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Optimization of Transmission Systems in Rice Threshers and Straw Choppers: Enhancing Energy Efficiency and Productivity through V-Belt and Pulley Design

Ahcmad Fauzan[1], Fauzi Abdillah[2], Abdul Muchlis[3*]

[1]Teknik Industri, Universitas Bhayangkara Jakarta Raya, Jakarta, Indonesia

[2,3]Teknik Mesin, Universitas Gunadarma, Depok, Indonesia

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Corresponding author*:

muchlis07@staff.gunadarma.ac.id

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Abstract: Rice threshers and straw choppers are essential to improve post-harvest efficiency, yet small-scale machines often experience capacity loss and wasted motor power due to non-optimal V-belt–pulley transmission design (e.g., incorrect pulley ratio, belt length, and speed matching), which reduces speed stability and increases mechanical losses. **Objective:** This study aims to analyze and optimize the V-belt–pulley transmission system of a combined rice thresher–straw chopper to improve power utilization and achieve target operating speeds for both processes. **Methodology:** A quantitative engineering approach was applied using analytical transmission design calculations and design verification through mechanical layout/simulation. Key parameters were derived from machine requirements and transmission relations, including processing capacity, force and torque, shaft speed, power demand, pulley diameters, transmission ratios, belt speed, belt length, center distance, and wrap angle. **Findings:** Using a 1 HP (750 W), 1450 rpm electric motor, the designed system achieved a calculated threshing capacity of 90 kg/h and straw chopping capacity of 84 kg/h under a 2-minute batch assumption. The required output power was 270.60 W (threshing) and 245.97 W (chopping), while the motor-side power demand was 308.27 W and 280.30 W, respectively, resulting in a total requirement of 588.57 W (≈78% motor power utilization). With an 80 mm driver pulley, the selected driven pulleys were 105.45 mm for the thresher (1100 rpm; ratio 1.32) and 116 mm for the chopper (1000 rpm; ratio 1.45). The belt speed was 6.06 m/s, with belt lengths of 2110 mm (A83) and 1480 mm (A58). **Implications:** The results provide practical parameter benchmarks for designing low-cost small-scale agricultural machines that better match motor power to required speeds and torque, reducing transmission mismatch. **Originality:** This study presents a parameter-complete V-belt–pulley design framework for a dual-function thresher–chopper, explicitly linking capacity targets to transmission sizing and motor power utilization.

Keywords: Agricultural Machinery, Rice Threshers, Straw Choppers, Transmission Systems, V-Belt Design, Pulley Design

INTRODUCTION

Rice threshing machines and straw choppers are pivotal in the post-harvest process of rice production, enabling efficient grain separation and straw processing. Transmission systems play a critical role in optimizing the power transfer from the motor to the threshing mechanism, with the performance of the machine heavily influenced by factors such as pulley design, belt tensioning, and alignment. When pulleys and V-belts are not aligned correctly, efficiency decreases, leading to unnecessary wear, excessive power consumption, and potential breakdowns. Misalignment, combined with suboptimal pulley ratios, affects the rotation speed of the threshing mechanism, reducing its overall capacity and impacting grain quality. Moreover, environmental conditions such as contamination, temperature fluctuations, and humidity significantly influence the longevity and performance of these components, demanding precision in design and maintenance (Abdeen et al., 2021).

Another challenge in rice threshing machines is optimizing straw management. Unused straw is often burned, leading to pollution and waste of a valuable resource. However, when appropriately managed, straw can serve as animal feed, compost, or even bioenergy. This highlights the need for integrated machines that perform both threshing and straw chopping simultaneously. To address this, innovations like VAFT machines that use 360° concave designs and pneumatic cleaning systems have been introduced, improving both grain quality and overall operational efficiency. However, a well-designed transmission system is crucial to ensure the performance of these multi-functional machines, as it impacts power efficiency, operational capacity, and the longevity of key components.

