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Automatic Bamboo Fed Type Cutting Mechanism Prototype

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Bamboo, cutting process, FEA, automated

Abstract

Currently, most of the bamboo cutting process is done manually. However, the growing demand for bamboo products and the high cost of labor in some countries requires automatic bamboo cutting machine to increase the production rate. The aim of this project was to develop a bamboo cross cutting mechanism prototype which is controlled by Programmable Logic Controller (PLC). Structural design work was carried out using Finite Element Analysis (FEA) to determine the stability and reliability of this prototype. The cutting mechanism was designed to cut bamboo stem at specific length uniformly. It consists of a rotary disc cutter which is powered by a 240VAC motor, bamboo stem positioner and chain-type feeding system. The feeding mechanism feeds the bamboo stem to the rotary cutter in a proportional manner. Once assembled, the prototype underwent for system verification and production rate was calculated to determine its processing capacity. The result shows this prototype has cut length offset at 2.3 cm in average and the production rate was approximately 15.3 cuts per minute or 943.3 cuts per hour in average. The cut length offset is quite wide and can be improved by redesigning the bamboo stem positioner mechanism.

1. Introduction

Bamboo is a renewable natural resource, versatile and fast-growing tropical plant that has a wide range of uses, including food, construction, fuel, and various household and industrial products [1-2]. Recent studies show that bamboo market demand has increased tremendously in recent years through several economic sectors [3-4]. Global warming and environmental pollution because of plastics, together with bamboo easy growing character made many researchers intend to focus their research in bamboo as an alternative material to replace plastics [5]. Most bamboo processing plants are located near to the plantation area due to transportation cost. Main activities in the processing plant include cutting, splitting, slicing, fiber extraction, treatment, chipping as well as pyrolysis [6-8]. In tile bamboo production, cross cutting bamboo stem at even length is crucial to obtaining same size of bamboo tiles [9-10]. As the large amount of bamboo stem needs to be processed, production rate is one of the key indicators for an efficient processing plant. High production rate is generally dependent on skilled labour.

In some countries where skilled labor is costly and scarce, automation offers a viable solution for achieving high production rates in processing plants [11-12]. To address this, this research proposes and investigates an automated bamboo cross-cutting mechanism. The primary objective of this project is to develop a system capable of cutting bamboo to uniform lengths automatically. During the design phase, the forces acting on the proposed mechanism were analyzed. Bamboo contains a significant amount of silica, with levels varying by species. Silica content influences bamboo's toughness, strength, and hardness, which in turn affects processing methods [13-15]. The stronger the bamboo, the greater the reaction forces generated during cutting.

There are two fundamental methods for cross-cutting bamboo: the rotary disc type and the band saw type. The rotary disc method includes cutting machines such as circular saws, table saws, and miter saws, while the band saw method uses an endless toothed steel belt to cut materials. In manual operations, bamboo or wood stems are either fed into the cutter or cut by moving the cutter toward the material. However, cutting bamboo with a circular saw raises concerns about instability and vibration. To address these challenges, structural studies were conducted using Finite Element Analysis (FEA) to assess stability, stress distribution, and potential structural deformation in the positioning platform. After finalizing the conceptual and detailed design, the mechanism was fabricated and tested. The testing phase verified the operation of the system, and the production rate of the cutting mechanism prototype was calculated.

2. Methodology

2.1 Mechanism Design

This research involves three main stages: design, fabrication and assembly, and testing. The design phase begins with a review of several existing bamboo and wood cross-cutting machines. During the brainstorming process, a few promising bamboo cross-cutting machines were shortlisted [16-18]. Most existing machines operate manually, where the disc cutter moves toward the bamboo stem, either by hand or through hydraulic actuation. However, this method poses safety risks, as the continuously running cutter increases the potential for injuries during the cutting process [19-20]. To improve safety, this project adopts a different approach by feeding the bamboo stem to a fixed cutter rather than moving the cutter toward the bamboo. This fixed cutter design ensures that the rotating disc cutter remains fully enclosed, allowing the bamboo stem to be cut only within a protected and confined area.

