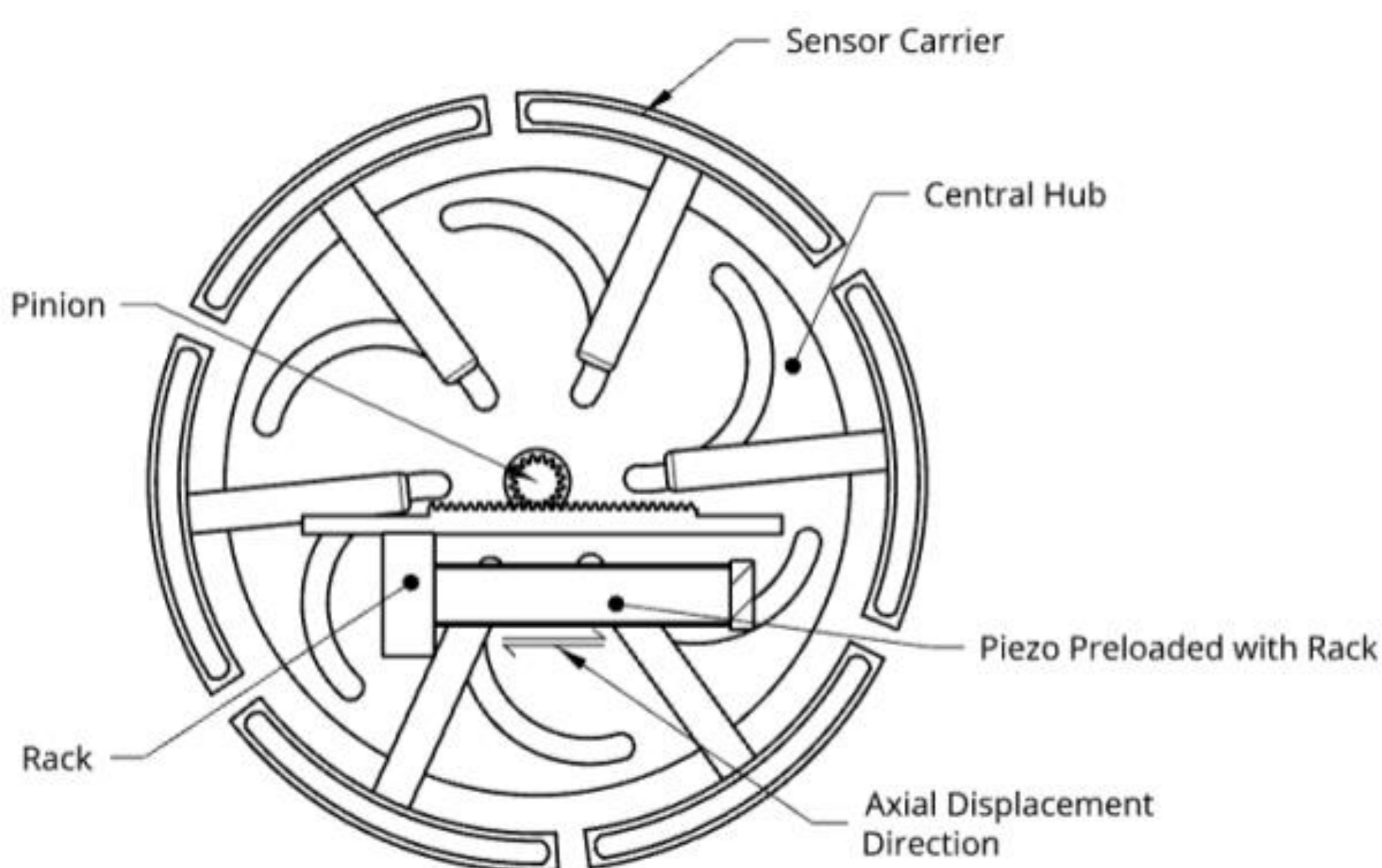
DEVELOPMENT OF A PIEZOELECTRIC-BASED HIGH-PRECISION SENSOR POSITIONING SYSTEM FOR PIPELINE INSPECTION

