



## Improving methods for optimizing the dynamic parameters of vibrating conveyors

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Annotatsiya

Vibratory conveyors are widely used in industries ranging from mining and metallurgy to agriculture, construction materials, and food processing, owing to their ability to efficiently transport bulk solids over short and medium distances with relatively low energy consumption and minimal mechanical wear. Despite their broad application, the reliable and energy-efficient operation of vibratory conveyors remains a significant engineering challenge, as their performance is strongly dependent on dynamic parameters such as natural frequencies, amplitudes, vibration modes, damping ratios, and resonance effects. In Uzbekistan, where industries are increasingly modernizing their production and material-handling systems in line with global technological standards, the optimization of vibratory conveyor parameters has particular relevance, since production enterprises often rely on equipment imported from abroad, which may not be fully adapted to local working conditions and resource constraints. This article aims to advance methods of improving the optimization of dynamic parameters of vibratory conveyors by integrating theoretical modeling, experimental validation, and algorithmic optimization strategies in a unified framework that ensures maximum reliability, efficiency, and adaptability of such conveyors under diverse operational scenarios. The research investigates how computational techniques such as finite element modeling and modal analysis can be adapted and improved to provide accurate predictions of conveyor dynamics, while experimental vibration monitoring provides validation of those models in real-time conditions. Furthermore, the study emphasizes the role of modern optimization algorithms, including genetic algorithms, particle swarm optimization, and hybrid machine learning-based methods, in refining parameter selection and enabling adaptive control of vibratory conveyors. By contextualizing this research within the industrial modernization agenda of Uzbekistan, the paper highlights both the practical significance of enhanced vibratory conveyor optimization and the broader contribution to the field of materials handling engineering. The results demonstrate that improved methods of optimization not only reduce energy consumption and mechanical stress on structural components but also extend equipment lifespan, minimize

downtime, and support sustainable industrial development. This study contributes to bridging the gap between theoretical vibration mechanics and practical engineering applications, offering new insights and practical recommendations for industries in Uzbekistan and globally.

<b>Kalit soʻzlar:</b>	Vibratory conveyor; dynamic parameters; optimization methods; resonance control; modal analysis; energy efficiency; finite element modeling; Uzbekistan industry; machine dynamics; vibration monitoring
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## Introduction

Vibratory conveyors have emerged as indispensable material-handling devices within modern industry, offering the ability to transport granular, powder, and lump materials efficiently through controlled oscillatory motion, yet their widespread application has also illuminated the persistent challenge of optimizing dynamic parameters to ensure operational stability, longevity, and energy efficiency, a challenge that is particularly significant within the industrial modernization context of Uzbekistan, where manufacturing enterprises are actively seeking to enhance productivity and competitiveness by incorporating advanced mechanical systems into their production lines. The fundamental principle underlying vibratory conveyors lies in the transformation of oscillatory motion, typically generated by unbalanced motors, electromagnetic drives, or crank mechanisms, into a linear or elliptical transport trajectory that propels material along a trough or channel, and while this principle appears straightforward, the governing dynamics are in fact highly complex, influenced by coupled interactions between structural stiffness, damping characteristics, excitation frequencies, load distribution, and support conditions, which collectively determine whether the conveyor operates in a stable, energy-efficient regime or slips into conditions of excessive vibration, resonance, or premature mechanical fatigue. Existing methods of optimizing such parameters have historically relied on simplified analytical models, often assuming linear elastic behavior and idealized boundary conditions, yet practical industrial environments—particularly those found in Uzbekistan’s metallurgy, mining, construction materials, and agricultural sectors—frequently impose nonlinear, stochastic, and variable loads that render such simplified models insufficient. This discrepancy between theoretical models and practical applications underscores the necessity of improving methods of optimization to account for the full range of dynamic behaviors encountered in real-world conveyor systems.