To implement this concept, a movable metal platform was incorporated into the design. This platform serves two primary functions: positioning the bamboo stem in the cutting-ready position and feeding it into the disc cutter (Fig. 1). Hence, this prototype consists of two major components which were the main chassis and moveable platform. The positioning mechanism consists of a 12V DC motor and rollers that guide the bamboo stem to the cutting position (Fig. 2). The desired cut length can be pre-determined by adjusting the location of the limit switch. Once the bamboo stem reaches the cutting position, the feeding mechanism moves the platform, holding the bamboo securely during cutting. The platform is designed as a jig or holder to fix the bamboo stem in place, restricting all degrees of freedom except for movement along the x-axis (Fig. 3). Two linear rollers beneath the platform support the weight of the raw material while allowing smooth movement along the y-axis.

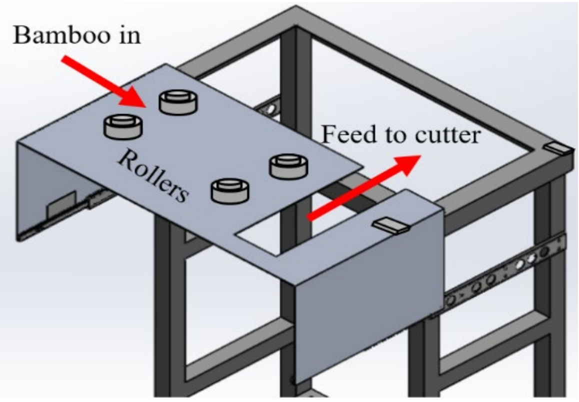


Fig. 1 *Conceptual design model*

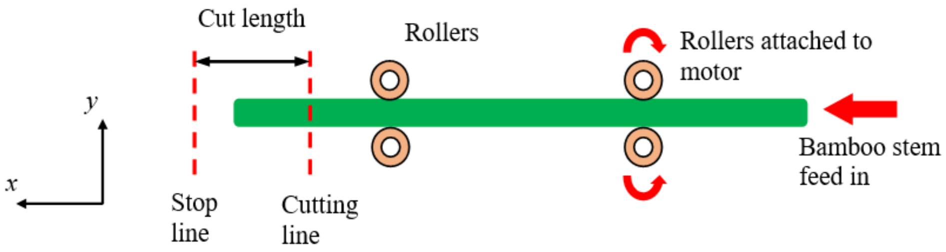


Fig. 2 *Function of positioner*

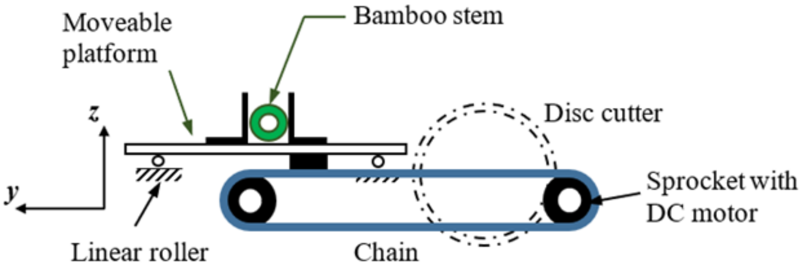


Fig. 3 *Feeding mechanism setup (Front view)*

A 9-inch circular disc cutter (model: MACE Plus MT-CS2000) was used as the cross cutter and securely mounted on a custom-fabricated metal frame bench. The cutter operates on 240 VAC and is activated via a relay connected to a Programmable Logic Controller (PLC). A chain and sprocket system was implemented to drive the movable platform. A high-torque 12 VDC electric motor was selected as the driving mechanism. Motor torque plays a crucial role, as it not only moves the platform but also ensures consistent engagement between the bamboo stem and the disc cutter until the cutting process is complete. The required torque was calculated using Eq. 1:

$$\tau = rF_T \sin\theta \tag{1}$$

where;
r = sprocket radius
F_T = tangential force
θ = angle between sprocket radius and tangential force

Load pulling force or tangential force, F_T could be calculated by determining total weight of movable platform and bamboo stem original length in average. Sprocket radius, r was calculated by multiplying half of number of sprocket teeth, N to sprocket pitch diameter, Ø. This relation is exhibited as in Eq. 2;

