

Advancements in Simulation-Based Dynamic Modeling and Analysis of Complex Mechanical Systems for Engineering Applications

Mahesh Yadav

M. Tech. in Machine Design Engineering CBS Group of Institutions, Jhajjar, Haryana.

Abhishek Singhroha

A.P Mechanical Department, CBS Group of Institutions, Jhajjar, Haryana.

ABSTRACT

The dynamic modeling and analysis of mechanical systems has become a critical aspect of modern mechanical engineering. With the increasing complexity of systems, traditional methods are often insufficient to capture nonlinearity and multi-physics interactions. Simulation-based techniques, such as finite element analysis and multibody dynamics, offer a more accurate approach for system behavior prediction. Recent advancements in computational mechanics have allowed for more robust modeling, enabling better optimization, fault diagnosis, and performance evaluation. Approaches like physics-informed neural ordinary differential equations (PINODE) and hybrid models are enhancing model accuracy while maintaining interpretability. Simulation-driven frameworks play a key role in system identification and control applications.

***Keywords:** Dynamic Modeling, Simulation Techniques, Finite Element Analysis, Multibody Dynamics, Hybrid Models.*

I. INTRODUCTION

The dynamic modeling and analysis of mechanical systems using simulation techniques has emerged as a fundamental area of research in modern mechanical and machine design engineering. With the increasing complexity of engineering systems, there is a growing need for accurate, efficient, and computationally feasible methods to predict system behavior under varying operating conditions. Traditional analytical methods, although useful for simplified systems, often fail to capture nonlinearities, uncertainties, and multi-physics interactions present in real-world mechanical systems. As a result, simulation-based approaches have become indispensable tools for design optimization, fault diagnosis, and performance evaluation. Recent advancements in computational mechanics have significantly enhanced the ability to model complex dynamic systems. Tebaldi and Zanasi (2026) emphasized that robust dynamic modelling is essential in systems and control engineering, particularly for nonlinear mechanical systems. Their work demonstrated that automated modelling approaches can improve both computational efficiency and robustness against measurement noise when compared to classical Euler–Lagrange formulations. This highlights the increasing shift toward algorithm-driven modelling frameworks capable of handling complex engineering systems. Similarly, Scutaru and Pruncu (2024) observed that the evolution of numerical methods and computational tools has transformed the field of mechanics. The integration of experimental data with simulation-based modelling has enabled researchers to study nonlinear dynamic behaviour with higher accuracy. These advancements have expanded the scope of mechanical system analysis to include multibody systems, vibration behaviour, and elastic deformation modelling, thereby improving predictive capabilities in engineering design. Simulation techniques such as finite element analysis (FEA), multibody dynamics (MBD), and numerical integration methods have become essential in studying mechanical systems under real-world constraints. Rong et al. (2019) highlighted that flexible multibody system dynamics provide a crucial theoretical foundation for analyzing complex engineering systems in aerospace, robotics, and automotive applications. However, they also pointed out that challenges remain in improving computational efficiency and numerical stability, especially for large-scale systems with multiple degrees of freedom. The increasing use of simulation-based

optimization has further enhanced the reliability of mechanical systems. Siregar (2025) emphasized that traditional reliability methods are insufficient for systems operating under variable and uncertain load conditions. By integrating finite element methods, probabilistic modelling, and machine learning techniques, simulation frameworks can predict failure mechanisms and improve system robustness. This integration supports the development of adaptive and intelligent mechanical systems capable of responding to changing operational environments. In addition, data-driven and hybrid modelling approaches have gained significant attention in recent years. Roehrl et al. (2020) introduced physics-informed neural ordinary differential equations (PINODE), which combine physical laws with neural network-based learning. This hybrid approach improves model accuracy while maintaining physical interpretability, making it highly suitable for system identification and control applications in mechanical engineering. Furthermore, the application of simulation techniques extends to fault diagnosis and vibration analysis. Wang et al. (2023) developed a dynamic model for dual-rotor systems with inter-shaft bearing faults and demonstrated that simulation results closely matched experimental observations. Such studies highlight the importance of simulation in detecting mechanical faults and understanding vibration characteristics in rotating machinery systems. Mass–spring–damper systems, commonly used as fundamental models in mechanical engineering, have also benefited from advanced simulation techniques. Gantada and Basri (2025) demonstrated that MATLAB-based optimization and numerical integration methods can accurately estimate system parameters while maintaining robustness under noisy conditions. These simplified models provide a foundation for understanding more complex mechanical behaviours.