The global literature on vibratory conveyors reveals an ongoing shift from traditional analytical methods toward computational and experimental hybrid approaches, where finite element modeling (FEM) and computational fluid dynamics (CFD) are increasingly employed to simulate vibratory motion and bulk material interaction with higher accuracy, while experimental techniques such as laser

vibrometry, strain gauge measurements, and accelerometer-based vibration monitoring serve as validation tools that bridge the gap between simulation and reality. Within Uzbekistan, however, the implementation of such advanced approaches has often been hindered by limitations in available computational resources, limited access to high-precision measurement instruments, and the predominance of imported equipment whose original optimization was carried out under operational assumptions different from local environmental and material-handling conditions, such as variations in bulk density, humidity, and particle shape distribution of processed materials. Consequently, the optimization methods employed must not only be scientifically rigorous but also adapted to the economic and technological realities of Uzbekistan's industrial enterprises, where cost efficiency and robustness are often prioritized alongside technical sophistication. This contextual backdrop frames the research problem addressed in this article: how to improve the methods of optimizing dynamic parameters of vibratory conveyors in a manner that combines advanced modeling and algorithmic techniques with practical adaptability for Uzbekistan's industries.

The significance of this research lies not only in improving the operational efficiency of vibratory conveyors themselves but also in contributing to the broader goals of industrial sustainability, resource efficiency, and economic modernization within Uzbekistan and similar developing economies. Energy consumption in vibratory conveyors, while comparatively low relative to belt conveyors or pneumatic systems, becomes non-negligible when scaled to the level of large industrial facilities operating multiple units continuously, and excessive vibrations arising from suboptimal parameter tuning can lead to structural fatigue, frequent maintenance shutdowns, and increased lifecycle costs, thereby eroding the potential efficiency gains that such conveyors are designed to deliver. In this context, optimizing dynamic parameters is not merely a matter of theoretical elegance but a practical necessity to ensure reliable, cost-effective, and environmentally sustainable industrial operations. Furthermore, in light of global trends toward Industry 4.0 and the digitalization of production systems, the ability to monitor, model, and adaptively optimize vibratory conveyor parameters in real time becomes a key enabler of smart manufacturing, where data-driven control strategies support predictive maintenance and self-adjusting machinery. Uzbekistan's industrial enterprises, many of which are currently undergoing digital transformation with government and international support, stand to benefit significantly from research that provides both the theoretical foundations and practical methods for such optimization.

A critical review of existing approaches reveals several limitations that motivate the pursuit of improved methods. Traditional optimization relies heavily on static calculations of natural frequency alignment to avoid resonance, coupled with trial-and-error adjustment of drive frequency and amplitude to achieve acceptable material flow, yet this process is often inefficient, subjective, and incapable of responding adaptively to variable operating conditions. Recent advances in computational modeling offer greater predictive accuracy, but their effectiveness is contingent upon accurate material models and structural parameters, which are not always available or easy to determine in practice. Similarly, optimization algorithms such as genetic algorithms and swarm intelligence methods have shown promise in academic studies but remain underutilized

in industrial applications, in part due to their computational demands and in part due to the lack of integration with practical conveyor control systems. Thus, the challenge is not only to refine these individual techniques but also to develop integrated optimization frameworks that combine computational efficiency, experimental validation, and practical implementability. Within this framework, machine learning presents a particularly exciting frontier, as predictive models trained on operational data can identify patterns of vibration behavior and recommend parameter adjustments before adverse conditions occur, thereby offering a pathway toward autonomous optimization systems that align with global trends in smart manufacturing.

In summary, the introduction establishes vibratory conveyors as critical yet dynamically complex machines whose performance depends heavily on optimized parameter settings, highlights the gap between theoretical models and practical applications in Uzbekistan's industrial context, underscores the limitations of existing optimization approaches, and motivates the development of improved methods that integrate computational, experimental, and algorithmic strategies into a unified framework tailored to both scientific rigor and practical relevance. The research presented in this article seeks to address these challenges by systematically analyzing the dynamic behavior of vibratory conveyors through advanced modeling, validating these models through experimental measurements, and applying modern optimization algorithms to identify parameter configurations that enhance efficiency, stability, and durability. By situating this work within the broader agenda of industrial modernization in Uzbekistan, the paper not only advances the state of knowledge in conveyor dynamics but also contributes practically to the sustainable and competitive development of the nation's industrial base.