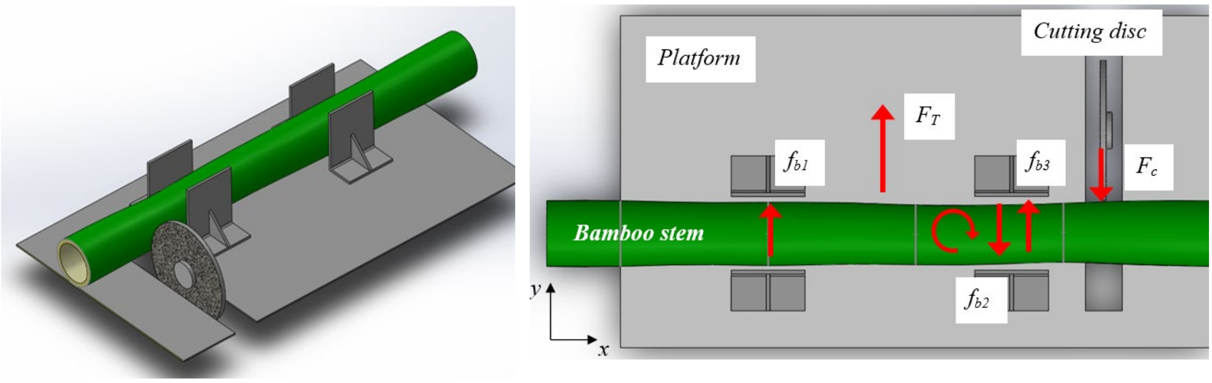
$$r = \frac{\text{Ø}}{2} = \frac{1}{2}\left(\frac{p}{sin\left(\frac{180°}{N}\right)}\right) \tag{2}$$

where;
N = number of teeth
Ø = pitch diameter
p = pitch

2.2 Modelling and Simulation

The movable platform feeder is supported by two roller rails at the bottom plate and is attached to the main frame. These rails allow the platform to move freely along the x-axis. Figure 4(a) illustrates a 3D CAD model of the movable platform with a bamboo stem in place. The design of this platform is crucial to ensuring a smooth cutting process without damaging the machine, the bamboo, or compromising worker safety. To address these concerns, the proposed design underwent Finite Element Analysis (FEA) to evaluate its structural integrity. FEA was used to identify the optimal design by determining critical weak points, stress distribution, deformation areas, and potential shrinkage zones [21-22].

Before conducting the FEA simulation, key system dynamics parameters were identified, analyzed, and predefined [23]. Since the movable feeder is driven by an electric motor, it generates a tangential force, F_T directed toward the disc cutter. When the disc cutter makes contact with the bamboo surface, it produces a contact force F_C in the opposite direction. This interaction creates a moment at the center of the bamboo stem, resulting in a reaction force f_b at the bamboo holders. The most significant reaction forces acting on the holder surface, labeled as fb_1, fb_2, and fb_3, are depicted in Figure 4(b). These forces were used as input parameters for the FEA simulation. The magnitudes of these forces are provided in Table 1. Static structural analysis in Solidwork FEA had been utilized to perform this simulation.



(a) **(b)**

Fig. 4 *3D Moveable platform with bamboo stem in place (a) CAD model; (b) Free body diagram*

Table 1 *Reaction force values*

Simulation no.	f_{b1}	f_{b2}	f_{b3}
1	10 N	5 N	1 N
2	50 N	25 N	10 N
3	80 N	40 N	20 N
4	100 N	50 N	20N

In pre-processing setup, the platform material was set as plain carbon steel, the same material available in the laboratory. The yield strength was set almost 220 MPa and the Poisson's Ratio was 0.28. Mesh size was set to fine with tolerance was approximately 0.91mm. Tetrahedron type mesh was selected with aspect ratio was 19.04. Acting forces on the platform holders were set as exhibited in Table 1.

2.3 System Design

All electromechanical components were mounted on a steel bench structure and controlled using a Programmable Logic Controller (PLC) (Model: OMRON CP2E). PLC was utilized in this project because of its reliability in industrial environment and ability to program and reprogram [24-25]. In this project, there is possibility of extending the process. Hence, it would be better if the program used in the system design is reprogrammable. The block diagram of the developed system is shown in Fig. 5. The process sequence begins with motor-driven rollers pulling the bamboo stem into position for the cutting process. To ensure precise positioning, a limit switch with an adjustable mounting was attached to the structure. Once the bamboo stem reaches the correct position, the movable platform feeds it into a fixed circular cutter, as illustrated in Fig. 6. This sequence was programmed using the PLC's ladder logic diagram in CX-Programmer. After fabricating the prototype structure, all actuation components and the control system were installed. Fig. 7 presents the final assembled prototype.