II. RESEARCH BACKGROUND

Tibaldi and Zanasi (2026) emphasized that the development of efficient and robust dynamic models was crucial in systems and control engineering. They proposed a novel formulation for the dynamic modeling of nonlinear mechanical systems, applicable across various automotive and robotic case studies, and introduced a systematic procedure to automatically obtain the model formulation. Their study indicated that, when compared with the conventional Euler-Lagrange approach, the proposed model demonstrated superior performance in terms of robustness against measurement noise, particularly for systems influenced by external variables. Additionally, it was reported that the model reduced execution time during inverse dynamics computations. The findings suggested that this methodology could enhance both accuracy and computational efficiency in practical applications, providing a more reliable framework for dynamic analysis and control of complex mechanical systems. The study was positioned as a significant contribution to advancing automated modelling techniques within the field.

Schupp (2026) highlighted that numerical bifurcation analysis was regarded as a suitable approach for investigating the long-term behaviour of nonlinear dynamical systems under varying system parameters. The study aimed to present a software environment designed for such analysis, emphasizing path-following and continuation methods, particularly in applications involving mechanical systems, and more specifically, railway vehicles modelled as multibody systems. The research focused on both stationary and periodic behaviours of these systems. Three primary aspects were identified as central: integrating the bifurcation software into a broader simulation package for arbitrary mechanical systems, directly computing periodic solutions such as limit cycles, and managing differential algebraic equations (DAEs). The developed algorithms were ultimately applied to a realistic simulation model of a railway vehicle operating on a straight track, demonstrating the capability of the framework to capture and analyse complex dynamical behaviours in engineering applications, thereby confirming its relevance for both theoretical and practical studies in mechanical system analysis.

Gantada and Basri (2025) presented a modelling, simulation, and analysis framework for a mass–spring–damper (MSD) system aimed at characterizing the physical parameters of mass, damping, and stiffness using standard MATLAB without requiring additional toolboxes. They synthesized experimental data through a combination of step and multi-level sinusoidal excitations to enrich frequency content and introduced small Gaussian noise to displacement measurements to emulate sensor limitations. Parameter estimation was carried out in the time domain by minimizing the squared difference between the ODE45-integrated model response and the measurement data using the `fminsearch` (Nelder–Mead) algorithm. Model performance was evaluated through out-of-sample validation with alternative inputs, including chirp and small step signals, and a Monte Carlo sensitivity analysis to examine robustness against $\pm 10\%$ parameter variations. Their results demonstrated high model fidelity on training data, robustness on validation data, and residuals without systematic patterns, with natural frequencies and damping ratios aligning closely with synthetic references. The study provided a concise, reproducible workflow for laboratory damper testing and low-order mechanical system diagnostics.

Siregar (2025) examined the increasing demands on mechanical systems to perform reliably under variable and often unpredictable load conditions in diverse industrial applications. He argued that traditional reliability analysis methods, which generally assumed static or uniform loads, were inadequate for capturing the dynamic behaviour and failure mechanisms encountered in real-world scenarios. The study explored the application of simulation-based optimization to enhance the reliability of mechanical systems subjected to fluctuating operational demands. Siregar highlighted the use of advanced modelling techniques, including finite element analysis, probabilistic simulation, surrogate modelling, and multi-objective optimization, for evaluating performance, predicting failure modes, and identifying design improvements. He emphasized the necessity of incorporating uncertainty, validating virtual models against experimental data, and employing machine learning tools to augment simulation insights. Applications were examined across rotating machinery, joints and interfaces, and thermal-mechanical systems, demonstrating that integrating simulation with real-time monitoring, material modelling, and sustainable engineering practices played a pivotal role in developing robust, cost-efficient, and future-ready mechanical systems.

Wang et al. (2025) investigated the impact of cracks on disc components, emphasizing that such defects could substantially reduce service life. They noted that previous studies commonly assumed predefined crack paths, such as tangential or radial cracks, and seldom examined the stress response of discs during vibration. Furthermore, they highlighted those conventional dynamic models, with numerous degrees of freedom, demanded significant computational resources to calculate stress variations. To overcome these limitations, they conducted vibration experiments to determine actual crack paths and developed a reduced-order dynamic model of discs with breathing cracks based on shell theory. The proposed model was validated by comparing its stress calculations with experimental observations. Subsequently, the experimentally determined crack paths were incorporated into the model to analyse dynamic stress variations during crack propagation. Their findings indicated that cracks exhibited a breathing effect, inducing nonlinear vibrations. As cracks propagated, the maximum stress at the disc root decreased progressively at a diminishing rate, whereas the maximum stress at the crack tip decreased linearly.

