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Modular System Design of Jajar Legowo Rice Transplanter Machine

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ABSTRACT

The Jajar Legowo rice transplanter has been proven to significantly improve the efficiency and effectiveness of rice planting, delivering better quality and uniformity. However, mobility on terraced land remains the primary challenge, thereby hindering the adoption of this technology by farmers. This study aimed to redesign the jajar legowo rice transplanter into a modular system to improve adaptability and ease of transport in such terrains. The research consisted of two main stages: module determination which included functional analysis, weight assessment, and component interconnection evaluation, while design analysis employed Finite Element Analysis (FEA) to assess structural strength and reliability through stress simulation. The findings indicated four main modules for the transplanter, namely: main transmission module, wheel module, feeding transmission module, and floating module. The module components have a maximum weight of 62.9 kg, which can be feasibly transported by two operators. The transmission neck interface and wheel transmission sustained operational loads of 700 N and 1000 N, respectively, with corresponding safety factors of 1.7 and 1.9. This study successfully developed a modular design for the jajar legowo rice transplanter machine that can be effectively used on terraced field. The design meets three critical adaptability indicators: (1) module weights remain within the lifting capacity of a maximum of two operators, (2) sufficient structural strength is maintained to endure operational loads, and (3) the assembly and disassembly process is achieved without the need for additional tools, minimizing the risk of component loss in the field.

1. INTRODUCTION

Rice production in Indonesia is predominantly carried out on paddy fields, while the remainder is cultivated on dry land. Terraced land constitutes approximately 15–20% of the total paddy field area in the country (Razali *et al.*, 2017). While terraced fields play a crucial role in rice cultivation, their unique topographical characteristics present several challenges to adopting agricultural machinery. These challenges include restricted access to farm roads, inconsistencies in terrace levels, and variations in the sizes and shapes of terraced plots, all of which hinder mechanisation and efficiency in farming practices (Cebro & Sitorus, 2019; Syahri *et al.*, 2019).

One of the rice planting systems that enhanced rice production was the jajar legowo system. This planting method offered several advantages, including a 16% increase in productivity compared to conventional techniques (Prasetyo & Kadir, 2019). Additionally, it allowed for a higher planting density, accommodating up to 150,000 rice plants per hectare, and improved plant quality by optimising exposure to sunlight and air circulation (Permata, *et al.*, 2017;

Prasetyo & Kadir, 2019; Alif *et al.*, 2023). The fundamental principle of the lajar legowo system lay in its planting arrangement and spacing, where every two to four rows of rice plants were interspersed with empty rows. This layout facilitated better plant growth and enhances ease of access for maintenance and harvesting (Alif *et al.*, 2023; Permata *et al.*, 2017; Rebekka *et al.*, 2018).

The jajar legowo rice transplanter machine increased the effectiveness and efficiency of rice planting (Prasetyo & Kadir, 2019). The efficiency of labour use for one unit of rice transplanter jajar legowo machine was equivalent to that of 20 manual planting workers (Umar et al.,, 2017; Umar & Pangaribuan, 2017; Faisal *et al.*, 2019). The advantages of using rice transplanter machines included savings in planting costs, irrigation water use, uniformity of spacing and planting depth, and increased productivity (Chaitanya *et al.*, 2018). The jajar legowo rice transplanter machine had a working capacity of 6 hours/ha with a planting distance in rows that could be adjusted between 10 cm and 18 cm with a planting depth of 3-6 cm (Salim *et al.*, 2021). Structurally, the rice transplanter machine consisted of three main components: the drive and main transmission unit, the right and left wheel transmission unit, and the feeding unit (Umar, 2017; Salim *et al.,* 2021).

One potential solution for optimizing the use of rice transplanters on terraced land was to convert the existing machine into a modular system. The modular system was a technology development system that allowed parts of the technology to be independent or called modules. Each module had a standardised interface that could be coupled with other functional components. A modular technology was developed through modular design studies (Tseng *et al.*, 2018; Wang *et al.*, 2021). The planning of modular designs took into account the specific needs of technology users, with key considerations including flexibility, scalability, cost-efficiency, customisability, and reusability (Gwiaza *et al.*, 2015; Cheng *et al.*, 2018).

The design of the connection or interface between modules played a crucial role in ensuring interchangeability and interoperability within the modular system. Since the interface design directly influenced the primary function of each module, achieving an optimal design that aligned with development objectives became essential (Tseng *et al.*, 2018). A well-structured interface enhanced flexibility, enabling the use of multiple functions, while its complexity determined the overall ease of operation. Interface designs were generally classified into two categories: structural and physical interactions (Scalice *et al.*, 2008). Additionally, operational loads on the machine contributed to fatigue, which could lead to failures in the interface structure over time (Polat *et al.*, 2018; Islam *et al.*, 2021).

The jajar legowo rice transplanter machine has been widely used by farmers in flat rice fields; however, it remains difficult to operate in terraced areas. Given the machine's advantages in improving the efficiency and effectiveness of rice planting, modifications are considered necessary to enable its application on terraced land. These modifications are primarily intended to enhance the machine's mobility, allowing it to reach planting plots more effectively. This research aims to modify the jajar legowo rice transplanter machine into a modular system to facilitate machine mobility. The implementation of the jajar legowo modular rice transplanter system not only enhanced the effectiveness and efficiency of planting in terraced areas but also helped address the shortage of planting labourers.