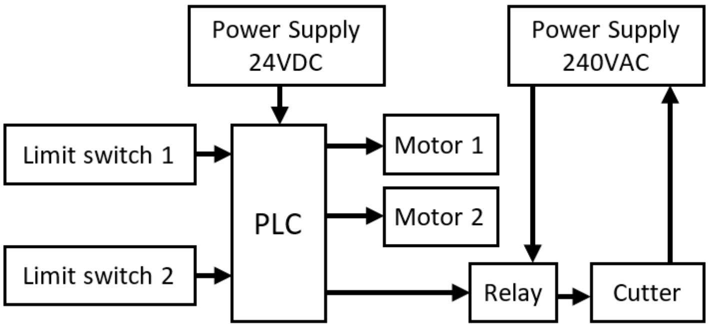


Fig. 5 *System block diagram*

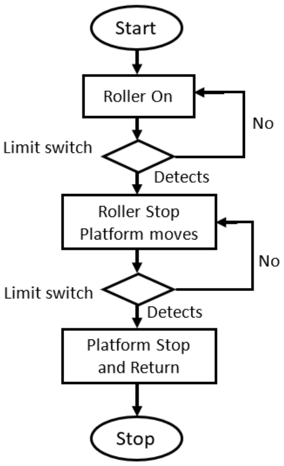


Fig. 6 *Operation flow chart*

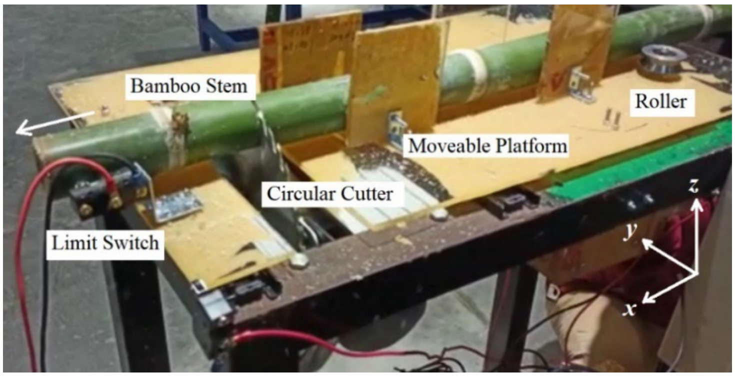


Fig. 7 *Actual system setup*

2.4 System Testing

Two tests were conducted to verify the functionality and production rate of this prototype. Raw bamboo age one-to-two-year age cleaned and pre-cut at 120 cm were obtained from Hangterra Bamboo Sdn. Bhd. for this research. These bamboo stems diameter were at the average range between 5 cm and 6 cm and the thickness was up to 1 cm at middle lower part.

2.4.1 Functionality Test

The primary objective of this test was to evaluate the functionality and performance of the prototype. To conduct the test, bamboo stems were randomly selected and cut into 30 cm segments. The process began with a 120 mm diameter bamboo stem being placed onto the movable platform. Once in position, a sensor detected the bamboo stem, triggering the feeding mechanism. The rollers then pulled the bamboo into the designated cutting position. As soon as the limit switch confirmed that the bamboo had reached the correct position, the cutting machine was activated. Simultaneously, the movable platform fed the bamboo stem into the fixed circular cutter. This sequence was repeated until three bamboo stems had been processed. Throughout the test, the entire operation was closely monitored to identify any malfunctions or irregularities. If any issues arose during the cutting process, the system would halt automatically to prevent damage. Additionally, the system was monitored to ensure that no excessive vibrations or mechanical stress occurred, which could compromise the machine's durability or operator safety. After the test, the movable platform was thoroughly inspected to check for any signs of malfunction, structural damage, or broken components. Final bamboo cuts were measured to observe the cutting accuracy.