Scutaru and Pruncu (2024) observed that, although the field of mechanics had often been regarded as difficult for further advancement, the rapid development of technology and numerical computation techniques had significantly altered this perception. They reported that increasingly sophisticated models had been developed to predict, with greater accuracy, the phenomena occurring in dynamic systems. The authors indicated that researchers had increasingly focused on investigating mechanical systems with

complex behaviour through both experimental methods and computer-based modelling. It was emphasized that a fundamental requirement for such investigations was the nonlinear nature of the system. They further noted that progress in mechanics and dynamical systems had been driven by multiple sources, including computer simulation, experimental science, mathematical analysis, and theoretical modelling. Their review highlighted a broad range of relevant areas, such as modelling of mechanical systems, nonlinear and multibody systems, simulation of system behaviour, elastic elements, multi-degree-of-freedom systems, experimental modal analysis, and the mechanics of materials.

Rathee (2023) had examined friction as a fundamental element necessary for the effective functioning of mechanical systems, while also emphasizing its dissipative nature that was found to reduce useful energy and overall system efficiency. The study had identified friction analysis as a significant research area because of its crucial role in enhancing machine performance. It had been noted that friction analysis was complex, as friction depended on multiple interacting factors, making accurate evaluation challenging. In this review, the author had presented a concise overview of existing literature on various friction models developed for different types of mechanical systems. The research had covered both static and dynamic friction models, along with their numerical modelling and simulation approaches. The distinguishing features of these models had also been highlighted to demonstrate the relevance of earlier techniques. Furthermore, the study had provided insights into the current state of research and had suggested possible future directions for advancing friction analysis in mechanical engineering.

Wang et al. (2023) investigated the vibration characteristics associated with inter-shaft bearing failures in a dual-rotor system. For this purpose, an eight-degree-of-freedom dynamic model of a dual-rotor system incorporating inter-shaft bearings was developed. The model equations were solved using the Newmark- β numerical method. The study examined the dynamic behaviour of the rotor system under conditions where the inner ring and outer ring of the inter-shaft bearing exhibited either single-point defects or composite faults. The comparative findings indicated that the fault frequency distribution observed in the envelope spectrum of the simulation closely matched the experimental test results, thereby confirming the validity and reliability of the proposed dynamic model. It was further reported that inter-shaft bearing faults generated fault characteristic frequencies modulated by rotor rotational frequency, multiple frequency components, and fault frequency interactions. Additionally, apart from speed-synchronized vibrations caused by eccentricity, the rotor vibration response was also accompanied by prominent higher-order harmonic components.

Scutaru and Pruncu (2022) observed that although the field of mechanics had previously been regarded as difficult for further advancement, recent technological progress and the rapid development of numerical calculation techniques had significantly altered this perception. The authors indicated that these advancements had encouraged researchers to revisit traditional mechanical problems and develop increasingly sophisticated models for describing dynamic system behaviour with greater precision. Their review suggested that modern computational approaches had improved the understanding of vibrations, symmetries, and complex interactions in mechanical systems. They also highlighted that the integration of advanced mathematical modelling with engineering applications had broadened the scope of mechanics research. In support of this perspective, prior studies such as those by Vlase et al. had examined vibration behaviour in mechanical bar systems with symmetries, while Li et al. and Xu et al. had explored optimization and ecological performance in high-temperature proton exchange membrane fuel cells. Overall, the study emphasized the renewed relevance and expansion of mechanics through computational innovation.

Lim et al. (2022) reported that the deep-seabed mining system, designed for underwater resource extraction, comprised several interconnected components, including a mining vessel, lifting riser, lifting pump, buffer system, flexible riser, and mining robot. The authors observed that the system operated under extreme environmental conditions such as high fluid resistance, elevated water pressure, and deep-sea surroundings, which had significantly increased the time and cost associated with equipment design and testing. To address these challenges, they proposed the adoption of simulation-based technology for system evaluation and optimization. The study emphasized that factors such as large marine-induced motions, vibrations generated by mechanical operations, and the driving resistance encountered by the mining robot on subsea soft soil had made integrated dynamic analysis essential. Accordingly, the paper introduced an integrated dynamic simulation method capable of analysing the interactions among multiple system components within a unified environment and discussed the effectiveness of the obtained simulation results.