2. MATERIALS AND METHODS

The research was conducted at the design and manufacturing laboratory of the Indonesian Agricultural Engineering Polytechnic, Serpong, Banten. The equipment used in this research consisted of design instruments and stress analysis using SolidWorks. The main material in this research was a walk-behind type jajar legowo rice transplanter machine unit. This machine measured 241 cm in length, 120 cm in height, and 170 cm in width, and was powered by a 4-stroke, 4.0 kW gasoline engine. Several components, such as shafts, gears, and toggles, were made from AISI 304 steel, while the main frame was constructed from ASTM A36 steel. The research followed a three-stage methodology, which included determining the rice transplanter module, design and simulation stage, and module integration stage.

2.1. Determination of Rice Transplanter Modules

Determination the rice transplanter module consists of three stages: functional analysis, interaction analysis between components, and weight analysis. The process of determining the module was mathematically formulated as follows.

$$M_i = \alpha F_i + \beta I_i + \gamma W_i \tag{1}$$

with M_i denotes module feasibility score for the component, F_i is function analysis value (main function represented by a component), I_i represent component interaction complexity value, and W_i is weight feasibility value (based on operator weight proportion). Coefficients α, β, and γ are weight of each factor (adjusted based on design focus).

Functional analysis was used to determine the main functions of the rice transplanter machine as a whole. Interaction analysis between components was used to detail the working mechanism of the components. A detailed analysis was conducted based on the relationship between components, the complexity of the structure and mechanism, the potential for grouping into modules, and the ease of modification. Analysis of each rice transplanter component's weight aimed to determine the ease with which the module can be moved while operating on terraced land. Component weight analysis was also used as one of the bases for determining the module to be used. Based on Waghmode *et al.* (2020), the maximum weight that can be transported continuously by farmers or operators is recommended to be 40% of the operator's weight. The selection of modules, in addition to considering the carrying ability of the operator, also based on the ease and speed of the loading and unloading process when in the field. Consideration of the division of modules to form a series module also based on the level of complexity of the machine setting process. The division of modules must follow the principles of simplicity and speed in the loading and unloading process (Xia *et al.*, 2019).

2.2. Design and Simulation

The design stage needed to be carried out before modifying the rice transplanting machine into a modular system. The design results served as the basis for the module interface design model for each module series. Simulations were performed using SolidWorks software and the FEA stress analysis method. A stress analysis simulation carried out to see the structural ability of the recommended design to withstand specific loads or forces based on the assumption of the load received by the component when the machine operating. In this software, material properties must be assigned to the design prior to simulation, and these must correspond to the actual materials to be used, namely ASTM A36 steel and AISI 304. Various loading levels, ranging from 300 N, 500 N, 700 N, to 1000 N, are applied to the interface areas of the components predicted to experience material fatigue. A material is considered robust if it demonstrates a safety factor greater than 1.5. The direction and value of loading are determined based on the engine's condition when operated. The results of this simulation will obtain the maximum stress and strain on the structure, the maximum deformation value, the part of the component that gets the most significant load, and the estimated change in shape (deformation) due to the structure that gets a specific load (Polat *et al.*, 2018).

2.3. Module Integration

The module integration process assembled various modules of the rice transplanter machine, ensuring they functioned cohesively and efficiently. This process was intended to make all modules work in synergy while maintaining compatibility. Key factors such as size, interface design, and mechanical functionality were taken into account to ensure proper module connection and operation. The module integration process was required to consider the system's scalability, which referred to the ability to add more modules over time to enhance the machine’s performance and functionality. This scalability played a crucial role in ensuring that the machine could evolve and adapt to changing technological requirements. The module integration system was designed to uphold the principle of ease in maintenance and repair. Individual modules could be replaced or serviced without disrupting the overall system, thereby minimising machine downtime.

In this study, three indicators were used to assess the system’s adaptability for use in terraced fields. The first indicator is the ease of machine transportation, which is determined by the ability of operators to carry the modules based on their weight. The second indicator is the ease of module assembly and disassembly, characterized by the use of a locking system that requires no additional tools, thereby reducing the risk of component loss in the field. The final indicator is the system’s reliability, which was evaluated based on the structural strength of the interface, transmission, and locking mechanisms, with a minimum safety factor of 1.5 being required. When all of these criteria are met, the system is considered suitable and adaptable for operation on terraced field.

3. RESULTS AND DISCUSSION

3.1. Rice Transplanter Module

3.1.1. Function Analysis of Jajar Legowo Rice Transplanter Machine

According to Xia *et al.* (2019), the determination of the module relied on the analysis of the functions of the constituent components of the technology. Figure 1 illustrates the construction of the jajar legowo rice transplanter machine. The machine comprised six main functions: operational function, chassis function, walking function, planting function, depth control function, and auxiliary function (Figure 2).