Previous research on rice threshing machines and their transmission systems has focused on optimizing power transfer and improving efficiency. Studies have highlighted the importance of threshing cylinder speed and concave clearance in reducing grain loss and enhancing power consumption. Research shows that speeds around 839 r/min significantly lower grain loss while optimizing power usage (Abdeen et al., 2021). Additionally, the correct adjustment of concave clearance and bar spacing contributes to improved efficiency, with optimal settings leading to high threshing efficiency and minimal grain breakage (Tang et al., 2016). These findings emphasize that machine design adjustments play a crucial role in achieving high-performance threshing, with appropriate configurations being essential for balancing productivity and energy consumption.

Recent studies on rice threshers mainly fall into three connected technical streams. First, mechanism and design innovation improves separation quality and adaptability: whole-feeding concepts aim to increase threshing precision and reduce breakage, while variable-diameter drums developed via MBD–DEM coupling help the machine adjust to feeding-rate changes and reduce blockage (Liu et al., 2022). Variable-speed inertial pulley concepts also enhance threshing/cleaning behavior under changing conditions (Jing et al., 2024), supported by kinematic modeling of the threshed mass (Bogus & Pusikova, 2019) and database-driven intelligent design platforms that accelerate parametric design of threshing devices (W. Li et al., 2020). Dust mitigation has also been explored through dust-control thresher concepts to improve the working environment (J. Li et al., 2021)

Second, parameter optimization and performance evaluation show that cylinder speed, feed rate, and structural settings strongly control efficiency, loss, and power demand: Taguchi-based optimization confirms the sensitivity of performance to operating parameters (Abdeen et al., 2021) and further evidence links threshing-unit structure/parameters to measurable improvements in rice threshing performance (Abdeen et al., 2025) alongside control-oriented parameter prediction for longitudinal axial systems (Tang et al., 2016) and experimental power analysis on axial-threshing test beds (Y. Li et al., 2011).

Mechanized threshing is consistently superior to manual threshing in capacity and outcomes, reinforcing the need for practical small-scale machines (Amponsah et al., 2017) and testing-system development supports repeatable performance assessment (Meng et al., 2023). Third, transmission efficiency and energy management research indicates that belt–pulley performance depends on stability/alignment and directly affects usable power: V-belt transmission design for agricultural machines and belt efficiency/stability have been highlighted as key reliability/efficiency factors (Balovnev et al., 2021; László et al., 2016), while broader drivetrain comparisons report measurable energy-efficiency differences between CVT and full powershift solutions (Neto et al., 2022) and identify further efficiency potential in power-split CVT concepts (Pelger et al., 2018). Component-level pulley–belt interaction also affects strength/efficiency (Saito et al., 2011) and energy-saving concepts such as flywheel accumulators and braking energy recovery are proposed to reduce peak power demand (Barbashov et al., 2023; Barbashov & Barkova, 2021).

This research aims to bridge the gaps identified in the literature regarding the efficiency and design of transmission systems in rice threshers and straw choppers. Specifically, the objectives are to: 1) Analyze and optimize the transmission system, focusing on V-belt and pulley design to enhance energy efficiency while maintaining the machine's capacity, 2) Determine the optimal specifications for transmission components such as V-belts, pulleys, and shafts, addressing the lack of technical guidelines for small-scale agricultural machinery, and 3) Develop a more efficient transmission design model that balances power, torque, and energy consumption, contributing to the advancement of agricultural machinery technology.

This study hypothesizes that a transmission-system optimization focused on V-belt and pulley design will improve the energy utilization of a small-scale rice thresher–straw chopper without sacrificing the required operating capacity. Specifically, selecting an appropriate pulley ratio and ensuring proper belt alignment/tensioning will minimize mechanical losses (e.g., slip and friction-related losses) and maintain stable target shaft speeds for threshing and chopping; defining optimal component specifications pulley diameters, V-belt type/length, and shaft/bearing compatibility will increase the reliability and consistency of power transfer under the designed load; and an integrated analytical design model linking motor power, torque, and rotational speed will predict a configuration that achieves the required throughput while keeping the motor working within an efficient operating margin. These hypotheses are assessed through analytical performance verification using power–torque–speed relationships and transmission calculations as the primary evidence base.