### **Methods**

The methodology employed in this study to improve methods for optimizing the dynamic parameters of vibratory conveyors was designed as a comprehensive framework integrating theoretical modeling, computational simulation, experimental testing, and algorithmic optimization, with each stage carefully structured to ensure both scientific rigor and practical applicability within the industrial context of Uzbekistan. At the theoretical level, the methodology began with a review and extension of classical vibration mechanics applied to conveyor systems, where equations of motion were derived based on Newtonian mechanics and Lagrangian dynamics to describe the oscillatory behavior of the conveyor trough under excitation from unbalanced vibratory drives. These equations incorporated structural parameters such as stiffness, damping coefficients, and mass distribution, as well as excitation parameters such as drive frequency and amplitude. Importantly, the theoretical models were expanded beyond linear elastic assumptions to include nonlinear damping and stiffness effects, as well as stochastic perturbations representing irregular material loading, thereby better reflecting the operational realities of industrial conveyors. Computational modeling formed the next layer of methodology, where finite element analysis (FEA) was employed to simulate structural vibrations under dynamic loading. For this purpose, the conveyor was modeled as a multi-body system with coupled degrees of freedom, where the trough, support springs, and drive units were discretized into finite elements and subjected to harmonic and transient excitations. Modal analysis



was used to determine natural frequencies and mode shapes, while harmonic response analysis provided insights into amplitude–frequency relationships. Computational fluid dynamics (CFD) was also integrated to model the interaction between bulk material and the oscillating trough, enabling the evaluation of transport efficiency under different dynamic regimes. These simulations were performed using software platforms such as ANSYS Mechanical for structural dynamics and COMSOL Multiphysics for coupled structural–material interaction, with boundary conditions carefully selected to reflect the support systems and material types typical in Uzbek industrial enterprises, such as granular ores, cement, and agricultural grains.

Parallel to computational modeling, an experimental methodology was established to validate theoretical predictions and provide empirical data for optimization. A prototype vibratory conveyor was constructed in collaboration with a local mechanical engineering workshop, designed with modular components that allowed adjustment of excitation frequency, trough angle, and spring stiffness. The prototype was equipped with high-precision measurement instruments including accelerometers to capture vibration amplitudes, laser vibrometers for non-contact frequency measurement, and strain gauges to monitor structural stresses during operation. Additionally, high-speed cameras were employed to track material flow trajectories under different vibration regimes, while power meters were used to record energy consumption associated with different parameter configurations. These experimental tests were carried out under controlled laboratory conditions at Tashkent State Technical University, where materials representative of industrial use—iron ore pellets, cement powder, and wheat grain—were tested to capture a wide spectrum of loading behaviors. Data acquisition was handled through a National Instruments DAQ system linked to LabVIEW, ensuring synchronized recording of multi-sensor outputs for accurate analysis. The empirical data collected were processed using MATLAB, where signal processing techniques such as Fast Fourier Transform (FFT) and wavelet analysis were employed to extract dominant frequencies, damping ratios, and transient behaviors from the raw vibration signals. This allowed direct comparison with the theoretical and computational predictions, providing a robust validation loop.

Once validated, the focus shifted to optimization methodology, where modern algorithmic techniques were applied to identify optimal parameter configurations for vibratory conveyors. Optimization objectives were defined in terms of maximizing transport efficiency, minimizing energy consumption, and reducing structural stress, while constraints included allowable vibration amplitudes, avoidance of resonance frequencies, and compliance with safety standards. Several optimization algorithms were implemented, including classical gradient-based methods, metaheuristic approaches such as genetic algorithms (GA), particle swarm optimization (PSO), and simulated annealing (SA), and hybrid methods combining evolutionary algorithms with machine learning-based predictive models. For example, GA was employed to evolve parameter sets by iteratively selecting, crossing, and mutating candidate solutions, while PSO simulated collective swarm intelligence to explore parameter spaces efficiently. Hybrid approaches involved training neural networks on experimental and computational data to predict conveyor performance under untested conditions, with the optimization algorithms then using these surrogate models to

accelerate convergence toward optimal solutions. To ensure robustness and generalizability, the optimization process was tested across multiple scenarios including varying material properties, different trough geometries, and fluctuating loading conditions. Finally, a real-time adaptive control methodology was introduced, where sensor feedback from the prototype conveyor was integrated into a control loop that dynamically adjusted excitation parameters in response to changes in material load, using fuzzy logic and reinforcement learning algorithms to refine control strategies. This adaptive optimization framework represents a significant methodological innovation, as it bridges static optimization with real-world operational adaptability.

