Development of a Machine for Cleaning the Core of Grass Straws

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ABSTRACT

Nowadays, plastic waste is one of the most pressing issues, especially in developing countries. Plastic waste comes from everyday products such as plastic food boxes, plastic bottles, disposable products, or plastc straws causing negative effects on the environment. On the other hand, grass straws are eco-friendly and safe and can be easily found in Southeast Asian countries such as Vietnam, Indonesia, and Malaysia. However, the process of grass straw production is implemented manually, resulting in low productivity and unsafe labor conditions. Among the stages of producing grass straws, cleaning the core of the straw is the most important because it determines its quality. Aiming to automate the grass straw production process, this paper introduces the first grass straw core cleaning machine in the world.

Keywords-design; prototype; machine; drinking straw; phragmites australis

I. INTRODUCTION

Products made from plastic are widely popular worldwide due to their ease of production and low cost. Plastic items are convenient, but they leave us with an overwhelming amount of plastic waste that is challenging to handle [1-3]. Global plastic production has increased to 400 million tons at the beginning of the year, while the lifespan of plastic products is about 10 years but it may take 500 years for them to decompose [4, 5]. According to the United Nations Environment Programme (UNEP), the annual global plastic waste discharged into oceans, seas, rivers, and lakes ranges from approximately 19 to 23 million tones [6]. Plastic waste from the food industry contributes some of that, coming from packaging and short-lived disposable items. The majority of plastic waste leaked into the environment is macroplastic, typically beverage bottles and small pieces of plastic coming from everyday utensils or packaging [7]. Plastic straws, an everyday use item, also contribute significantly to this issue. From the waste collected on the coastlines of the United States over a period of 5 years, there were up to 7.5 million plastic straws found littering the shores [8]. The abundance of plastic waste in the seas and oceans poses a significant threat to the organisms inhabiting those areas, as they are prone to ingesting harmful plastic particles [6], leading to ecological imbalances in the region [9].

There are many types of straws made from natural materials that do not harm the environment such as paper straws [10] or straws made from rice flour [11]. Paper is a biological product made from wood pulp and recently there have been studies using dry straws as a raw material for paper production [12], so paper straws are considered environmentally friendly. Paper straws are made by cutting paper rolls into strips, then rolling around the core to form the cylindrical shape of the straw. Optionally, straws can be crimped or folded to achieve specific designs. Paper straws are not really safe for the environment because glue is used to fix the pieces of paper, and this glue is not completely made from biological materials. Besides, the cost of the paper straw production line is quite high due to the need for mechanisms to roll paper into straw shapes at high speed and the presence of many other complex mechanisms. Straws made from rice flour are made by mixing glutinous rice flour with water which re put into molds to shape and are then dried [10, 13]. Today, consumers prefer products derived from the nature [14]. That is an opportunity for straws made from biomaterials to gradually replace plastic straws made from synthetic fibers.

Fig. 1. Grass straws.

Grass straws as shown in Figure 1, possess a comprehensive set of characteristics. They are environmentally friendly, are no danger to consumer's health and have a low production cost. The material used in the fabrication of these straws is derived from the stems of phragmites australis [15] and lepironia [16], constituting a low-cost and readily available source, particularly in Southeast Asian countries such as Indonesia, Malaysia, and Vietnam. Phragmites australis and lepironia arew chosen as the input primary materials due to their highly suitable characteristics such as their stem structures that possess sufficient rigidity [17, 18]. However, the production process of grass straws currently has low productivity due to the lack of specialized equipment [19]. Phragmites australis and lepironia, after harvesting, undergo initial processing by removing leaves and roots. Subsequently, they are segmented and cleaned to extract the core of the stems. Finally, they are subjected to drying, sterilization, and transformed into finished grass straws. Most of these stages are manually implemented using rudimentary tools, posing potential risks to laborers involved in the production process. With the goal of automating the grass straw production process, this paper introduces a machine for the cleaning of the core of the grass stem because this step mainly determines the quality of the finished grass straws.