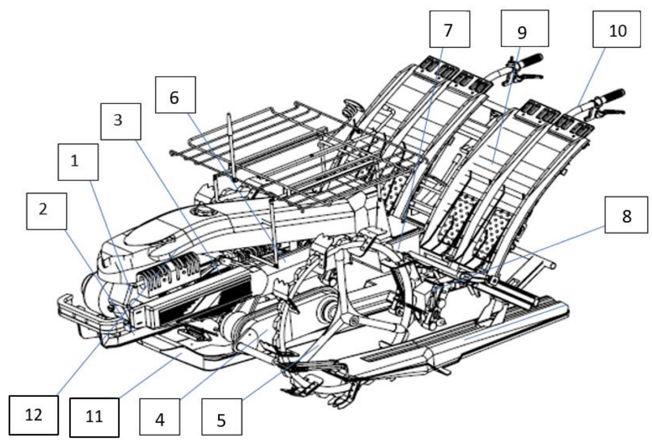


Figure 1. The construction of the jajar legowo rice transplanter machine

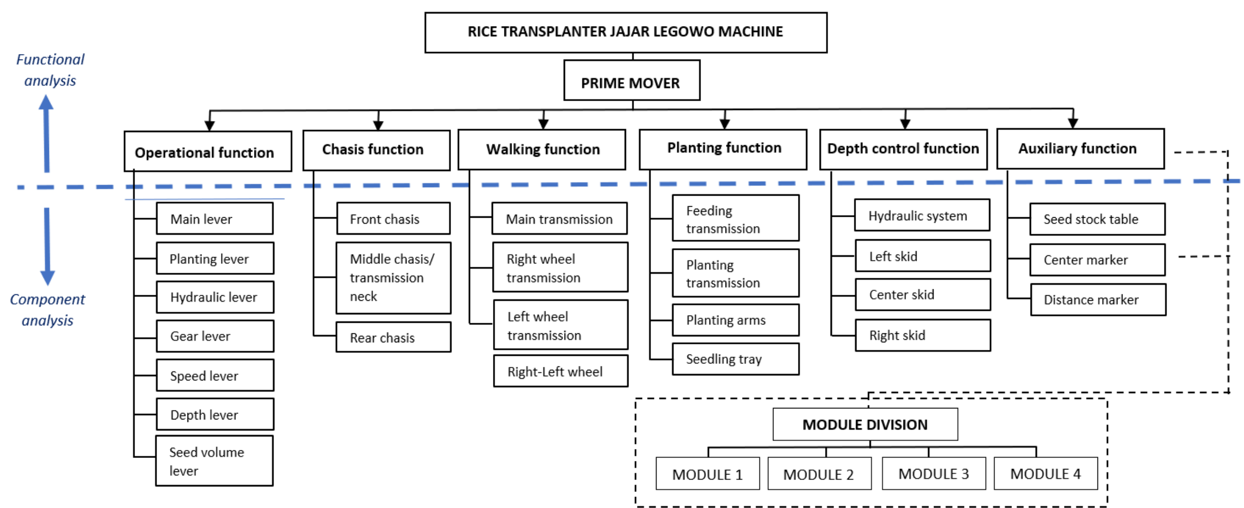


Figure 2. Module division method of rice transplanter jajar legowo machine

Figure 1 illustrates the main components of the jajar legowo rice transplanter machine, which include the prime mover (1), front chassis (2), main transmission (3), wheel transmission (4), wheel (5), transmission neck (6), feeding transmission (7), planting transmission (8), seedling tray (9), handle bar and control panel (10), floating skid (11), and head lamp (12). All the main components of the jajar legowo rice transplanter machine were operated using levers positioned on the control handlebar frame, ensuring easy access for the operator. The machine controls consisted of the main lever, planting lever, hydraulic lever, gear lever, speed lever, depth lever, and seed volume lever. These levers were linked to the corresponding components via steel cables.

The walking function of the jajar legowo rice transplanter machine operated by adjusting the proportion of gear movement in the main transmission and transferring it to the wheel transmission shaft. The right and left wheel transmissions were linked to the wheel shaft and distributed power through the sprocket-chain system. The planting function comprised several components, each with a specific role. The feeding transmission regulated the movement of the entire planting mechanism, while the planting transmission transferred rotational motion from the shaft to the planting arm. This arm extracted seedlings from the seedling tray and planted them into the soil in a continuous cycle. The module design took into account the integrity of the machine's primary functions. Highly complex components, such as the drive engine, main transmission unit, and feeding transmission, were kept as single units rather than being divided into smaller modules.

Table 1. Module analysis base on weight, function, materials, and complexity system of rice transplanter jajar legowo machine

NO	Part Name	Total Weight (kg)	Material Composition	Main Function	Connection	Structure Complexity	Module Division	Module Weight (kg)
1	Gasoline engine 4.0 kW	16.95	Special steel, aluminium casting, plastic	Prime mover		high	Module 1	62.9
2	Front chasis	6.15	AISI A36 Steel	Engine & main transmission chasis		low		
3	Main transmission	39.8	Special steel, aluminium casting	power divider to feeding function, wheels, main versneling, and planting distance in rows		high		
4	Right wheel transmission	7.35	AISI A36 Steel, chain, sprocket, S45C shaft	transmit power to the wheels		medium	Module 2	32.7
5	Right wheel	9.0	AISI A36 steel & rubber	movement function		low		
6	Left wheel transmission	7.35	AISI A36 Steel, chain, sprocket, S45C shaft	transmit power to the wheels		medium		
7	Left wheel	9.0	AISI A36 steel & rubber	movement function		low		
8	Transmission neck	5.95	AISI A36 Steel, chain	main transmission connector to feeding transmission		low	Module 3	59.65
9	Feeding transmission	13.3	Aluminium casting, S45C shaft & sprocket	feeding seeds and planting		high		
10	Planting transmission	10.8	Aluminium casting, S45C shaft & sprocket	planting seeds in the rice field		high		
11	Seedling tray	8.8	Plastic, AISI A36 steel	a board where rice seeds are placed		high		
12	Handle bar & contol panel	20.8	Plastic, AISI A36 steel	control path, planting, depth, reverse, planting distance		medium		
13	Center skid	4.95	Plastic, AISI A36 steel	support the machine from sinking in the mud, determine the planting depth		medium	Module 4	11.45
14	Left skid	2.6	Plastic, AISI A36 steel			low		
15	Right skid	2.6	Plastic, AISI A36 steel			low		
16	Head lamp cover	1.3	Plastic, AISI A36 steel	helps when the machine operates at night		low		