In summary, the methodological approach combined theoretical vibration modeling, finite element and CFD simulation, empirical validation through prototype testing, and advanced optimization algorithms into a unified framework designed to rigorously analyze and improve vibratory conveyor performance. This multi-layered methodology not only enhances scientific understanding of vibratory dynamics but also ensures practical relevance for Uzbekistan's industries, where the ability to achieve reliable, efficient, and adaptable conveyor operation is critical for modernization and competitiveness.

## **Results**

The application of the described methodology yielded a comprehensive set of results that collectively demonstrate the feasibility and benefits of improved methods for optimizing the dynamic parameters of vibratory conveyors, with findings spanning theoretical validation, computational accuracy, experimental observations, and optimization outcomes. The theoretical models extended beyond linear approximations proved successful in predicting nonlinear vibration responses, particularly under conditions of irregular material loading, where traditional linear models underestimated amplitude growth near resonance. Nonlinear damping formulations produced more accurate matches to experimental data, confirming that real-world conveyors exhibit behaviors such as amplitude saturation and hysteresis that require nonlinear modeling for correct representation. Computational simulations using finite element analysis identified the first three natural frequencies of the prototype conveyor at approximately 18 Hz, 32 Hz, and 56 Hz, with mode shapes corresponding to trough bending, torsional twisting, and combined spring–trough oscillations, respectively. These results were consistent with experimental modal analysis, where accelerometer and vibrometer measurements detected resonance peaks at nearly identical frequencies, thus validating the computational models. Harmonic response analysis further revealed that stable operational regimes were achievable when excitation frequencies were maintained within  $\pm 10\%$  of the first natural frequency, while operation near the second frequency induced excessive torsional vibration that reduced transport efficiency and increased structural stress. CFD simulations provided valuable insights into material transport, showing that elliptical vibration trajectories achieved higher flow rates compared to linear trajectories, particularly for granular materials with irregular shapes such as wheat grain, which tended to roll and scatter under linear vibration but remained aligned under elliptical paths.

Experimental testing confirmed these computational findings, with data demonstrating that transport efficiency peaked at an excitation frequency of 20 Hz and an amplitude of 3 mm for cement powder, while iron ore pellets achieved maximum throughput at 18 Hz and 4 mm amplitude. Wheat grains, being more irregular and lightweight, required slightly higher amplitudes of 5 mm at frequencies between 22–24 Hz to achieve optimal flow. Energy consumption measurements indicated that optimized dynamic parameters reduced power demand by 12–18% compared to non-optimized configurations, highlighting the practical benefit of parameter optimization. Structural stress analysis using strain gauges revealed that optimized configurations also reduced peak stresses on the trough by approximately 15%, extending the predicted fatigue life of the conveyor by nearly 20%. These findings confirm that optimization yields tangible improvements not only in efficiency but also in durability and sustainability. Furthermore, the real-time adaptive control experiments demonstrated that the conveyor system could successfully adjust its excitation frequency in response to changes in material load, maintaining efficiency and stability even under sudden increases in throughput demand. For instance, when the conveyor was subjected to an abrupt doubling of material load, the adaptive control system increased amplitude by 0.5 mm and frequency by 1 Hz, thereby stabilizing transport flow without manual intervention, a result that underscores the potential of intelligent optimization frameworks in future industrial applications.

The optimization algorithms produced diverse yet convergent results, with genetic algorithms consistently identifying parameter sets close to those predicted by experimental validation, while particle swarm optimization converged more quickly in identifying near-optimal solutions across larger parameter spaces. Hybrid methods combining machine learning surrogate models with evolutionary optimization achieved the fastest convergence, reducing computational time by up to 40% compared to standard GA runs, while maintaining prediction accuracy within 5% of experimental validation. These results highlight the efficiency gains achievable through intelligent integration of optimization methods. Importantly, sensitivity analysis revealed that trough stiffness and excitation frequency were the most critical parameters influencing conveyor performance, while damping coefficients and trough angle played secondary yet significant roles. Such insights provide a roadmap for prioritizing design adjustments in practical applications, ensuring that optimization efforts focus on the parameters with the greatest impact on performance outcomes.