Li (2021) examined the growing significance of mechanical systems in engineering projects in China and emphasized that their operational reliability was closely associated with both personal safety and economic efficiency. The study highlighted the necessity of monitoring system performance to identify potential hazards in advance and to ensure stable equipment operation. It was reported that the research aimed to provide a deeper understanding of the dynamic characteristics of rotating machinery systems, thereby offering a basis for parameter optimization, fault diagnosis, and vibration control. Using the ADAMS concept, the author investigated the steady and transient steering characteristics of an automobile train system comprising one tractor and five double-axle steering trailers. Design research analysis, experimental design analysis, and optimum design analysis were employed to evaluate the effects of structural and service parameters on trajectory-following ability. The findings indicated that the proposed optimization schemes reduced trajectory deviation by 70%–80%, thereby significantly improving system stability.

Roehrl et al. (2020) proposed that accurate dynamic model identification was essential for the simulation and control of diverse technical systems, particularly where conventional modelling approaches proved inadequate. It was observed that first-principles methods often suffered from high bias, while purely data-driven models tended to exhibit high variance, demand large datasets, and offer limited interpretability. To address these limitations, the authors introduced Physics-Informed Neural Ordinary Differential Equations (PINODE), a hybrid modelling framework that integrated physical laws with neural network-based function approximation. The study demonstrated that equations of motion derived from Lagrangian mechanics could be directly embedded into a deep neural network architecture, thereby enabling the incorporation of prior physical knowledge where available. The proposed method was evaluated using a forward model of a real-world mechanical system characterized by substantial uncertainties. The findings indicated that PINODE achieved high accuracy, data efficiency, and physical plausibility, highlighting its relevance for system identification and model-based control of mechanical systems.

Rong et al. (2019) reviewed the recent progress in flexible multibody system dynamics (MSD), which had been recognized as a significant and challenging area in modern mechanics. The authors observed that flexible MSD had provided an important theoretical and technical foundation for evaluating dynamic performance and optimizing the design of complex systems across engineering domains such as machinery, aviation, aerospace, robotics, weapons, and biological engineering. It was reported that the two central issues in this field had been the development of efficient and accurate dynamic modelling methods and the formulation of stable and reliable numerical solution algorithms. The review summarized recent advances in modelling approaches, including reference frame selection, kinematic descriptions of

flexible bodies, derivation of dynamic equations, model reduction methods, and techniques for handling contact/collision, uncertainty, and multi-field coupling. Furthermore, numerical solution technologies and their latest developments were discussed in detail. The study also indicated future research directions for improved modelling and numerical computation in flexible MSD.

Pappalardo et al. (2018) had focused on developing a numerical procedure for solving the system identification problem of linear dynamical models representing multibody mechanical systems. The study had employed an input–output representation of system evolution through a sequence of matrices known as Markov parameters, which incorporated state-space matrices for describing dynamic behaviour under the assumption of structural linearity. Since direct extraction of system Markov parameters from observable measurements had been difficult, the authors had introduced a state observer to derive observer Markov parameters from experimental input–output data using a least-squares approach. These parameters had then been recursively used to compute both system Markov parameters and observer gain Markov parameters. Thereafter, generalized Hankel matrices had been constructed to extract the state-space model through a numerical algorithm based on the Moore–Penrose pseudoinverse and singular value decomposition. A numerical example using a simple vehicle model had demonstrated the effectiveness and validity of the proposed identification procedure.

Sehgal and Kumar (2017) proposed a novel structural dynamic model updating technique for damped mechanical systems by integrating the response surface method with Derringer’s desirability function approach. It was reported that response surface models were employed in place of finite element models to improve computational efficiency during the updating process. The study indicated that Derringer’s function approach was particularly effective in addressing multi-objective optimization problems associated with model updating. Unlike earlier techniques developed mainly for undamped systems, this work extended the methodology to damped mechanical systems. The updating procedure was formulated as a two-stage optimization problem in which desirability functions were constructed using natural frequencies, modal assurance criterion values, and resonance and anti-resonance points from frequency response functions. In the first stage, updated elastic parameters were estimated, while in the second stage, damping constants were identified. The results demonstrated substantial error reductions, with total absolute errors decreasing significantly across frequencies, parameters, and response functions.