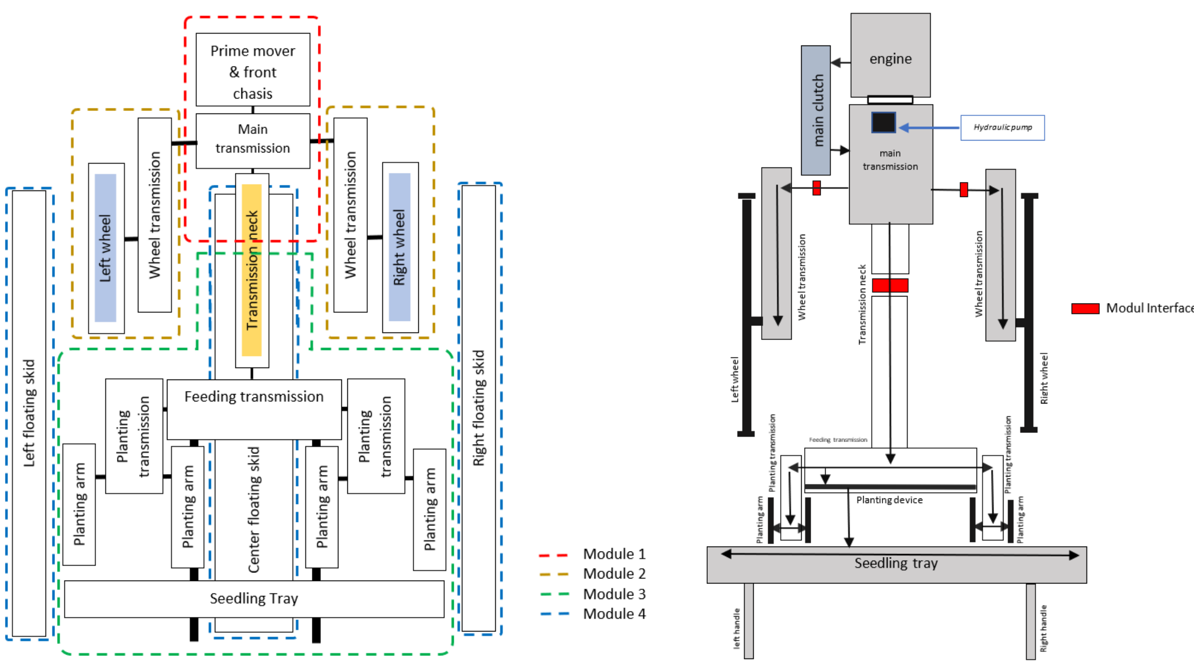
3.1.2. Weight Analysis

The measured weights of each main component of the jajar legowo rice transplanter machine are shown in Table 1. Based on these measurements, the weights of the four highly complex component units are as follows: main transmission, 39.8 kg; handlebar, 20.8 kg; engine drive, 16.95 kg; and feeding transmission, 13.3 kg. The design requirement for determining the rice transplanter machine module focused on the lifting capacity of the operator when transporting the module to and from the field. According to Waghmode *et al.* (2020), the maximum weight that can be transported continuously represents 40% of the operator's body weight. For an operator with an average weight of 80 kg, the recommended maximum transport weight would be 32 kg. However, when two individuals carry the load, the maximum weight that can be lifted increases to 64 kg.

3.1.3. Interconnection of Rice Transplanter Machine Components

The complexity level of the components was a consideration for determining the module in addition to the limiting factor of component transportability. The interconnection of the machine components is presented in Table 1. As the prime mover connected to the main transmission, the engine proved to be highly complex, with various cables and transmission linkage systems carrying out additional functions. The engine shaft connected to the main transmission through a belt-pulley system, with a specific tightness setting. This adjustment required high precision and would have necessitated the use of multiple tools had it been designed as a separate module.

The planting function component was highly complex, as it consisted of four main parts: the feeding transmission, planting transmission, planting arm, and seedling tray. The power distribution from the feeding transmission shaft to the planting transmission was precisely balanced on both sides. Any setting error caused the rotation of the planting arm to become misaligned, resulting in uneven plant rows. The planting arm, which was attached to the end of the feeding transmission shaft, also required complex adjustments. The settings of the four planting arms had to be at precise and uniform angles to ensure that the seedlings were picked up simultaneously with a consistent volume. Additionally, the seedling tray needed to move in synchronization with both the sliding shaft of the feeding transmission and the movement of the planting arm.



(a) (b)

Figure 3. (a) Module divison scheme of rice transplanter jajar legowo machine, (b) Interface placement of modular rice transplanter jajar legowo machine

Based on the component weight analysis, interconnection, and complexity analysis, the jajar legowo rice transplanter machine was divided into four main modules, as shown in (a) (b)

Figure 3a. Module 1 (main transmission module) had a weight of 62.9 kg and comprised the driving engine, main transmission, and front chassis. Module 2 (wheel transmission module) had a weight of 32.7 kg and consisted of two sets of right and left wheels. Module 3 (feeding transmission module), weighing 59.65 kg, comprised a combined transmission neck, feeding transmission, planting transmission, planting arm, seedling tray, and handlebar and control panel. Module 4 (floating skid module) had a weight of 11.45 kg and comprised all floating skid and headlamp components.

