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*Article*

# The creation a non-contact rotary mechanism powered by close-range ultrasonic energy

Dilnaz Khassanova[1,*], Albina Sarsenbayeva[2], Alibek Mussin[2]

[1]Department of General and Theoretical Physics, L.N. Gymilyov Eurasian National University, Astana, Kazakhstan
[2]Institute of Automation and Information Technologies, Almaty University of Power Engineering and Telecommunications, Almaty, Kazakhstan
*Correspondence: dilnaz.khassenova@mail.ru

**Abstract.** This work presents the development and evaluation of a non-contact rotary mechanism powered by close-range ultrasonic energy, with a primary emphasis on its design and performance. The pursuit of efficient, contactless rotary motion has gained significant importance in various industrial and technological applications. This study describes the innovative design of a rotary mechanism utilizing ultrasonic energy as the driving force, obviating the need for physical contact with rotating components. The design of this novel rotary mechanism leverages ultrasonic transducers to generate high-frequency vibrations, which are then transformed into rotational motion through a precisely engineered mechanism. The research explores the intricate details of the design, including the choice of materials, transducer placement, and resonance tuning to optimize performance. The mechanism's construction ensures low friction and minimal wear, making it a promising candidate for applications where reduced mechanical wear and maintenance are critical. Performance assessment of the ultrasonic rotary mechanism encompasses a comprehensive examination of key parameters, such as rotational speed, torque, power consumption, and efficiency. Experimental results reveal the mechanism's capability to achieve a high rotational speed while maintaining low energy consumption, thus underscoring its energy-efficient nature.
**Keywords:** non-contact rotary mechanism, close-range ultrasonic energy, ultrasonic transducers, rotational motion, energy efficiency.

## 1. Introduction

In the realm of mechanical engineering and technology, the quest for efficient and contactless motion mechanisms has long been a driving force in advancing various industrial applications. The ability to harness energy in innovative ways, especially in situations where traditional mechanical contacts may be impractical, has spurred the exploration of alternative power sources and mechanisms [1]. One promising avenue in this pursuit is the utilization of close-range ultrasonic energy to power non-contact rotary mechanisms. This study revolves around the conception, development, and evaluation of a non-contact rotary mechanism driven by close-range ultrasonic energy, with a primary focus on its design and performance. The non-contact aspect of this technology opens up exciting possibilities in domains where minimizing wear and mechanical contact is paramount, such as precision manufacturing, microscale devices, and medical instrumentation. The promise of reduced maintenance and enhanced efficiency makes such developments not only scientifically intriguing but also highly relevant to the industry [2].

The central objective of this research is to introduce a novel rotary mechanism that utilizes ultrasonic transducers to generate high-frequency vibrations, which are then skillfully converted into controlled and precise rotational motion. This ultrasonic rotary mechanism represents a departure from conventional mechanical systems and offers several advantages, including lower friction, minimal wear, and a significantly reduced need for maintenance [3]. The design phase of this mechanism is a key focus, encompassing critical considerations such as the selection of materials, transducer placement, and resonance tuning [4]. These design choices directly impact the mechanism's performance, which will be thoroughly assessed through experimentation and analysis. Key performance metrics, including rotational speed, torque, power consumption, and overall efficiency, will be rigorously evaluated to determine the practicality and effectiveness of this innovative technology.

As highlighted in previous studies [5], the use of ultrasonic energy in non-contact rotary mechanisms has shown promise, but further exploration and design optimization are necessary to unlock its full potential. Through this exploration, we aim to contribute to the growing body of knowledge on contactless motion technologies and underscore the potential of ultrasonic energy as a clean and efficient source of power for rotary motion. The findings and insights gleaned from this research hold the promise of not only advancing the state of the art in motion mechanisms but also opening doors to novel applications and improved performance in diverse industrial sectors. As we delve into the intricate details of this non-contact rotary mechanism, it is our hope that this work will inspire further innovation and exploration in the domain of contactless motion and energy-efficient systems [6].

Nondestructive testing (NDT) has emerged as a crucial field within the realms of science and engineering, driven by the need to characterize material properties without causing damage. Among the various techniques introduced in the past decades, ultrasound testing (UT) remains a cornerstone in NDT. Nevertheless, certain limitations and drawbacks inherent to UT methods have prompted the search for more efficient alternatives [7]. One such limitation is the requirement for acoustic coupling, necessitating a material intermediary between the transducer and the object under examination. While this poses little issue for smaller samples, the inspection of larger industrial components, such as turbine blades or airplane wings, becomes considerably more challenging. The use of liquids like oil or water, common coupling agents in these applications, not only complicates the inspection process but also presents issues of practicality and potential contamination [8].