RESEARCH METHOD

The unit of analysis in this research is the rice threshing machine and straw chopper, specifically focusing on the transmission system that connects the motor to the threshing and chopping mechanisms. This includes the pulley system, V-belt transmission, and associated components such as shafts and bearings. The aim is to optimize the power transfer efficiency and reduce energy consumption while maintaining high operational performance in small-scale agricultural machinery.

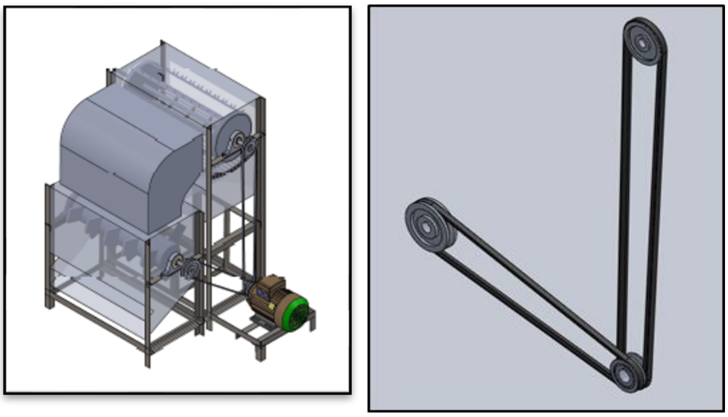

Figure 1. rice threshing machine (left) and Tranmission System (right)

Figure 1 shows the integrated rice thresher–straw chopper and its V-belt–pulley transmission system that transfers power from the electric motor to the working shafts. The pulley–belt arrangement is designed to deliver different operating speeds for the threshing and chopping units, enabling stable rotation, effective grain separation, and uniform straw size reduction. This configuration emphasizes that proper transmission sizing and alignment are essential to minimize power losses and improve mechanical efficiency in small-scale operation.

Research Design

This study adopts a hybrid research design combining experimental and analytical methods to address the technical objectives. Experimental methods will be employed to test various pulley and V-belt configurations, as well as to measure the energy consumption, power transmission efficiency, and throughput of the rice threshing and straw chopping machine. Analytical methods will be used to simulate the machine's performance, optimizing the transmission system's design through theoretical calculations, such as torque, belt tension, and pulley size adjustments, to achieve the desired efficiency improvements.

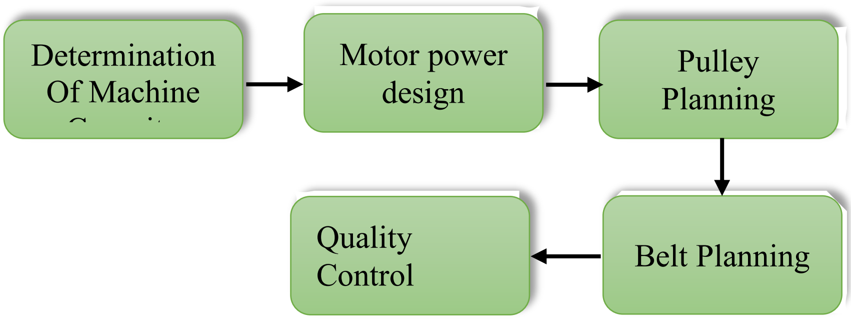

Figure 2. Reseacrh Scheme

The following Table 1 presents the results of the calculations for the belt transmission system used in the rice threshing and straw chopping machine. These calculations include key parameters such as motor power, speed, transmission ratios, RPM, belt speed, and output torque. The results are essential for designing a transmission system that ensures optimal performance and efficiency for the machine's operation.