3.2. Module Interface Design and Simulation

The interface was a crucial component that connected and facilitated interaction between different modules, creating a cohesive system. The interface design of the modular jajar legowo rice transplanter has two main functions: it connected the module frames securely and linked the power transmission components within the module. When designing the interface, the key considerations were ease of disassembly and installation, as well as maintaining the machine's structural integrity. Most components of the rice transplanter were made from aluminium casting, ASTM A36 steel, and AISI 304 stainless steel.

The interface design employed a simple and robust knock-down system, which user-friendly for operators. As a result, the frame and transmission locking interfaces were designed without additional keys. To ensure that the interface could withstand the operational workload, stress analysis simulations were conducted on the critical parts of the interface components. Figure 4 illustrated the position of the interfaces on the jajar legowo transplanter machine. The first interface, located at the transmission neck, linked the main transmission module (Module 1) to the feeding transmission module (Module 3). The second interface, situated in the wheel transmission section, connected Module 1 to the wheel transmission module (Module 2). In contrast, the third interface served to connect the floating skid module (Module 4) to all three modules: Module 1, Module 2, and Module 3.

3.2.1. The Transmission Neck Design and Simulation

The transmission system in the original construction, which connected the main transmission to the feeding transmission, used chain sprockets housed within the transmission neck frame. This system posed certain challenges in terms of connecting the transmission components. To address this, the chain-sprocket transmission system was replaced with a shaft-gear transmission system, allowing for a more efficient and simplified loading and unloading process, while maintaining effective power transmission (Figure 4). In the revised system, the chain in the main transmission was connected to the sprocket shaft, which featured a 45° bevel gear. The bevel gear was connected to a shaft running parallel to the frame, with the shaft's end attached to a coupling. This coupling linked the shaft to another coupling that connected it to the feeding transmission module's shaft. The coupling consisted of a square hollow shaft, which was affixed to the end of a square shaft interface. The shaft material used was AISI 304 steel, which had been surface-hardened to 50 HRC.

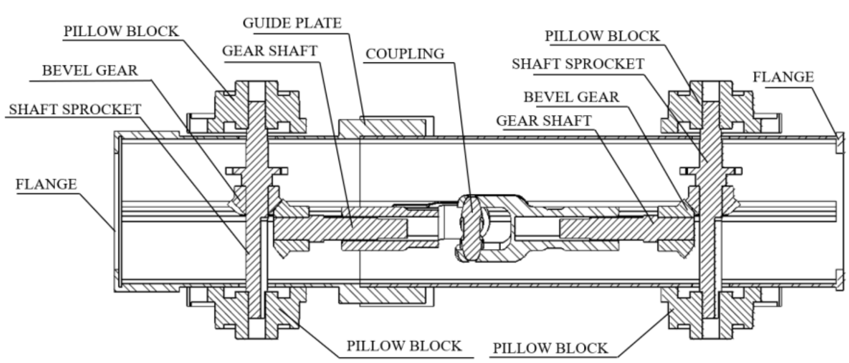


Figure 4. Transmission neck shaft structure

The original transmission neck frame had a total length of 460 mm and was made from ASTM A36 material, with a thickness of 2 mm and shaped like a pentagon. It featured two flanges for connecting with the front and rear transmission bolt mounts. The modular transmission neck frame was divided into two sections: the front frame, which measured 155 mm in length, and the rear frame, which measured 305 mm. The front frame was attached to the main transmission, while the rear frame was attached to the feeding transmission. The dimensions of the frame were designed to accommodate the shaft transmission system, pillow block space, and the frame's locking mechanism. The frame interface locking system used a three-unit toggle clamp mechanism, with two clamps positioned at the top and one at the bottom. To ensure precise connections, guide plates made from ASTM A36 plate, with a thickness of 10 mm, were added to the right and left sides of the frame (Figure a). At the top of the transmission neck, a lever holder made of 12 mm diameter steel was installed to assist in lifting the module during disassembly.

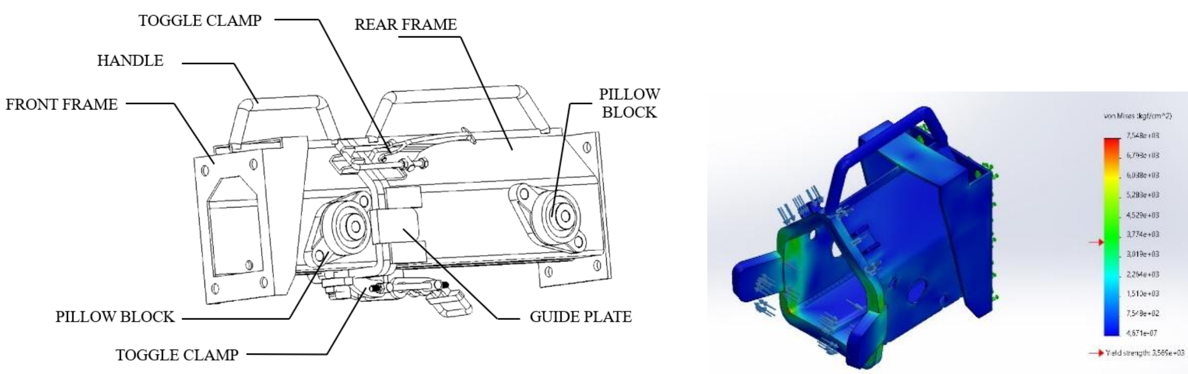


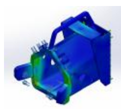
Figure 5. (a) Transmission neck frame structure with lock system (toggle clamp and guide plate), and (b) Transmission neck locking plate system stress analysis