II. METHODOLOGY

A. Principle of Straw's Core Cleaning Machine

The phragmites australis (Figure 2) are harvested from September to December. Its stem is stiff, with a diameter of about 8–10 mm, lying horizontally in the mud. Its upright stems are approximately 1.0 m tall, with horizontal nodes. In Vietnam, cogon grass typically grows in saline-alkaline flooded areas such as in Dong Thap and Ha Tien. Phragmites australis has natural growth characteristics such as high rigidity and especially its core is suitable for making straws. To become a workpiece for the proposed machine, the stem of phragmites australis needs to be cut into segments of 200 mm in length.

Based on shape of the workpiece, the detailed process of the straw core cleaning is described as Figure 3. It consists of 4 stages. Firstly, the workpiece is fed into the jig and is fixed by a clamping mechanism. After that, the drilling tool will remove the core of the workpiece to obtain the straws. The overall principle of the proposed machine is shown in Figure 3.

Fig. 2. Phragmites australis.

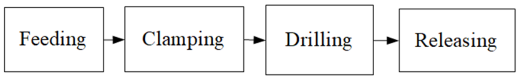


Fig. 3. Working process.

B. Dynamic Analysis of the Feeding Module

The cylindrical stem of phragmites australis is cut into segments of 200 mm in length which leads to the natural equilibrium state being a horizontal position. Borrowing the weight of the workpiece, this research came up with the idea of an inclined chute, as shown in Figure 4. The workpiece will slide along the guide chute and be stopped by a divider plate. The dividers will open and close sequentially to drop each straw onto the jig. Moreover, when the straws are lowered into the chute, there may be a situation where two or more straws simultaneously drop, leading to blockages in the pathway. Therefore, an anti-jamming mechanism as shown in Figure 5 is needed.

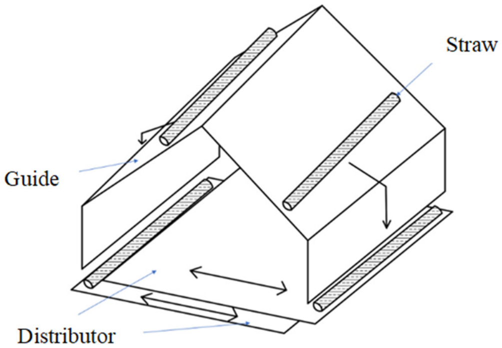


Fig. 4. Inclined chute for workpiece feeding.

When the workpiece is provided into the feeding module, it will slide along the guide channel and be stopped by the divider. The triangle plate on the two parallel axes will continuously rotate to evenly distribute the workpieces and prevent them from jamming and overlapping. The motion of feeding module is driven by a stepper motor through a toothed belt transmission. The initial tension force on the belt needs to be sufficient to eliminate the gap between the pulley and the belt, and to prevent slipping phenomenon. The initial tension force is expressed in (1):

$$Fo = (1.1 - 1.3) * F_v = (1.1 - 1.3) * q_m * \mathrm{b} * v^2 \quad (1)$$

where F_v is the centrifugal force, q_m is the weight of the 1 m belt, q_m = 19 g/m, v is the velocity of the pulley, $v = \frac{\pi d1n1}{60000} = \frac{\pi * 31{,}83 * 50}{60000}$ = 0.083 m/s, and b is the width of the belt, obtaining: $\mathrm{F_0} = 1.2 * 19 * 6 * 0.083^2 = 0.94$ N. The force acting on the shaft of the blade as determined by:

$$\mathrm{F_{r1} = F_{r2} = F_0.\ sin\ \frac{180}{2} = 0.94\ N} \quad (2)$$

where α = 180° is angle of the belt. The required force to push the straw is defined by:

$$F_{r1} = 5.\mathrm{m.g.cos}\alpha_1 = 5 * 0.01 * 9.8\cos 45° = 0.35\ \mathrm{N} \quad (3)$$