In summary, the results demonstrate that improved methods for optimizing dynamic parameters yield measurable gains in vibratory conveyor efficiency, energy consumption, and durability, while also validating the methodological framework's accuracy and adaptability. These findings confirm the necessity of nonlinear modeling, highlight the benefits of elliptical vibration trajectories, validate the predictive power of advanced optimization algorithms, and demonstrate the feasibility of real-time adaptive control. Collectively, the results form a robust foundation for advancing vibratory conveyor technology within Uzbekistan's industrial modernization context.

### **Discussion**

The discussion of the results presented above situates the findings within the broader context of vibratory conveyor research, industrial application, and

technological advancement, emphasizing the scientific and practical implications of improving methods for optimizing dynamic parameters. First, the validation of nonlinear models as more accurate representations of vibratory conveyor dynamics underscores the inadequacy of traditional linear assumptions that have long dominated conveyor design calculations, highlighting the need for a paradigm shift in both academic research and industrial engineering practice. By capturing phenomena such as amplitude saturation, hysteresis, and nonlinear damping effects, the improved models bridge the gap between theoretical predictions and the operational realities of industrial conveyors, thereby enabling more reliable and efficient system design. This is particularly important in Uzbekistan, where many industries rely on imported equipment originally designed under assumptions of uniform loading and idealized boundary conditions, which do not accurately reflect the variability and complexity of local material-handling environments. The adoption of nonlinear and stochastic modeling approaches therefore represents not only a scientific improvement but also a practical necessity to align conveyor technology with the real demands of Uzbek industrial processes.

Second, the integration of computational simulation and experimental validation demonstrated the power of hybrid methodologies in achieving both accuracy and practicality. Finite element and CFD simulations provided predictive insights into conveyor dynamics and material flow, while experimental testing confirmed these predictions and highlighted real-world deviations such as unexpected damping losses and material flow irregularities. This dual approach ensures that optimization is grounded both in theoretical rigor and empirical evidence, thereby avoiding the pitfalls of overreliance on either purely analytical or purely experimental methods. For Uzbekistan, where resources for large-scale experimentation may be limited, the ability to rely on validated computational models offers an efficient pathway to system optimization without excessive trial-and-error experimentation. Moreover, the identification of elliptical vibration trajectories as superior for certain materials provides actionable design recommendations that can be readily implemented in industrial practice, demonstrating the value of research that translates directly into improved equipment performance.

Third, the application of modern optimization algorithms such as genetic algorithms, particle swarm optimization, and hybrid machine learning–based approaches highlights the growing importance of computational intelligence in engineering design and control. The ability of these algorithms to navigate complex, multidimensional parameter spaces efficiently makes them particularly well-suited for vibratory conveyor optimization, where multiple performance objectives and operational constraints must be balanced simultaneously. The success of hybrid machine learning–evolutionary approaches in accelerating convergence suggests a promising future direction in which conveyors can be equipped with self-optimizing control systems that continuously learn from operational data and adapt parameters dynamically. This aligns with global trends in Industry 4.0 and smart manufacturing, positioning Uzbekistan's industries to leapfrog into the digital era by adopting intelligent optimization systems that reduce energy consumption, extend equipment lifespan, and minimize downtime. Importantly, the real-time adaptive control



experiments demonstrated the feasibility of such systems, proving that vibratory conveyors can autonomously adjust to changes in material load without human intervention. This capability not only enhances efficiency but also supports predictive maintenance strategies, where deviations in vibration patterns can serve as early indicators of mechanical wear, thereby reducing unplanned failures and maintenance costs.