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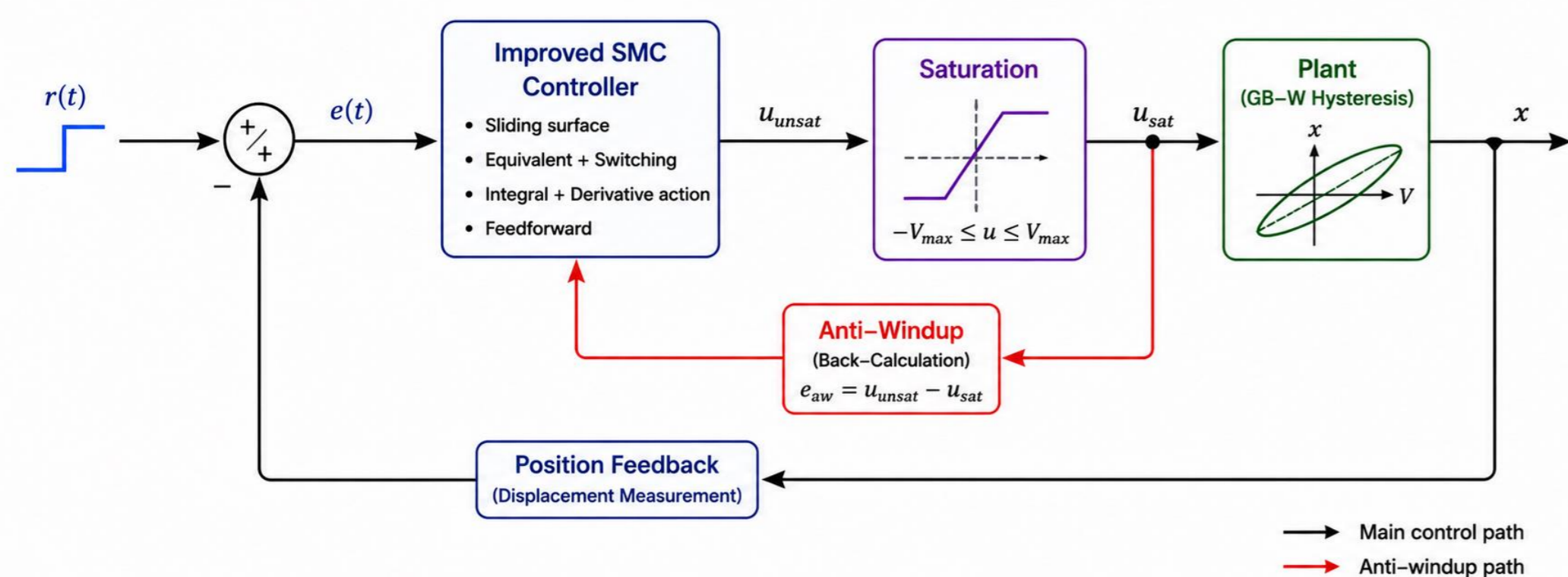
INTRODUCTION & AIM

Precise sensor positioning is critical for reliable non-destructive pipeline inspection in confined environments. Although piezoelectric actuators offer high resolution and fast response, their performance is limited by hysteresis, nonlinear dynamics, and actuator voltage constraints. We present a compact piezoelectric positioning system for pipelines with diameters of 50–100 mm, combining a Generalized Bouc–Wen hysteresis model with an improved Sliding Mode Controller incorporating derivative compensation, integral action, filtered switching dynamics, saturation handling, and anti-windup compensation.



Piezoelectric-driven positioning mechanism converting axial actuator displacement into precise radial sensor motion through a rack-and-pinion transmission and flexure-guided central hub.