The transmission neck bore a load when the control handlebar was pressed down, lifted, and pulled to the left and right throughout the rice planting process. The interface components that endured the highest load were the ends of the toggle lock and the guide plates positioned on each side of the frame. The loading values in the simulation given to the locking system are 300 N, 500 N, 700 N, and 1000 N. The load was directed horizontally outward, as the response of the leverage force in various conditions caused the two locking plates to deform outward (Figure 7). According to the simulation results, the locking system successfully withstood horizontal loads up to 1000 N. The maximum stress experienced by the locking system was 5.48×10^2 $kgf.cm^{-2}$, while the yield strength value of ASTM A36 material was 25.49×10^2 kgf/cm^2. At the same loading, the maximum displacement value was 6.65×10^{-3} cm, with a maximum equivalent strain of 1.10×10^{-4} and FoS 4.7 (Table 2). These analytical findings demonstrated that the system was safe to use as a transmission neck lock, as it could endure a 1000 N horizontal load.

A load simulation was conducted on the upper toggle lock to evaluate the system's capability to handle operational loads. The lock was made from AISI 304 shaft material, which has a yield strength of 2108.84 $kgf.cm^{-2}$. This toggle lock was paired with the retaining part, so when the lever of the toggle was pulled, horizontal tensile stress was generated in both parts. This tensile stress locked the two interface surfaces together. The stress analysis results for the toggle locking component are presented in Table 2. The applied loads started at 300 N, followed by 500 N, and 700 N. At 700 N load, the locking component experienced a maximum stress of 2.10×10^3 $kgf.cm^{-2}$, a maximum displacement of 2.53×10^{-2} cm, and an equivalent strain of 6.24×10^{-4}. The factor of safety (FoS) at a 700 N load was 1, indicating that the toggle clamp was safe to use for loads up to 700 N.

The bottom toggle clamp of the transmission neck was designed to maintain the interface's position when subjected to an upward force. According to the simulation results for the toggle clamp, the design was able to withstand forces of up to 1000 N, with stress, displacement, and equivalent strain values of 2.19×10^2 $kgf.cm^{-2}$, 7.56×10^{-4} cm, and FoS 9.9, respectively.

Table 2. Stress analysis of transmission neck modular component

Component	Material Properties	Load (N)	Stress ($kgf.cm^{-2}$)	Displacement (cm)	Equivalent strain	Factor of Safety (FoS)
Lock transmission neck	ASTM A36 Steel	300	1.65×10^{2}	1.99×10^{-3}	3.96×10^{-5}	15.5
	Yield strength 2549.29 $kgf.cm^{-2}$	500	2.72×10^{2}	3.57×10^{-3}	6.94×10^{-5}	9.4
	Tensile strength 4078.86 $kgf.cm^{-2}$	700	3.84×10^{2}	4.66×10^{-3}	7.67×10^{-5}	6.6
	Mass density 0.00785 $kg.cm^{-3}$	1000	5.48×10^{2}	6.65×10^{-3}	1.10×10^{-4}	4.7
Upper toggle neck	AISI 304 Yield strength 2108.84 $kgf.cm^{-2}$	300	9.02×10^{2}	1.08×10^{-2}	2.67×10^{-4}	2.3
	Tensile strength 5272.11 $kgf.cm^{-2}$	500	1.50×10^{3}	1.72×10^{-2}	4.14×10^{-4}	1.7
	Mass density 0.008 $kg.cm^{-3}$	700	2.10×10^{3}	2.53×10^{-2}	6.24×10^{-4}	1
Lower toggle neck	ASTM A36 Steel	300	1.35×10^{2}	4.14×10^{-4}	4.15×10^{-5}	19
	Yield strength 2549.29 $kgf.cm^{-2}$	500	2.25×10^{2}	6.53×10^{-4}	6.91×10^{-5}	11
	Tensile strength 4078.86 $kgf.cm^{-2}$	700	1.53×10^{2}	5.29×10^{-4}	4.78×10^{-5}	14
	Mass density 0.00785 $kg.cm^{-3}$	1000	2.19×10^{2}	7.56×10^{-4}	6.84×10^{-5}	9.9

A stress analysis simulation on the modular transmission neck frame revealed that the frame could handle 500 N loads applied in downward, upward, and lateral directions (Figure). The maximum stress experienced under loads from the top, bottom, and sides were 1.04×10^{2} $kgf.cm^{-2}$; 1.70×10^{3} $kgf.cm^{-2}$; 1.18×10^{3} $kgf.cm^{-2}$, respectively. The safety factors for the three loading directions indicated that bottom loading had the lowest factor of safety (FoS) value of 1.7, while the top and side loading conditions had FoS values of 2.5 and 2.2, respectively. This variation in values was attributed to the asymmetrical shape of the frame at the top.

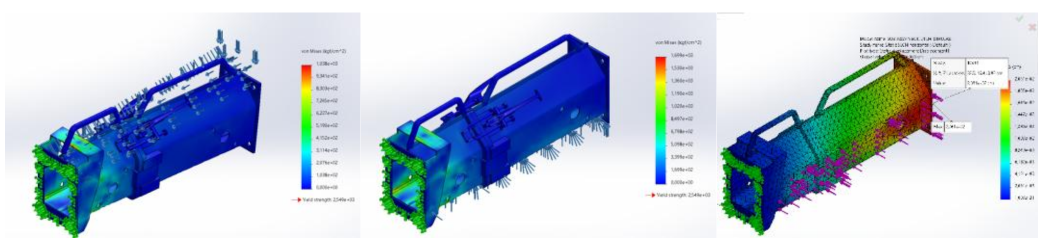


Figure 6. Stress analysis of transmission neck by current direction.

