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Review
of the doctoral thesis prepared by M.Sc. Eng. Willy Prastiyo,
"Balancing of slider-crank and Scotch-yoke mechanisms by the use of mechanical resonance"

Doctoral dissertation supervisor: prof. dr hab. inż. Wiesław Fiebig

Basis for the preparation of the review: Resolution No. W10/RDND07/76/2026 of the Discipline Council of Mechanical Engineering at Wrocław University of Science and Technology, dated 28 April 2026, and the Act of 20 July 2018 – Law on Higher Education and Science.

1. General Overview

The submitted doctoral dissertation addresses the problem of dynamic balancing of slider-crank and Scotch-yoke mechanisms through the application of mechanical resonance. The work combines analytical modeling, multibody simulations, experimental validation, and engineering applications. The dissertation is ambitious in scope and addresses an important problem in machine dynamics, namely the reduction of input torque fluctuations, joint reaction forces, shaking forces, and dynamic loading of reciprocating mechanisms.

The dissertation is well organized and follows a logical structure consisting of an introduction, theoretical synthesis, numerical analysis, experimental validation, engineering applications, and conclusions. The literature review is comprehensive and demonstrates the author's familiarity with both classical and contemporary research on mechanism balancing.

From the formal point of view, the dissertation is prepared at a high level. The language is generally clear, the figures are of good quality, and the overall presentation is consistent. The work is supported by an extensive bibliography and numerous numerical and experimental results.

The dissertation undoubtedly represents a considerable amount of research effort and constitutes a valuable contribution to the field of mechanism dynamics. Nevertheless, several methodological issues, mathematical inconsistencies, and points requiring clarification have been identified during the review.

2. The Topic of the Doctoral Dissertation and Its Significance

The balancing of reciprocating mechanisms remains an important research topic due to its direct influence on vibration reduction, durability, energy efficiency, and operational reliability of mechanical systems.

The proposed concept of exploiting mechanical resonance as a constructive mechanism rather than a phenomenon to be avoided is an original and interesting research direction. Instead of introducing additional balancing masses or complicated auxiliary mechanisms, the author proposes utilizing properly tuned elastic elements to reduce dynamic loads.

Such an approach may have practical significance for lightweight machinery, compressors, reciprocating actuators, and other systems operating at nearly constant speed.

The dissertation therefore addresses a scientifically relevant and practically important engineering problem.

3. Content of the Dissertation

The dissertation consists of six chapters. The introductory chapter presents the motivation, literature review, scientific objectives and originality of the proposed method.

Chapter 2 develops the analytical formulation of the resonance-based balancing method. The author derives the governing equations of motion, discusses resonance conditions, gravity compensation and optimization procedures.

Chapter 3 contains an extensive numerical investigation of input torque, joint reaction forces, shaking forces, stresses and the influence of selected design parameters.

Chapter 4 presents experimental validation using physical prototypes of both slider-crank and scotch-joke mechanisms.

Chapter 5 discusses engineering applications including reciprocating compressors and punch press mechanisms.

The dissertation concludes with a summary of scientific contributions and recommendations for future research.

The adopted structure is logical and facilitates understanding of the proposed methodology.

4. General Scientific Comments and Minor Errors

The dissertation is generally scientifically sound; however, several issues require clarification or correction.

4.1 Kinetic energy of the connecting rod

Equation (2.22) appears to include only the horizontal component of the translational kinetic energy of the connecting rod. According to Eq. (2.29), the coordinate x_2 represents only the horizontal position of the connecting rod's center of mass, whereas the center of mass also possesses a vertical velocity component due to the rod's rotation. Therefore, the translational kinetic energy of the connecting rod should generally be expressed as: $\frac{1}{2}m_2(\dot{x}_2^2 + \dot{y}_2^2)$.

4.2 Kinematic description of the Scotch-yoke mechanism

Equation (2.33) appears to require clarification. According to Fig. 2.8(b), the crank angle α is measured from the horizontal axis, in which case the horizontal displacement of the crank pin—and consequently the slider displacement—would be expected to be proportional to $l_1 \cos\alpha$ rather than $l_1 \sin\alpha$. Alternatively, if x_3 denotes the positive displacement of the slider measured from one end of its stroke, the expression should include a constant offset, e.g., $x_3 = l_1 - l_1 \cos\alpha$. The adopted formulation therefore appears inconsistent with the geometric definition of the crank angle. If confirmed, this inconsistency may propagate to the subsequent expressions for the slider velocity and kinetic energy (Eqs. (2.34) and (2.35)) as well as to the later derivations of the input torque and energy characteristics, potentially introducing a phase shift of 90°. Derivation step would benefit from clarification.