2.4.2 Production Rate

The test was conducted to determine number of bamboo that can be cut in certain time. This is because the feeding time and positioning time were fixed. As each bamboo has 120mm pre-cut length, continuous operation might slightly different time to allocate the bamboo stem at the moveable platform. Production rate test was conducted by observing numbers of cut could be achieved in three different cutting period; 1 minute, 2 minutes and 3 minutes. All the data were recorded and analyzed. Once all trials were completed, the collected data was recorded and analyzed to determine the average production rate and identify any potential inefficiencies in the process. The results helped refine operational parameters for optimizing cycle time and improving the overall efficiency of the cutting system.

3. Results

3.1 Structural Analysis

The structural analysis conducted through FEA simulations indicates a direct correlation between the increase in reaction force and the corresponding rise in stress, body displacement, and strain within the platform structure. The simulation results reveal that at a reaction force of 10 N for fb_1, the maximum stress recorded was 9.47×10^5 Nm^{-2}. However, as the reaction force increased to 100 N, the maximum stress escalated significantly to 1.35×10^7 Nm^{-2}. The data presented in Table 2 demonstrates that this increase follows an almost linear trend, with a slight tendency toward logarithmic growth. The critical stress concentration is observed at the sharp edge near the chain holder at the bottom of the platform, specifically adjacent to the fb_1 holder. This region experiences the highest stress accumulation due to its geometric constraints and the localized reaction forces exerted during the cutting process. The stress distribution, as illustrated in Fig. 9, exhibits a consistent pattern across different force inputs, reinforcing the reliability of the simulation results.

During the cutting operation, the movable platform exhibited minimal displacement, indicating that the reaction forces effectively counteracted the applied loads. As the disc cutter made contact with the bamboo surface, it generated a counteracting reaction force that was transmitted across all supporting holders. The cutting force initially surged to a high magnitude due to the structural resistance of the bamboo fibers. However, as the cutter advanced past the middle circular portion of the bamboo stem, the resistance progressively weakened, resulting in a gradual reduction in cutting force. This phenomenon occurs due to the progressive fiber separation, which diminishes the material's ability to resist shear forces as the cutting edge moves through the stem. Furthermore, the FEA simulation results confirm that the current platform design meets structural integrity requirements, ensuring its suitability for implementation under the analyzed conditions. The von Mises stress distribution indicates that the stress induced by the cutting force remains within acceptable limits, thereby validating the platform's ability to withstand operational loads without failure.

Table 2 *Result of stress. displacement and strain*

Simulation no.	*Maximum Stress (N/m^2)*	*Maximum Displacement (mm)*	*Maximum Strain*
1	1.35 x E7	0.352	3.26 x E-5
2	1.09 x E7	0.278	2.61 x E-5
3	6.77 x E6	0.176	1.63 x E-5
4	9.47 x E5	0.031	2.08 x E-6