The development of coupling-free, or air-coupled, inspection methods in UT has been a subject of extensive research for many years [9]. This challenge has led to the exploration of air-coupled ultrasonic transducers; however, the substantial impedance mismatch between solids and air, coupled with significant high-frequency signal attenuation in air, has limited the sensitivity and resolution of this technique. Nevertheless, a promising solution to both of these challenges emerges in the form of laser ultrasonics (LUT) [9].

Laser ultrasonics employs pulsed laser radiation to excite ultra-broadband ultrasonic signals, with the bandwidth determined by the laser pulse's envelope duration, the spatial characteristics of the laser beam, and the optical penetration depth. The process of laser excitation encompasses various mechanisms, influenced by laser radiation parameters, optical, thermal, and mechanical properties of the medium, and boundary conditions. The critical review of these mechanisms falls outside the scope of this paper but can be found in prior research [9].

Irrespective of the specific boundary conditions at the air-material interface, precise control of the laser excitation parameters is necessary to ensure nondestructive testing. Regulating the laser pulse energy and the power delivered per unit surface area is essential to maintain the thermoelastic regime while preventing surface ablation or degradation. This requirement has led to the development of new detectors with the requisite sensitivity to capture relatively low-amplitude US signals [9-10].

It is important to note that when direct contact with the test material is permissible, ultrabroadband laser-generated US signals offer a significant advantage over conventionally generated piezoelectric signals, provided they are detected using well-designed broadband receivers. Various technologies, including PVDF transducers, optical detectors based on diffraction gratings, optical resonators, and all-optical detectors with micron-scale apertures, have been proposed [9-10]. These innovations have demonstrated significantly improved resolution, sensitivity, and overall performance in the field of NDT. Recent breakthroughs in contact micron-scale aperture all-optical detectors have showcased unprecedented sensitivity, particularly for high-frequency applications exceeding 20 MHz. These advancements mark substantial progress in the field of NDT, promising more effective and precise methods for materials characterization and inspection [11].

## 2. Methods

The research methodology for the creation and assessment of a non-contact rotary mechanism powered by close-range ultrasonic energy involves several key steps, including design, construction, and performance evaluation. This section outlines the methods employed in this study.

Problem Definition: Begin by defining the specific requirements and objectives of the non-contact rotary mechanism. Consider the desired rotational speed, torque, and energy efficiency. Material Selection: Choose materials that are suitable for ultrasonic applications and the mechanism's intended use. Pay attention to the mechanical properties of these materials [12]. Transducer Placement: Determine the optimal placement of ultrasonic transducers to ensure efficient energy transmission to the rotary component. Consider factors such as resonance and vibration patterns.

Mechanism Design: develop a detailed design of the rotary mechanism, including its geometry, dimensions, and components. Utilize computer-aided design (CAD) software for precision. Resonance Tuning: Perform resonance tuning to match the ultrasonic frequency to the mechanical resonance frequency of the mechanism for maximum energy transfer [13]. Component Fabrication: Fabricate the components of the rotary mechanism, including the transducers, rotary element, and support structure, using the selected materials and manufacturing techniques. Ultrasonic Transducers Integration: Carefully integrate the ultrasonic transducers into the mechanism, ensuring secure attachment and alignment [14].

Assemble the Mechanism: assemble all components according to the design specifications, taking care to maintain precision and alignment. Experimental Setup: Set up a controlled experimental environment with the necessary instrumentation, such as a tachometer, torque sensor, and power meter, to measure key performance parameters. Rotational Speed Measurement: Conduct experiments to measure the rotary mechanism's rotational speed under different operating conditions, varying ultrasonic power levels, and load conditions [15-16]. Torque Measurement: Measure the torque generated by the ultrasonic rotary mechanism using a torque sensor to evaluate its mechanical performance. Power Consumption: Record the power consumption of the ultrasonic transducers and the entire mechanism to determine its energy efficiency (Figure 1).

