Dynamic Analysis and Design Optimization of Washing Machine Suspensions

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KEYWORDS: *Washing Machine Dynamics, Suspension System Optimization, Supercritical Speed Regime, Vibration Analysis.*

The dynamic performance of modern front-loading washing machines is strongly influenced by the behavior of their suspension systems, particularly during high-speed spinning. Increasing demands for higher spin speeds, larger load capacities, and reduced vibration and noise levels impose significant challenges on the mechanical design. Among these, excessive vibrations, structural collisions, and machine walking remain critical issues that directly affect product reliability and the user experience.

This study presents an analytical investigation of the dynamic behavior of a front-loading horizontal-axis washing machine with a particular focus on the supercritical speed regime. In contrast to most existing works, which primarily rely on computationally expensive multibody simulations or focus on transient ramp-up behavior, this research develops a linear six-degree-of-freedom mathematical model derived using Lagrangian mechanics. The model is implemented in MATLAB and validated against a high-fidelity multibody simulation model in ADAMS, showing good agreement in terms of eigenfrequencies and damping characteristics.

The proposed model enables efficient evaluation of steady-state system responses under harmonic excitation caused by rotating unbalance forces. Based on this framework, a comprehensive parameter study is conducted in the supercritical speed range, which is particularly relevant for the spin-drying phase of washing machines. Key suspension parameters—including spring stiffness, spring angle, damping coefficient, damper angle, and damper positioning—are systematically varied to investigate their effects on critical performance indicators, including displacement amplitudes, spring and damper forces, and walking forces.

Unlike traditional optimization approaches that rely on black-box algorithms, this work emphasizes a physics-based, qualitative understanding of parameter sensitivities. The results reveal clear relationships between suspension design parameters and system behavior, enabling the identification of parameter regions that reduce vibration amplitudes, minimize transmitted forces, and mitigate walking tendencies.

The findings provide practical design insights for improving suspension systems in next-generation washing machines while maintaining computational efficiency. Furthermore, the developed analytical framework establishes a foundation for future investigations of nonlinear effects and transient behavior in the critical speed range.