3.2.2. Design and Simulation of Wheel Transmission

The wheel transmission module of the jajar legowo rice transplanter machine consisted of a wheel transmission and a wheel unit located on the right and left sides of the main transmission. Inside the wheel transmission, a chain and two sprockets transmitted power from the main transmission shaft to the wheel shaft. The wheel was able to move vertically, adjusting to the depth of the field, as it was driven by a hydraulic arm (Figure a). The initial interface between the main transmission shaft and the wheel transmission frame consisted of three M10 bolts that were secured between the hydraulic arms. The interface between the wheel axle and the transplanter wheel was connected via three 9.5 mm diameter locking pins.

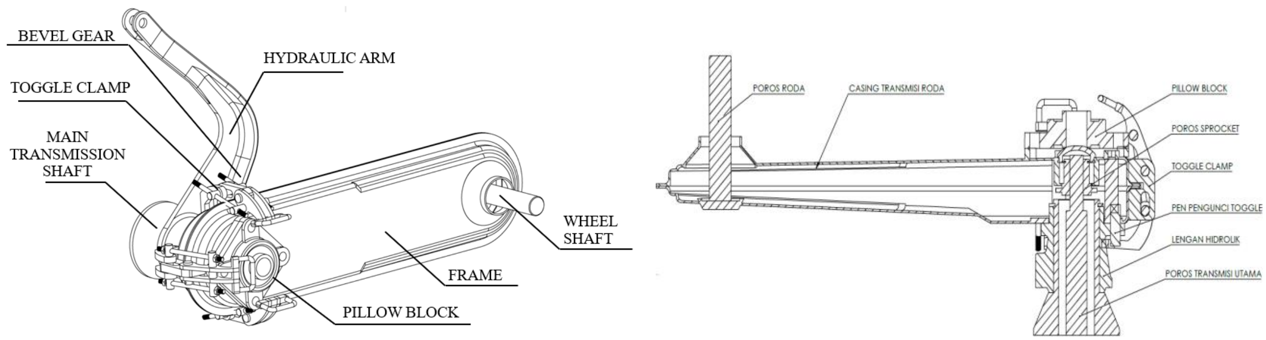


Figure 7. (a) Design construction of modular wheel transmission, and (b) Design structure of shaft sprocket wheel transmission

In its original configuration, the bolt-and-nut system used to secure the transmission frame required a significant amount of time for installation and removal, along with the need for additional tools. To simplify and facilitate the loading and unloading of the module, the bolt-nut locking system was replaced with a toggle clamp system. The lock operated by hooking the toggle end onto the pin and pulling until the toggle was securely locked.

To further improve ease of assembly, a pillow block was added to ensure that the sprocket shaft could be easily connected to the main transmission shaft during disassembly. The square end of the main transmission shaft was paired with a sprocket that had a square hole. When the module was detached, the sprocket shaft remained fixed in place, preventing it from falling and ensuring it was simple to reassemble (Figure 10).

The primary load on the wheel transmission system was concentrated at the hook end of the three toggle clamp units, while the pin experienced dynamic loads during machine operation. The pin was made of AISI 304, which possesses a higher tensile strength compared to the ASTM A36 material used for the toggle. Table 3 presented the results of the tensile load simulation on the toggle clamp and pin. The simulation demonstrated that the stress on both components increased in proportion to the applied load.

The toggle clamp exhibited the capacity to withstand loads of up to 1000 N. Under both horizontal and vertical hook loading, the maximum stress, maximum deformation, and equivalent strain values were 1.16 x 10^3 kgf.cm^{-2}, 9.46 x 10^{-3} cm, dan 4.35 x 10^{-4}, respectively. The toggle clamp system in the wheel transmission remained safe to use at these loads, with a factor of safety (FoS) value of 1.9. The most vulnerable part of the three toggle types was the hook attached to the locking pin. This section, which exhibited the highest stress, was highlighted in red (Figure).

Table 3. Stress analysis of wheel transmission toggle clamp

Component	Material Properties	Load (N)	Stress (kgf.cm^{-2})	Displacement (cm)	Equivalent strain	Factor of Safety (FoS)
Wheel toggle clamp 	ASTM A36 Steel (Hook)	300	3.93 x 10^2	2.84 x 10^{-3}	1.29 x 10^{-4}	6.1
	Yield strength 2549.29 kgf.cm^{-2}					
	Tensile strength 4078.86 kgf.cm^{-2}	500	5.8 x 10^2	4.73 x 10^{-3}	2.18 x 10^{-4}	3.8
	Mass density 0.00785 kg.cm^{-3}					
	AISI 304 (Pen)	700	8.12 x 10^2	6.62 x 10^{-3}	3.05 x 10^{-4}	2.7
	Yield strength 2108.84 kgf.cm^{-2}					
	Tensile strength 5272.11 kgf.cm^{-2}	1000	1.16 x 10^3	9.46 x 10^{-3}	4.35 x 10^{-4}	1.9
	Mass density 0.008 kg.cm^{-3}					