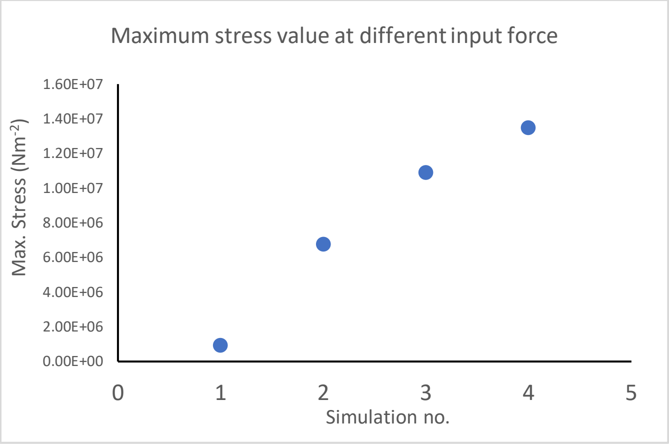
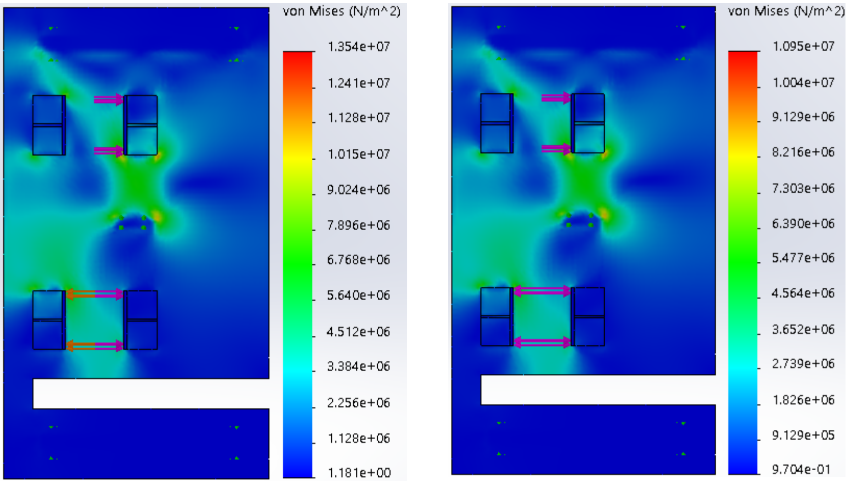
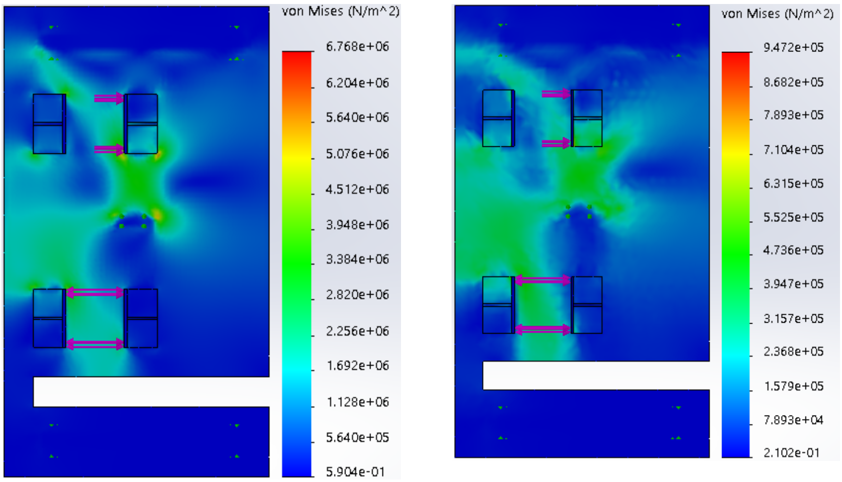


Fig. 8 *Maximum stress at different reaction force value*



100 N – 50 N – 20 N 80 N – 40 N – 20 N



50 N – 25 N – 10 N 10 N – 5 N – 1N

Fig. 9 *Stress distribution mapping in moveable platform*

The presence of stress has the potential to induce deformation in the structure. In the case of a moveable platform, deformation can be analyzed by examining its displacement under applied forces. Each metal possesses a specific yield strength, which determines its ability to withstand stress before transitioning from an elastic to a plastic state. As long as the applied force remains within the yield strength limit, the material retains its elastic properties, allowing it to return to its original shape upon unloading. However, variations in structural geometry and force magnitude influence the overall elasticity response, potentially altering the displacement characteristics.

Fig. 10 illustrates the maximum displacement values corresponding to increasing reaction forces. The displacement results indicate a trend that closely follows the applied stress distribution on the moveable platform. Displacement is not uniform across the structure; instead, it is concentrated at specific regions, particularly along the platform edges, as shown in Fig. 11. Notably, the highest displacement is observed near the cutter slot, suggesting a localized stress concentration. The analysis further reveals that the displacement increases by approximately 14% from the lowest to the highest reaction force magnitude, highlighting the direct correlation between applied force and structural deformation.