Table 1. Calculation Results of the Belt Transmission System

Parameter	Result
Motor Power	0.75 kW

Parameter	Result
Motor Speed	1450 RPM
Threshing Ratio	1.32 : 1
Threshing RPM	1100 RPM
Chopping Ratio	1.45 : 1
Chopping RPM	1000 RPM
Belt Speed	6.06 m/s
Output Torque	2.35 Nm (Threshing) and 2.19 Nm (Chopping)
Belt Length (Threshing)	2110 mm (Threshing) and 1480 mm (Chopping)

Based on the calculation results in Table 1, the designed belt transmission system will provide efficient power transfer between components, ensuring the machine operates at the required speeds and torque for both the threshing and straw chopping functions. The output torque values of 2.35 Nm for threshing and 2.19 Nm for chopping, along with the specified belt lengths, highlight the machine's ability to handle the required tasks effectively, ensuring reliability and performance in agricultural applications.

Data Sources

Data sources for this research include both experimental measurements and simulation outputs. Experimental data will be obtained through tests conducted on the prototype machine, measuring parameters such as motor power, rotation speed, torque, and the efficiency of the transmission system under varying conditions. Simulation outputs will be generated using software like SolidWorks, which will simulate the machine's performance based on different transmission configurations, environmental factors, and operational scenarios. Additionally, secondary technical data from previous studies and industry benchmarks will be utilized for comparison and validation purposes.

Data Collection Techniques

Data will be collected using various test rigs and instrumentation. The test rig will consist of a fully functional rice threshing and straw chopping machine equipped with sensors for measuring motor power consumption, torque, rotation speed, and belt tension. The data collection setup will include strain gauges for torque measurement, rotational sensors for speed monitoring, and power meters for energy consumption analysis. Calibration procedures will involve adjusting the sensors and equipment to account for measurement errors and ensuring that the results are accurate and reliable. Boundary conditions for the simulations, such as the operational parameters (e.g., motor power, belt tension, pulley diameter), will be established based on the physical machine's settings.

Data Analysis Techniques

The data analysis techniques employed will involve both statistical evaluation and numerical solvers. Statistical methods will be used to analyze the experimental data, identify performance trends, and evaluate the significance of different transmission configurations on machine efficiency. Performance metrics, including energy consumption, throughput, and grain loss, will be compared across various setups to identify the optimal configuration. Numerical solvers will be applied to simulate the behavior of the transmission system, using computational models to predict the effects of different design choices on overall performance. Error analysis will be conducted to assess the accuracy of the simulation results, and validation procedures will ensure that the experimental and simulation outcomes align with real-world expectations.

RESULT AND DISCUSSION

Machine Capacity Determination

The first data presented involves the machine capacity determination for rice threshing and straw chopping. The process time for both threshing and chopping was set to 2 minutes. The mass of rice is 3 kg, and the mass of straw is 2.8 kg. The machine capacity was calculated using the formula for output capacity (Q). The rice threshing capacity was determined to be 90 kg per hour, while the straw chopping capacity was 84 kg per hour, based on the 2-minute processing time. This calculation shows that the machine is designed for efficient processing, with a reasonable throughput capacity for small-scale agricultural operations.

Table 2 Results of V-belt Transmission System Calculations

Parameter	Result
Motor Power	0.75 kW
Motor Speed	1450 RPM
Threshing Ratio	1.32 : 1
Threshing RPM	1100 RPM
Chopping Ratio	1.45 : 1
Chopping RPM	1000 RPM
Belt Speed	6.06 m/s
Output Torque	2.35 Nm (Threshing) and 2.19 Nm (Chopping)
Belt Length (Threshing)	2110 mm

Parameter	Result
Belt Length (Chopping)	1480 mm

Motor Power Design

In this section, the motor power design is analyzed to ensure that the system operates efficiently under the required conditions. The force required to thresh rice (29.43 N) and chop straw (27.468 N) was calculated based on the mass of rice (3 kg) and straw (2.8 kg) and the gravitational acceleration (9.81 m/s²). These forces were then used to determine the torque values needed for both threshing and chopping operations.

The required torque for the threshing process was calculated using the formula, where $F$is the force and $r$is the radius of the pulley (80 mm or 0.08 m).

$$T = F \times r,$$

For the threshing mechanism, the calculated torque was 2.35 Nm, which indicates the rotational force needed to power the threshing drum. For the chopping mechanism, the same formula was used with a similar force, resulting in a calculated torque of 2.19 Nm. These torque values are crucial for selecting the appropriate motor size and ensuring that the system can handle the mechanical load without overloading the motor.