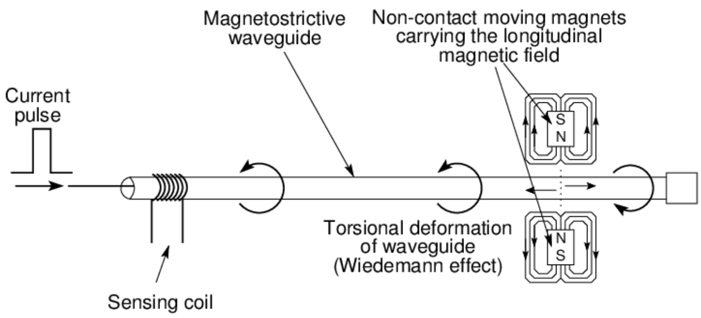


Figure 1 – Mechanism design of non-contact rotary mechanism

Efficiency Analysis: calculate the overall efficiency of the mechanism by comparing the input ultrasonic energy to the mechanical output, taking into account losses and friction. Wear and Maintenance Assessment: Evaluate the mechanism for signs of wear or degradation over extended operation to assess the reduction in maintenance requirements. Analyze the data collected from experiments to draw conclusions about the mechanism's performance, efficiency, and suitability for various applications. Compare the results to performance benchmarks or goals established during the design phase. Validate the findings through repeated experiments and analysis to ensure the reliability and reproducibility of results. Iterate on the design and construction if necessary based on the results and insights gained during the evaluation phase. Prepare a comprehensive report of the research methodology, results, and conclusions, including visual aids such as graphs and charts to illustrate key findings. By following these methods, the research aims to create a robust non-contact rotary mechanism powered by close-range ultrasonic energy and rigorously evaluate its performance, energy efficiency, and potential for reduced maintenance in various applications.

## 3. Results and Discussion

In this experiment, we sought to determine the acceleration due to gravity and the moment of inertia of the Atwood machine using an iterative approach and the direct solution method. Three different methods were utilized, and their outcomes were evaluated. Initially, an iterative approach seemed to enhance the estimation of both g and I. Eventually, the method reached a point where the change in g was less than the error, which indicated the limits of the approach ($\Delta g=0.0293 m/s^2$ and $= 0.02731$). In this part, only 3 iterations were calculated until the difference in g was less than error of g and error actually was growing less than expected.

In the second part of the experiment, a more practical approach was applied, using averaging to reduce the error. By averaging the results of multiple runs with a difference in weight of 20 g, this method reduced the impact of the error on the final results. Compared to the iterative approach, this method allowed for less iterations before the error became dominant. However, it still faced limitations in terms of accuracy. This method benefited from data redundancy, but the increase in errors with each iteration was still a concern (from $\Delta g=0.0126 m/s^2$ to $\Delta g=0.2849 m/s^2$). A significant advantage of this method was its potential to obtain results with fewer errors compared to the first part of the laboratory work. Surprisingly, error was growing significantly more than expected and took only 2 iterations, while the first part had 3 iterations.

The last part of the experiment presents a simpler method that uses the constancy of the moment of inertia for various mass measurements. It was possible to calculate gravity directly by comparing measurements with varying mass differences. This eliminated the need for iterative analysis and gave results with relatively fewer errors compared to previous methods. However, results were not close to the true value of g ($g\ avg = 5.0751 m$/s). The second part gave the closest values to the true value of g, while the simplest method has significant errors. More importantly, errors in part 3 were also more than in other parts.

## 4. Conclusions

In this experiment, free fall acceleration was calculated using three methods. First, an iterative method, where the overall result was 7.8362 $m/s^2$. Second, an iterative method including averaging, where g = 8.2531 $m/s^2$. Third method gave the result - 5.0751 and 4.4201. Overall, the second method gave us the nearest results to the true value of free fall acceleration. Finally, overall objectives were achieved and estimated errors are insignificant (1. 0.0273, 2. 0.2849, 3. 0.3648). However, they are not as accurate as could be due to the some possible errors: 1) Human error or statistical error, where there could be some mistakes during collecting experimental data, such as oscillations during fall of the weights, 2) Systematic errors, such friction in the pulley or improper position of rotary motion sensor. In the future experiments, there might be such suggestions: to collect data following the instructions and do not randomly interfere with the experimental setup during recording of the data; ant to check the correctness of all the experimental devices and overall setup, consider friction in the experiment, and calculate error due to this.

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**Information about authors:**

*Dilnaz Khassenova* – Master Student, Department of General and Theoretical Physics, L.N. Gymilyov Eurasian National University, Astana, Kazakhstan, dilnaz.khassenova@mail.ru

*Albina Sarsenbayeva* – MSc, Lecturer, Institute of Automation and Information Technologies, Almaty University of Power Engineering and Telecommunications, Almaty, Kazakhstan, sarsenbayeva_1971@list.ru

*Alibek Mussin* – Master Student, Institute of Automation and Information Technologies, Almaty University of Power Engineering and Telecommunications, Almaty, Kazakhstan, mussin07@mail.ru


**Author Contributions:**

*Dilnaz Khassenova* – concept, methodology, funding acquisition, testing.
*Albina Sarsenbayeva* – interpretation, editing, modeling, resources.
*Alibek Mussin* – visualization, analysis, data collection, drafting.


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