



Nonlinear Dynamic Analysis and Comparative Study of Slider-Crank Mechanism Inversions with Revolute Joint Clearance

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Abstract - This research investigates the complex nonlinear dynamic behavior of the three primary inversions of a slider-crank mechanism (PRRR, RPRR, and RRPR) in the presence of revolute joint clearance. In precision machinery, manufacturing tolerances and wear lead to unavoidable clearances, which introduce additional degrees of freedom and high-frequency impact forces. A contact force model based on Lankarani-Nikravesh integration and Hertzian contact theory is employed to simulate joint interactions. Through the application of Poincaré maps and bifurcation diagrams, the transition from periodic to chaotic motion is analyzed. The study further evaluates the stabilizing effects of tangential friction and the compounding impact of multiple clearance joints. Results indicate that the sensitivity to clearance is highly dependent on the kinematic inversion, providing critical insights for the design of high-precision mechanical systems.

Keywords: Multi-body Dynamics, Joint Clearance, Chaos, Bifurcation, Slider-Crank Inversions, ADAMS/View.

1. INTRODUCTION

Modern high-speed machinery requires extreme kinematic precision. However, "ideal" joints do not exist in practice; clearances are necessary for assembly and movable engagement. These gaps lead to the loss of continuous contact, resulting in "impact-rebound" phenomena. Previous studies have focused on the standard slider-crank, but a comparative analysis of its **inversions** is rare. This paper addresses that gap by evaluating how the redistribution of fixed links and moving masses affects the susceptibility to chaotic vibration



2. MATHEMATICAL FORMULATION

2.1 Contact Force Model

The interaction between the journal and the bearing is modeled using a nonlinear spring-damper approach. The normal contact force F_n is defined as:

$$F_n = K\delta^n + D\dot{\delta}$$

Where:

- K is the equivalent stiffness based on material properties (Young's modulus and Poisson's ratio).
- δ is the penetration depth.
- D is the damping coefficient representing energy dissipation during impact.

2.2 Friction Model

To simulate realistic conditions, the Modified Coulomb Friction Law is applied to the joint surfaces to account for stiction and sliding transitions:

$$F_f = \mu(v_t) F_n$$

where v_t is the relative tangential velocity.

3. KINEMATIC INVERSIONS AND SIMULATION

Three configurations were modeled in **MSC ADAMS/View 2024**:

1. **RPRR (Standard)**: Link 1 fixed. Typical for internal combustion engines.
2. **RRPR (Whitworth)**: Link 3 fixed. Used in quick-return mechanisms.
3. **PRRR (Oscillating Cylinder)**: Link 4 fixed. Common in marine engines and steam pumps.

Simulation Parameters:

- Crank Speed: 300 - 600 RPM.
- Clearance Size: 0.1mm to 0.5mm.
- Integrator: WSTIFF (for stiff, nonlinear differential equations).

4. RESULTS AND DISCUSSION

4.1 Chaos and Periodicity

Poincaré portraits for the RPRR inversion showed a distinct "cloud" of points at higher clearance values ($c > 0.3\text{mm}$), signifying a transition from a stable limit cycle to a chaotic attractor. In contrast, the RRPR inversion exhibited higher resilience to chaos at moderate speeds due to the different inertial distribution of the fixed link.

4.2 Bifurcation Analysis

Bifurcation diagrams were plotted with clearance size as the control parameter. We observed a period-doubling route to chaos. For the RPRR inversion, the system remained periodic until a critical threshold, after which the slider acceleration showed high-frequency oscillations and unpredictable peaks.



4.3 Influence of Multiple Clearances

When clearances were introduced at both the crank-pin and the small-end bearing, the nonlinearities did not merely add up; they coupled, leading to a much faster transition to chaos compared to single-joint clearance models.

5. CONCLUSION

- The dynamic performance of slider-crank mechanisms is significantly compromised by revolute joint clearance. Key findings include:
- The RPRR inversion is most sensitive to journal-bearing impacts at high speeds.
- Friction acts as a damping mechanism that can suppress chaotic regimes, suggesting that lubrication management is vital not just for wear but for dynamic stability.
- Designers should prioritize minimizing clearance at the crank-pin joint over the slider-pin joint to maintain better kinematic accuracy.

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