III. KEY FINDINGS FROM STUDY

Author (Year)	Methodology / Approach	System / Application Area	Key Findings / Contributions
Tebaldi & Zanasi (2026)	Automated nonlinear dynamic modeling using advanced formulation techniques	Automotive and robotic mechanical systems	Improved robustness against noise and reduced computational time in inverse dynamics compared to Euler–Lagrange methods
Schupp (2026)	Numerical bifurcation analysis using continuation and path-following methods	Railway vehicle multibody systems	Successfully captured stationary and periodic behaviors including limit cycles under varying parameters
Gantada & Basri (2025)	MATLAB-based simulation using ODE45 and fminsearch optimization	Mass–spring–damper system	Achieved accurate parameter estimation with high robustness under noise and validated model performance

Siregar (2025)	Simulation-based optimization integrating FEA, probabilistic modeling, and ML	Mechanical systems under variable loads	Enhanced reliability prediction and failure analysis under uncertain operating conditions
Wang et al. (2025)	Reduced-order modeling with experimental crack path integration	Cracked disc dynamic systems	Identified nonlinear vibration due to crack breathing and observed stress variation during crack propagation
Scutaru & Pruncu (2024)	Computational and numerical modeling review	General nonlinear mechanical systems	Highlighted increasing role of simulation in predicting complex dynamic behavior
Rathee (2023)	Review of static and dynamic friction models	Mechanical systems with friction effects	Identified complexity of friction modeling and its impact on system efficiency and energy loss
Wang et al. (2023)	Dynamic modeling using Newmark- β method	Dual-rotor system with bearing faults	Simulation results validated experimentally and accurately captured fault frequency characteristics
Lim et al. (2022)	Multibody dynamic simulation framework	Deep-seabed mining system	Developed integrated simulation for analyzing coupled mechanical interactions under extreme conditions
Li (2021)	ADAMS-based simulation and optimization	Vehicle-train steering system	Reduced trajectory deviation by 70–80% and improved dynamic stability
Roehrl et al. (2020)	Physics-informed neural ODEs (PINODE)	General mechanical system identification	Combined physical laws with neural networks for accurate and data-efficient modeling
Rong et al. (2019)	Review of flexible multibody system modeling methods	Aerospace, robotics, and mechanical systems	Identified challenges in numerical stability and efficiency in large-scale dynamic systems
Pappalardo & Guida (2018)	System identification using Markov parameters and SVD	Linear multibody mechanical systems	Provided efficient state-space reconstruction from experimental data
Sehgal & Kumar (2017)	Response surface method with desirability function optimization	Damped mechanical systems	Achieved significant reduction in modeling errors for frequency and damping estimation

IV. CONCLUSION

The study of dynamic modeling and analysis of mechanical systems using simulation techniques highlights a major transformation in modern mechanical and machine design engineering. The reviewed literature clearly demonstrates that simulation-based approaches have become essential for understanding, predicting, and optimizing the behavior of complex mechanical systems operating under real-world conditions. Traditional analytical methods, while still foundational, are often insufficient for handling nonlinearities, uncertainties, and multi-degree-of-freedom interactions that characterize advanced

engineering systems. Recent developments in computational mechanics have significantly improved the accuracy and efficiency of dynamic analysis. Studies such as Tebaldi and Zanasi (2026) have shown that automated nonlinear modeling techniques enhance robustness against measurement noise while reducing computational cost compared to classical formulations. Similarly, Scutaru and Pruncu (2024) emphasized that advancements in numerical methods and computational tools have enabled more precise modeling of nonlinear and multibody systems, thereby improving predictive capability in engineering design. Simulation-based frameworks such as finite element analysis, multibody dynamics, and numerical integration methods have proven highly effective in capturing complex system behaviors, including vibration, fatigue, and fault dynamics. Research by Wang et al. (2023, 2025) and Lim et al. (2022) demonstrates the importance of simulation in fault detection, crack propagation analysis, and large-scale system integration. Furthermore, hybrid modeling approaches such as physics-informed neural networks introduced by Roehrl et al. (2020) indicate a shift toward combining physical laws with artificial intelligence to achieve more accurate and data-efficient models. Overall, the literature confirms that simulation techniques not only improve design accuracy but also reduce experimental costs and development time. They provide engineers with powerful tools for analyzing system stability, optimizing performance, and enhancing reliability across various mechanical applications, including automotive systems, robotics, aerospace structures, and energy systems.