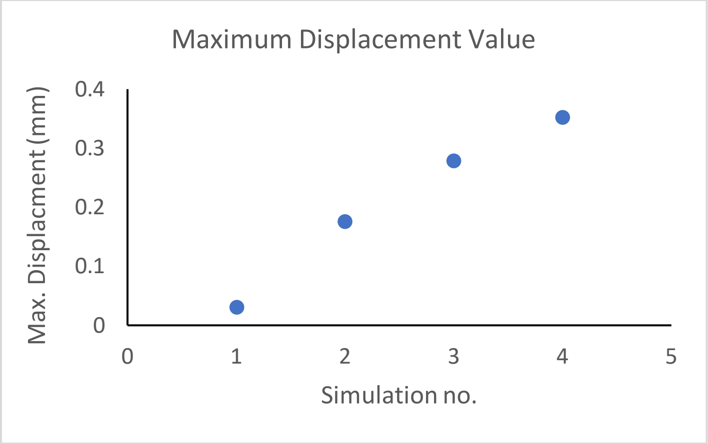


Fig. 10 *Maximum displacement at different reaction force inputs*

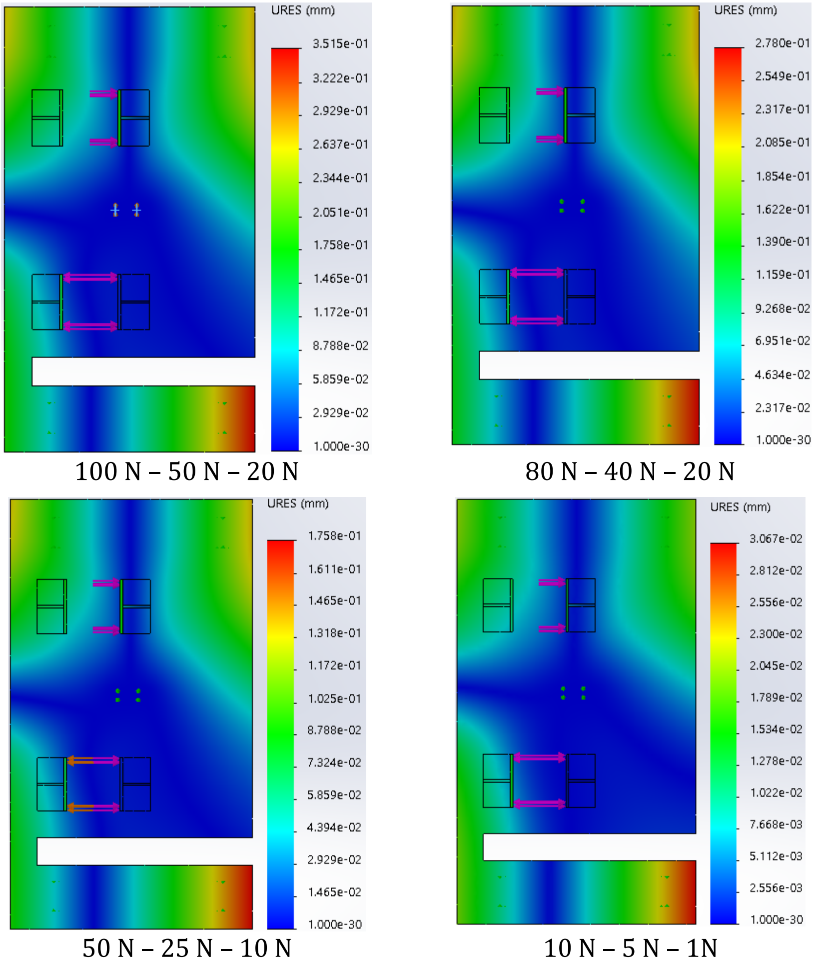


Fig. 11 *Displacement distribution in movable platform*

3.2 Functionality Test

During the functionality test, the installed mechanism operated according to the programmed sequence. All electromechanical components, including the DC motor and limit switches, functioned as expected. The average cutting time was recorded at 3.8 seconds, with a maximum cutting time of 4.2 seconds. Cutting accuracy exhibited variations, with cut lengths ranging between 30 cm and 35 cm. The average cutting gap was measured at 2.3 cm. The variation in cutting length accuracy primarily resulted from instability in the positioning mechanism. Although the gap between the rollers pulling the bamboo stem was adjusted to match the stem's diameter, the inherent straightness of the bamboo affected the pulling force. Additionally, variations in the bamboo's radial roundness and straightness influenced the clamping force, leading to fluctuations in friction and, consequently, positioning accuracy on the moveable platform.

The sensitivity of the limit switches and their mounting configuration were also contributing factors affecting cutting precision. To improve cutting accuracy, it is recommended that the pulling rollers be equipped with a spring mechanism to maintain a consistent clamping force, ensuring precise and stable positioning of the bamboo stem. Fig. 12 presents three samples of cutting results with varying thicknesses, while Fig. 13 illustrates the cut bamboo with length measurements.