METHOD

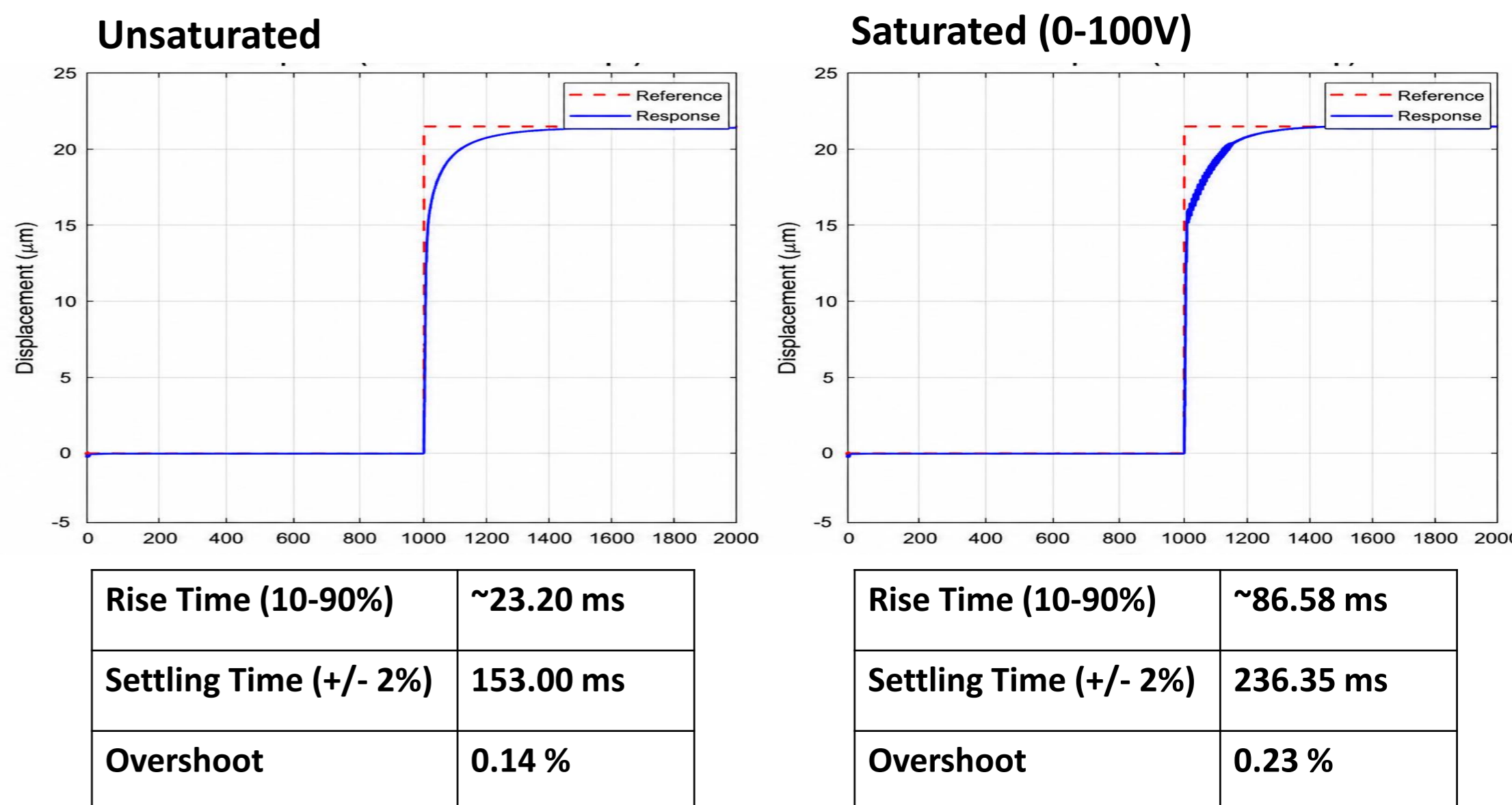


CONCLUSION

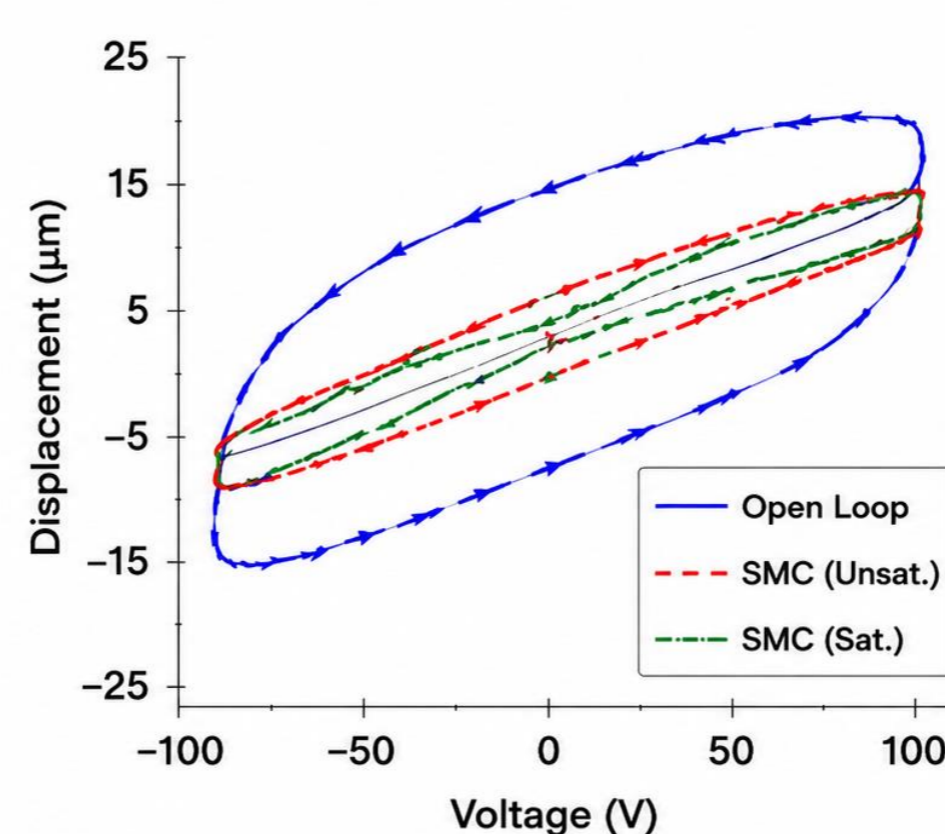
- Developed a GB–W hysteresis-based piezoelectric positioning system for pipeline inspection.
- Implemented an improved SMC with filtering, saturation, and anti-windup compensation.
- Achieved stable high-precision tracking within practical 0–100 V actuator limits.