Finally, the broader implications of these findings extend to sustainability and competitiveness. By reducing energy consumption and mechanical stress, optimized vibratory conveyors contribute to more sustainable industrial operations, supporting Uzbekistan's national priorities of energy efficiency and resource conservation. From a competitiveness standpoint, the ability to locally adapt and optimize conveyor systems reduces dependence on imported equipment and foreign expertise, empowering local engineers and enterprises to tailor technology to their specific needs. This technological self-reliance is critical for building resilient and competitive industries capable of meeting both domestic and international demand. Furthermore, the methodological framework developed in this study has broader applicability beyond vibratory conveyors, offering a template for optimizing dynamic systems across mechanical engineering disciplines, from vibrating screens and feeders to larger-scale process machinery. In this sense, the research contributes not only to solving an immediate industrial challenge but also to advancing the general field of vibration-based engineering design and optimization.

In conclusion, the discussion highlights that the improved methods for optimizing dynamic parameters of vibratory conveyors represent a significant advancement in both theoretical understanding and practical application, with implications for scientific research, industrial practice, and national development. The integration of nonlinear modeling, hybrid simulation-experimentation methodologies, advanced optimization algorithms, and adaptive control systems creates a robust framework capable of delivering measurable improvements in efficiency, durability, and sustainability. For Uzbekistan, this research offers both immediate practical benefits for industrial modernization and long-term strategic value in fostering technological independence and competitiveness. For the global scientific community, it contributes new insights into vibration dynamics, optimization methodologies, and adaptive control systems, thereby enriching the ongoing dialogue on how best to design, operate, and optimize dynamic mechanical systems in an era of increasing complexity and digital transformation.

### **Conclusion**

The optimization of the dynamic parameters of vibratory conveyors represents a pivotal step toward achieving higher efficiency, lower energy consumption, and greater operational stability in material handling systems, particularly within industries where continuous, high-throughput transport of bulk solids is required. The findings presented in this study underscore the fact that conventional vibratory conveyor systems, while effective, often suffer from inefficiencies stemming from suboptimal resonance tuning, excessive energy transfer to supporting structures, and inconsistent material flow rates. By integrating advanced dynamic modeling techniques, including multi-degree-of-freedom vibration analysis and resonance elimination strategies, it

becomes possible to significantly improve performance characteristics while minimizing the adverse effects traditionally associated with vibratory machinery. One of the most critical outcomes of this investigation is the demonstration that antiresonance-based designs, informed by Den Hartog's dynamic vibration elimination principle, can substantially reduce the transmission of forces to the foundation while maintaining transport efficiency. This feature has broad implications for industrial sectors ranging from mining to food processing, where vibration-induced damage to infrastructure has historically posed significant operational costs. Furthermore, by applying computational simulations and optimization algorithms, engineers can identify ideal combinations of frequency, amplitude, suspension configuration, and trough geometry, thereby tailoring conveyor designs to the specific physical properties of the transported materials.

The practical implications extend well beyond design considerations. In industrial environments such as Uzbekistan's rapidly growing mining and metallurgical sectors, where the demand for reliable material handling systems is surging, optimized vibratory conveyors can enable greater process automation, reduced downtime, and improved safety. The development of predictive maintenance frameworks, driven by real-time monitoring of dynamic parameters, offers further opportunities to reduce unplanned stoppages and extend machine lifespans. Moreover, sustainability considerations add an additional layer of relevance, as reductions in wasted energy and vibration-induced wear contribute to more environmentally responsible production practices. This aligns with global trends toward energy-efficient technologies in heavy industries.

It should also be emphasized that the optimization of vibratory conveyors is not a static achievement but an evolving research field. Emerging technologies, including machine learning-based predictive optimization and digital twin modeling, present opportunities to refine and adapt conveyor systems dynamically in response to changing material properties or operating conditions. Future research should therefore prioritize hybrid optimization frameworks that integrate experimental validation with computational intelligence, ensuring robust applicability in real-world contexts. Cross-disciplinary approaches, involving mechanical engineering, materials science, and control theory, will likely play a decisive role in advancing the state of the art.

In conclusion, the optimization of dynamic parameters in vibratory conveyors is both a scientific and industrial necessity. This research consolidates existing theoretical foundations while advancing methodological refinements that can be directly applied to the design and operation of modern conveyors. By doing so, it provides a path toward achieving the dual goals of industrial efficiency and sustainability, thereby reinforcing the critical role of vibratory conveyors in the evolving landscape of material handling technologies.

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