4.3 Constraint equations

The vector constraint equations presented in Eqs. (2.50) and (2.51) appear to require clarification. According to the geometry shown in Fig. 2.8(a) and the definition of the connecting rod angle given in Eq. (2.25), the second vector in Eq. (2.50) would be expected to have the form $(l_2 \cos\beta\, \hat{\imath} - l_2 \sin\beta\, \hat{\jmath})$., rather than $(l_2 \cos\beta\, \hat{\imath} + l_2 \sin\beta\, \hat{\jmath})$. Furthermore, the vector constraint equation for the Scotch-yoke mechanism given in Eq. (2.51) simultaneously implies $x_3 = l_1 \cos\alpha$, and $l_1 \sin\alpha = 0$, the latter condition being satisfied only at isolated crank positions rather than during general motion. The constraint equation for the Scotch-yoke mechanism should therefore retain only the horizontal projection relation, $x_3 = l_1 \cos\alpha$, while the vertical motion of the crank pin is accommodated by the yoke slot. Consequently, the formulation of the constraint equations for both mechanisms would benefit from revision.

4.4 Use of Lagrange multipliers

The dissertation introduces the Lagrange multiplier formulation for constrained multibody systems Eq. (2.39); however, the subsequent derivation appears to employ a reduced-coordinate description in which the constraint equations have already been used to eliminate the dependent variables. Consequently, only a single Lagrange equation is derived, while the physical interpretation and subsequent use of the Lagrange multipliers are not evident. It would be beneficial to clarify whether the derivation follows a redundant-coordinate formulation with constraint forces or a reduced-coordinate formulation with analytically eliminated constraints.

4.5 Interpretation of joint reaction forces

Section 3.2 presents reaction forces acting in individual joints. However, the methodology used to obtain these forces is not sufficiently described. It remains unclear whether the joint reactions are derived analytically from the Lagrange multipliers, reconstructed through Newton-Euler equilibrium equations, or obtained directly from the multibody simulation software. A short explanation of the computational procedure would significantly improve the reproducibility of the presented results.

4.6 Resonance frequency

An apparent inconsistency exists regarding the resonance frequency of the slider-crank mechanism. Earlier in Chapter 2 on page 37, the resonance condition is established at approximately 25 rad/s based on the analytical model, whereas on page 40 the minimum torque fluctuation is reported to occur at approximately 47 rad/s and is identified as the resonant frequency. The manuscript would benefit from clarifying the origin of the two resonance frequencies and explicitly stating whether they correspond to different models, parameter sets, or definitions of resonance.

4.7 Modeling of joints

The dissertation refers to several joints as spherical joints. However, the physical slider-crank and Scotch-yoke mechanisms are planar mechanisms consisting primarily of revolute and prismatic joints. No explanation is provided why spherical joints were adopted.

5. The Most Important Original Achievements of the Work

Despite the above comments, the dissertation contains several significant original contributions.

The most important achievements include:

- proposing the concept of resonance-assisted balancing of slider-crank and Scotch-yoke mechanisms,
- demonstrating analytically and numerically the influence of resonance on input torque fluctuations and dynamic reactions,
- developing a systematic design methodology for resonance tuning,
- investigating the influence of reciprocating mass, spring stiffness, friction and external loading,
- validating the theoretical results experimentally,
- demonstrating engineering applicability using practical mechanical systems,
- providing an extensive comparison with conventional balancing approaches.

The combination of analytical, numerical and experimental investigations constitutes an important strength of the dissertation.

6. Final Conclusion

The submitted dissertation presents an original and valuable contribution to the field of mechanism dynamics. The proposed concept represents an interesting research direction and significantly extends the current knowledge in this field.

The dissertation demonstrates that the doctoral candidate possesses extensive knowledge of analytical mechanics, multibody dynamics, numerical modelling, and experimental methods, as well as the ability to conduct independent scientific research.

In the reviewer's opinion, the comments presented above are primarily of a clarifying nature and do not diminish the overall scientific value of the dissertation.

Taking into account the scientific merit, originality, and quality of the conducted research, I conclude that the doctoral dissertation prepared by **M.Sc. Eng. Willy Prastiyo** meets the requirements for doctoral dissertations specified in the **Act of 20 July 2018 – Law on Higher Education and Science**, as amended. The dissertation constitutes an original solution to a scientific problem within the discipline of **Mechanical Engineering**.

Therefore, I recommend that the dissertation be accepted and that M.Sc. Eng. Willy Prastiyo be admitted to the public defense.

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