V. FUTURE SCOPE

The future of dynamic modeling and simulation in mechanical systems is expected to evolve significantly with the integration of advanced computational technologies and intelligent systems. One of the most promising directions is the incorporation of artificial intelligence and machine learning techniques into simulation frameworks. These hybrid models can improve predictive accuracy, reduce computational effort, and enable real-time decision-making in complex mechanical systems. Another important development area is digital twin technology, which enables real-time virtual replication of physical systems. This approach will allow continuous monitoring, performance prediction, and proactive maintenance of mechanical systems in industrial environments, significantly improving operational efficiency and reducing downtime. High-performance computing and cloud-based simulation platforms are also expected to play a critical role in enabling large-scale, high-fidelity simulations. These advancements will allow engineers to analyze highly complex multibody and multi-physics systems with greater speed and accuracy. Furthermore, uncertainty quantification and probabilistic modeling will become increasingly important in addressing variability in material properties, loading conditions, and environmental influences. This will lead to more robust and reliable mechanical system designs. Finally, future research will likely focus on sustainable engineering solutions, where simulation techniques are used to design energy-efficient, lightweight, and environmentally friendly mechanical systems. The integration of real-time sensor data with simulation models will further enhance adaptive control and intelligent optimization in next-generation mechanical systems. In conclusion, dynamic modeling and simulation techniques are expected to remain a central pillar of mechanical engineering innovation, driving advancements in design, analysis, and system optimization across multiple engineering domains.

REFERENCES

1. Tebaldi, D., & Zanasi, R. (2026). Efficient and Robust Modeling of Nonlinear Mechanical Systems. *arXiv preprint arXiv:2602.06639*.
2. Schupp, G. (2026). Computational bifurcation analysis of mechanical systems with applications to railway vehicles. In *The Dynamics of Vehicles on Roads and on Tracks Supplement to Vehicle System Dynamics* (pp. 458-467). CRC Press.

3. Gantada, M. S. P., & Basri, H. (2025). Modeling, Simulation, and Analysis of Mechanical Systems in Universal Vibration Damper Apparatus Using MATLAB Software. *COMSERVA: Jurnal Penelitian Dan Pengabdian Masyarakat*, 5(6), 1432-1445.
4. Siregar, B. M. (2025). Simulation-based optimization of mechanical system reliability under variable load conditions. *Technical Science Integrated Research*, 1(1), 15-18.
5. Wang, W., Guan, H., Ma, H., Wang, H., Mu, Q., Zeng, Y., ... & Wen, B. (2025). Dynamic stress analysis of a disc considering actual crack paths: experiment and simulation. *Mechanical Systems and Signal Processing*, 224, 112199.
6. Scutaru, M. L., & Pruncu, C. I. (2024). Mathematical Modeling and Simulation in Mechanics and Dynamic Systems. *Mathematics*, 12(2), 341.
7. Rathee, R. (2023). Numerical modeling and simulation of friction models for mechanical systems: A brief review. *Materials Today: Proceedings*.
8. Wang, C., Tian, J., Zhang, F. L., Ai, Y. T., & Wang, Z. (2023). Dynamic modeling and simulation analysis of inter-shaft bearing fault of a dual-rotor system. *Mechanical Systems and Signal Processing*, 193, 110260.
9. Scutaru, M. L., & Pruncu, C. I. (2022). Mathematical Modeling and Simulation in Mechanics and Dynamic Systems. *Mathematics (2227-7390)*, 10(3).
10. Lim, J. H., Kim, H. W., Hong, S., Oh, J. W., & Bae, D. S. (2022). Simulation technology development for dynamic analysis of mechanical system in deep-seabed integrated mining system using multibody dynamics. *Minerals*, 12(5), 498.
11. Li, T. (2021). Application of mathematical model in dynamic analysis and monitoring of mechanical system. *International Journal of Frontiers in Sociology*, 3(8).
12. Roehrl, M. A., Runkler, T. A., Brandtstetter, V., Tokic, M., & Obermayer, S. (2020). Modeling system dynamics with physics-informed neural networks based on Lagrangian mechanics. *IFAC-PapersOnLine*, 53(2), 9195-9200.
13. Rong, B., Rui, X., Tao, L., & Wang, G. (2019). Theoretical modeling and numerical solution methods for flexible multibody system dynamics. *Nonlinear Dynamics*, 98(2), 1519-1553.
14. Pappalardo, C. M., & Guida, D. (2018). A time-domain system identification numerical procedure for obtaining linear dynamical models of multibody mechanical systems. *Archive of Applied Mechanics*, 88(8), 1325-1347.
15. Sehgal, S., & Kumar, H. (2017). Novel dynamic model updating technique for damped mechanical system. *Journal of Theoretical and Applied Mechanics*, 47(4), 75.