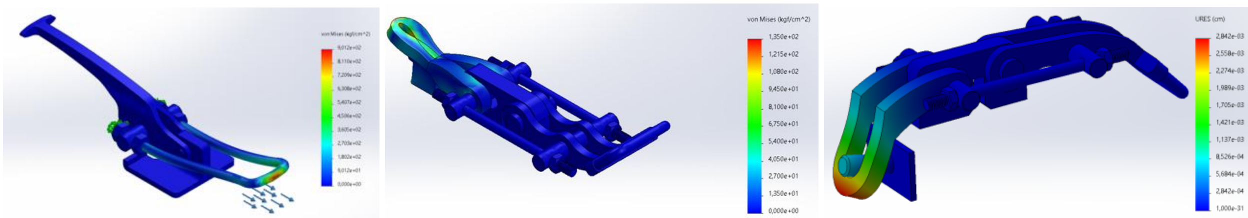


Figure 8. Stress analysis of transmission toggle clamp (pen and hook)

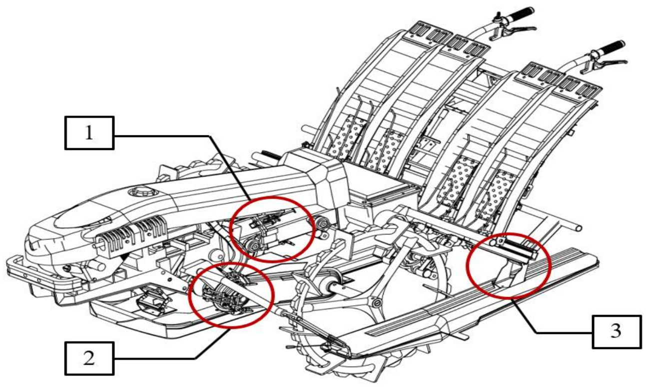


Figure 9. Modular rice transplanter jajar legowo main assembly design after modification; (1) transmission neck; (2) wheel transmission; and (3) floating skid pin

3.3. Module Integration

The entire module design was integrated into a complete system following the design and simulation. The three main parts of the modification to the modular jajar legowo rice transplanter system are illustrated in Figure . The first component to be modified is the transmission neck (1). This component connecting the main transmission module to the feeding transmission module via a shaft coupling for power transmission, and a toggle clamp was utilized as the frame lock. A further modification is applied to the wheel transmission (2). The power distribution system in the main transmission module was connected to the wheel transmission module through the interaction between the main transmission shaft and the sprocket shaft on the pillow block bearing. The locking mechanism between the wheel transmission frame and the main transmission utilized three toggle clamp units. The last modification is applied to each connecting pin of the floating skid (3). The floating skid module was connected to the main transmission module, wheel transmission module, and feeding transmission module using a pin shaft mechanism with diameters of 5 mm, 8 mm, and 10 mm. These pins can be easily disassembled without the use of keys. The design modifications to the transmission system, interface, and locking system of the rice transplanter jajar legowo machine result in improved ease of module assembly and disassembly, as well as a reduced risk of component loss during field operations (Table 4).

4. CONCLUSION

The module design for the modular system of the jajar legowo rice transplanter machine has been produced. The interface design of the modules and the locking mechanism simulation allowed for secure connections without the need for additional keys during disassembly. The transmission neck module was capable of safely supporting a maximum operational load of 500 N, with a factor of safety (FoS) value of 1.7 at bottom loading direction. The wheel transmission toggle clamp simulation confirmed its ability to withstand loads of up to1000 N, with a FoS value of 1.9. Through function analysis, component weight assessment, and examination of the relationships between components, the jajar legowo rice transplanter machine was divided into four distinct modules: the main transmission module (weighing 62.9 kg), the wheel transmission module (32.7 kg), the feeding transmission module (59.65 kg), and the floating skid module (11.45 kg). The weight of each resulting module is designed to be manageable and can be lifted by one or two operators with the aid of a supporting rod during transport across terraced field. Adaptability to terraced field conditions is achieved through the integration of a robust and easy-to-use toggle clamp for module locking, combined with module weights designed to allow efficient manual transport.

Table 4. Improvement result of modular rice transplanter jajar legowo

Problem Category	Components	Before Modification	After Modification	Improvement
Weight of unit	Main assembly rice transplanter unit	Total weight 166,7 kg and large dimension, it is not capable of being transported by operators.	The main assembly is divided into four primary modules: the main transmission module (62.9 kg), the wheel transmission module (32.7 kg), the feeding transmission module (59.65 kg), and the floating skid module (11.45 kg).	Each module is designed to be lightweight and easily transportable by the operator.
Transmission neck system	Transmission neck	A sprocket and chain mechanism is used to connect the main transmission to the feeding transmission. The system is difficult to be modified to facilitate the assembly and disassembly of the transmission.	The sprocket and chain system was modified into a shaft gear and coupling system that allows for easy assembly and disassembly.	The modification to a shaft gear system facilitates the assembly and disassembly process.
Wheel transmission system	Wheel transmission	A sprocket and chain mechanism is used to connect the shaft from main transmission to the wheel shaft. The upper sprocket will be detached during the assembly and disassembly process.	The sprocket on the upper shaft was modified to be attached to the transmission frame, allowing for easier assembly and disassembly.	The upper sprocket is not detached during assembly and disassembly, which facilitates a simpler and faster process.
Interface lock system	Transmission neck and wheel transmission	A bolt-and-nut system is used to secure the interface, which complicates the assembly and disassembly process and increases the risk of component loss.	The interface locking system is implemented using a toggle clamp.	The toggle clamp system is characterized by strong holding power, quick assembly and disassembly, and the prevention of component loss.
Connection shaft pin	Floating skid	The shear clip locking mechanism is at risk of being lost in the field.	System without the shear clip.	The system without the shear clip reduces this risk during field assembly and disassembly.

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