RESULTS & DISCUSSION

Final Controller Step Response Saturation Comparison



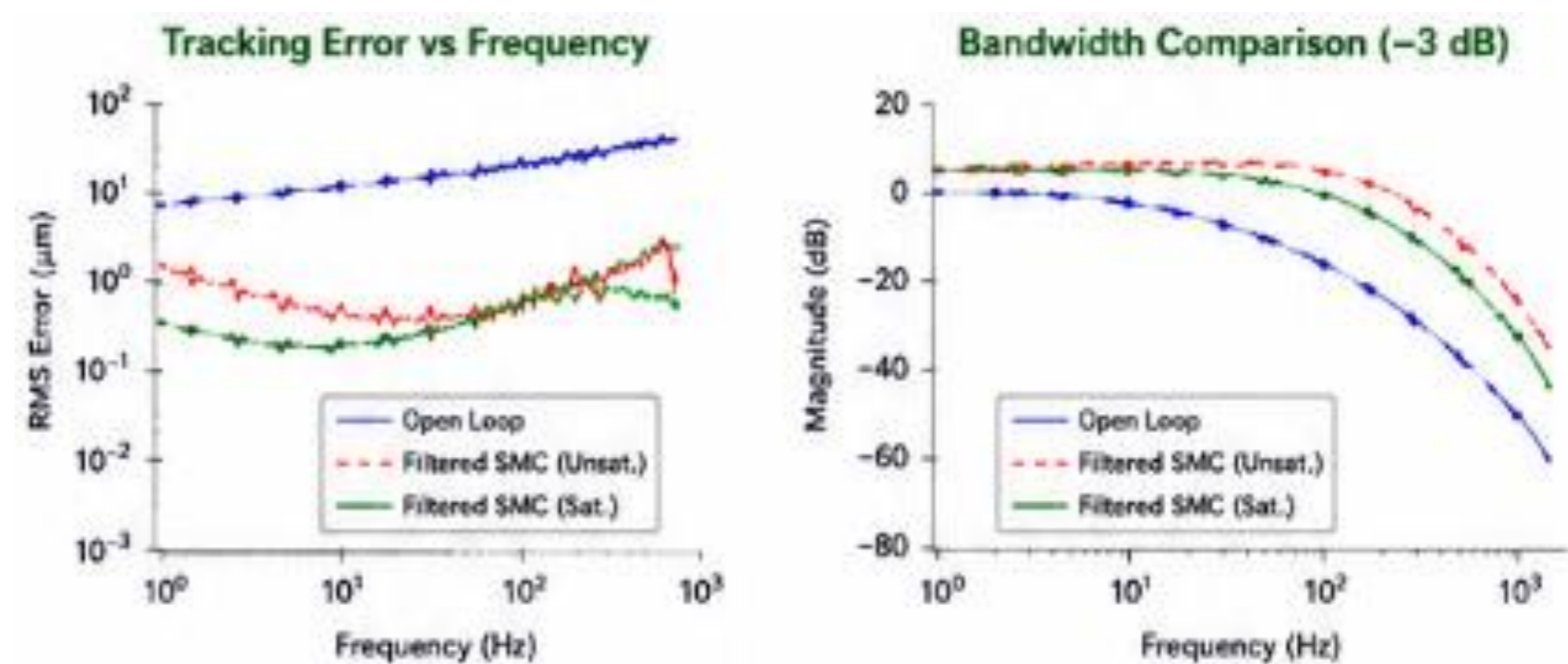
Hysteresis Loop Suppression (100Hz)



Performance Summary

Controller	Overshoot (%)	Settling Time (ms)	Max. Error (micrometers)
Open Loop	11.8	882	> 5.0
SMC (Unsaturated)	21.9	22.6	0.3
Filtered SMC (Unsaturated)	0.14	153.0	0.2
Filtered SMC (Saturated, 0-100 V)	0.23	236.4	< 50

PERFORMANCE IN FREQUENCY DOMAIN



FUTURE WORK / REFERENCES

Future Work

- Experimental validation and hardware implementation.
- Adaptive or learning-based hysteresis compensation.
- Extension to multi-axis positioning and closed-loop force control.

Selected References

- Shi X. Application of ultrasonic non-destructive testing in industrial pipeline inspection 2024.
- Yang D. et al. Piezoelectric Active Sensing-Based Pipeline Corrosion Monitoring Using Singular Spectrum Analysis 2024.