Next, the power consumption of the system was calculated for both the threshing and chopping mechanisms. Using the torque values and the rotational speed of the system, the required power for each system was determined to be 270.60 watts for threshing and 245.97 watts for chopping. The total power requirement for both operations was then calculated to be 516.57 watts. Based on this total power requirement, an electric motor with a 1 HP (750 watt) rating was selected, ensuring that the motor operates efficiently without being overpowered or underpowered.

Lastly, the motor efficiency was assessed by taking into account mechanical losses in the transmission system. The mechanical efficiency factors for the drive components were assumed to be 97.5% for the pulley system and 90% for the belt system, resulting in a motor power requirement of 308.27 watts for the threshing system and 280.30 watts for the chopping system. The total required motor power was thus calculated to be 588.57 watts, indicating that the selected motor would work at approximately 78% efficiency, meaning it operates within optimal limits, offering both energy efficiency and sufficient power for the required tasks.

Pulley and Transmission System Design

The pulley and transmission system design is a key factor in ensuring the machine operates at its optimal efficiency. In this study, the design process involved calculating the diameters of the pulleys and determining the necessary transmission ratios for both the threshing and chopping mechanisms.

The diameter of the motor pulley was fixed at 80 mm, which is a standard size for a V-belt drive system used in small agricultural machines. The driven pulleys for the threshing and chopping systems were calculated based on the motor speed (1450 RPM), and the required speeds for the threshing drum (1100 RPM) and the chopping blade (1000 RPM). Using the formula:

$$n_2 = \frac{n_1 \times d_1}{d_2}$$

Where $n_1$is the motor speed, $d_1$is the diameter of the motor pulley, and $d_2$is the diameter of the driven pulley, the diameter of the driven pulley for threshing was calculated to be 105.45 mm, and for chopping, it was 116 mm. These values were then adjusted to match the available standard sizes in the market (4.15 inches and 4.57 inches, respectively).

The transmission ratio for the threshing mechanism was calculated to be 1.32:1, meaning the motor pulley turns 1.32 times for each rotation of the driven pulley. Similarly, the transmission ratio for the chopping system was calculated to be 1.45:1. These ratios are critical for ensuring that the threshing and chopping mechanisms operate at their designated speeds while maintaining efficient power transfer from the motor.

In addition to the pulley sizing and ratio, the design of the V-belt system was also carefully considered. The V-belt is used to transfer rotational power from the motor pulley to the driven pulleys, and its efficiency depends on proper tensioning and alignment. The belt speed was calculated to be 6.06 m/s, which is suitable for the selected pulley sizes and motor speed. The required belt lengths were calculated to be 2110 mm for the threshing system and 1480 mm for the chopping system. Standard V-belt sizes (A58 and A83) were selected based on the calculated requirements, ensuring optimal performance and durability.

Pulley–belt alignment was treated as a key design requirement to reduce the likelihood of belt slip and to maintain stable rotational speed transmission. Accordingly, the transmission layout was configured to support proper alignment and tensioning during operation. Based on the analytical transmission design outputs, the system achieves the target speed reductions (1450 rpm to 1100 rpm for threshing and 1000 rpm for chopping) with calculated output torques of 2.35 Nm and 2.19 Nm, a belt speed of 6.06 m/s, and belt lengths of 2110 mm (threshing) and 1480 mm (chopping). It should be noted that the present results are limited to analytical calculations (speed ratio, torque, belt speed, and belt length). Direct experimental measurements of threshing efficiency and grain loss are not reported in this study and are therefore treated as future validation metrics.

Discussion

This study examines the optimization of rice threshing and straw chopping machines, focusing on the transmission system, energy efficiency, and overall performance. The main findings demonstrate that the machine's capacity for threshing (90 kg/hour) and chopping (84 kg/hour) is highly dependent on the motor power (0.75 kW) and the transmission system's efficiency. The system's performance was enhanced by the use of an appropriately designed V-belt and pulley system, ensuring that both the threshing (1100 rpm) and chopping (1000 rpm) processes operated smoothly and efficiently.