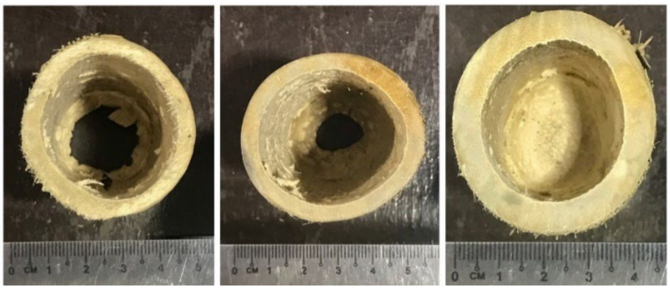


Fig. 12 *Actual system setup*

Fig. 13 *Actual system setup*

3.3 Production Rate

There were three different cutting times were tested. This preliminary part to investigate the trend of automatic cutting in time. The results will be useful to project production rate in different time frame. The cut bamboo length was fixed at 15 cm. In one minute, the prototype managed to cut 16 times. In two minutes, the prototypes cut 31 units of bamboo and 47 units bamboo in three minutes. Testing results showed the production trend increased proportionally to the processing time as exhibits in Fig. 14. Referring to these results, a projection was generated where the linear slope is 15.5. Results obtained in Fig. 14 was also used to calculate bamboo cutting production rate in hour. The production rate shows no significant difference between cutting period. As depicted in Table 3, each minutes has production rate of 960 units, 930 unit and 940 units for 1 minute, 2 minute and 3 minutes cutting period respectively. The average cutting rate was 15.33 cuts per minute or 943.33 cuts per hour. Number of cuts depends on the sequence motion for the mechanism. In this design, there are two motions, positioning bamboo stem when it fed in the system, and secondly feed the bamboo stem for cutting and return. This sequence continues until stop button is pressed. The production rate could be increased if the positioning and feeding motion could be speed up. However, it is vital also for the bench structure to be sturdy and stiff enough to absorb any vibration because of the motor activation.

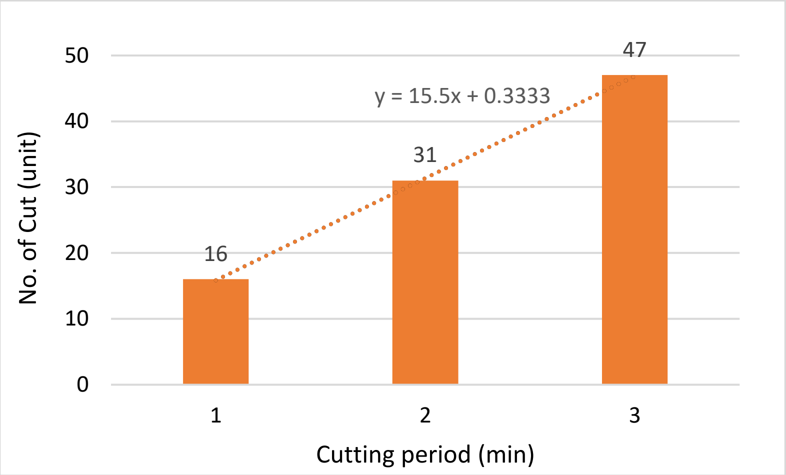


Fig. 14 *Cutting performance (in minute)*

Table 3 *Bamboo stem cutting rate*

Cutting period (min)	No. of cut (unit)	Cutting Rate (unit/hour)
1	16	960
2	31	930
3	47	940

4. Conclusion

Two tests were conducted in this research to observe the functionality and production rate of the developed prototype. Functionality test result shows that the prototype system works as the designed in the programme. The average cutting offset was 2.33 cm and the cutting accuracy lied between 30 cm and 35 cm. Cutting accuracy results can be improved, by altering the bamboo stem positioning mechanism design. Losing grip at the roller during positioning the bamboo stem can be improved by applying tensioner. In the second test, the achieved cutting rate was 15.33 cuts per minute. There were no significant changes in cutting rate as the cutting period changes.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Fakrul Nur Aiman Raman, Muhammad Farid Shaari;* ***data collection:*** *Fakrul Nur Aiman, Mohd Fathee Razali;* ***analysis and interpretation of results:*** *Mohd Nazrul Roslan, Khairu Kamaruddin, Norhazaedawati Baharuddin;* ***draft manuscript preparation:*** *, Fakrul Nur Aiman Raman, Muhammad Farid Shaari. All authors reviewed the results and approved the final version of the manuscript.*

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