The relationship between key components such as the motor, pulley diameter, and V-belt design is crucial for optimizing the machine's energy consumption and output. The research highlights how adjusting the pulley ratio and ensuring proper alignment reduced grain loss, maintained throughput, and minimized power consumption, showing the significance of a well-calculated transmission system. These results align with findings by (Abdeen et al., 2021) who observed improvements in threshing efficiency with optimized motor speed and concave clearance, and extend them by incorporating V-belt systems to further enhance energy savings.

When comparing these findings with previous studies, the outcomes align with (Liu et al., 2022), where similar optimizations in transmission systems led to improved performance and reduced blockages. However, this research adds value by emphasizing the impact of transmission design on energy efficiency and operational cost reduction for small-scale agricultural machinery, a gap not fully explored in prior works. This contributes to the existing knowledge by showing that V-belt and pulley systems can offer additional benefits, such as better energy management, for small-scale applications.

The implications of these findings suggest that optimizing the transmission system not only enhances the machine's energy efficiency but also contributes to more sustainable farming practices by reducing operational costs and increasing productivity. This research supports the notion that small-scale agricultural machinery can be designed to meet the growing demand for energy-efficient, cost-effective solutions in the agricultural sector. The integration of real-time monitoring for dynamic optimization also promises further improvements in machine adaptability to varying field conditions, ultimately improving the machine's effectiveness and lifespan.

While the study confirms the importance of transmission optimization in enhancing agricultural machinery performance, it also reveals certain limitations. Field testing across different agricultural environments and long-term durability studies are needed to ensure that these optimized systems perform well under real-world conditions. Future research should focus on addressing these challenges by incorporating advanced materials and sensor systems to further enhance machine durability and reduce maintenance costs. Additionally, further exploration of the environmental impact of such machines, particularly regarding straw utilization, would contribute to more sustainable agricultural practices.

In light of these findings, it is recommended that policymakers encourage the adoption of energy-efficient machinery through incentives or subsidies, particularly for small-scale farmers. The promotion of V-belt and pulley transmission systems in agricultural machinery should be prioritized to enhance efficiency and reduce costs. Furthermore, integrating real-time monitoring systems into these machines would allow for adaptive control, ensuring optimal performance under different field conditions. These measures would not only improve machine performance but also support sustainable farming practices and energy conservation in the agricultural sector.

CONCLUSION

This study optimized a V-belt–pulley transmission system for a combined rice thresher and straw chopper to improve energy utilization by stabilizing operating speed and reducing mechanical power losses. The analytical design results indicate that the selected pulley diameters and transmission ratios can achieve the required operating speeds 1100 rpm for threshing and 1000 rpm for chopping from a 1450 rpm, 0.75 kW motor. The resulting belt speed (6.06 m/s), belt length requirements (2110 mm and 1480 mm), and output torque values (2.35 Nm and 2.19 Nm) are consistent with the intended capacity of a small-scale machine, suggesting that the proposed configuration can provide stable torque delivery and speed regulation for integrated threshing–chopping operation.

The primary scientific contribution of this research is a structured, calculation-based engineering framework that integrates motor selection, pulley ratio design, belt sizing, and torque requirements into a unified transmission design reference for low-power agricultural machinery. This contribution is valuable because transmission inefficiencies in small-scale machines can significantly reduce usable output power and increase operating cost; therefore, the parameter benchmarks produced in this study can support more reliable and energy-aware transmission design in similar rice post-harvest machines.

However, this study is limited to analytical transmission design outputs and does not include experimental verification of threshing efficiency, grain loss, belt slip, vibration, thermal effects, or long-term durability under field conditions. Future work should validate the proposed design through prototype testing with appropriate instrumentation (power, torque, rpm, belt tension/slip, and temperature), apply standardized threshing performance metrics, and conduct durability assessment under variable load and environmental conditions to confirm the expected efficiency improvements and operational reliability.

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