where α_1 = 45° is the inclined angle of the guide plate. The required moment on the blade's shaft is:

$$\mathrm{M = F_đ.d + F_{r1}.Rp + F_{r2}.R_p = 0.042\ Nm} \quad (4)$$

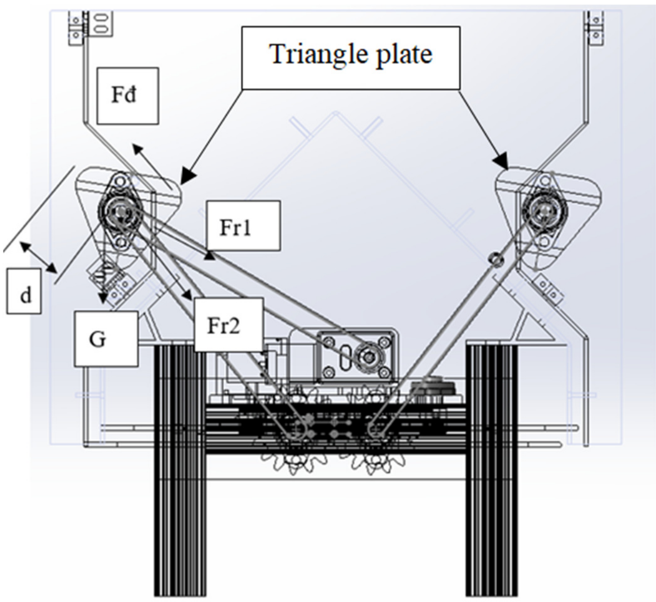


Fig. 5. Diagram of feeding module.

C. *Dynamic Analysis of Clamping and Drilling Module*

The clamping module consists of 4 pairs of grooved pulleys with non-slip rubber lining to clamp the straw as presented in Figure 6. The pairs of the pulleys are interconnected and operate in opening and closing motions. The drilling tools are attached to the DC motors for sequential in-and-out motion, guided by two rails for the two working lines.

The clamping force is generated by two pairs of linear springs at both sides of the pulleys as shown in Figure 7. Its value depends on the stiffness of the spring and is defined experimentally. This paper investigated 6 types of springs with stiffness values of 73, 81, 200, 1000, 1500, 3000 N/m, as shown in Figure 8.

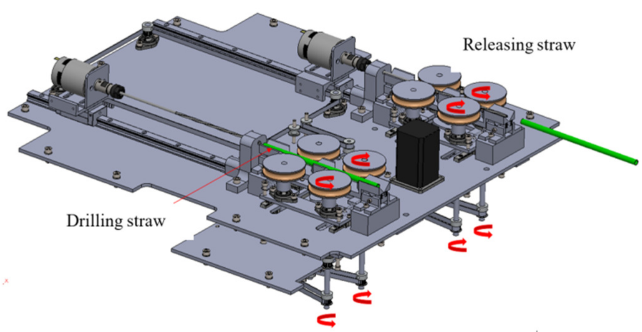


Fig. 6. Diagram of the clamping and drilling module.

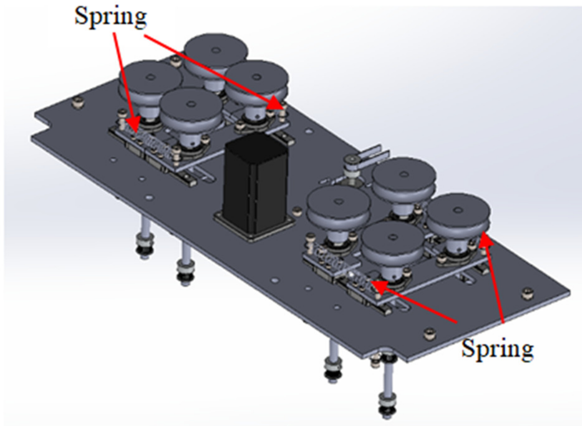


Fig. 7. Linear spring.

Fig. 8. Linear spring with various stiffness.

To determine the effect of the spring's stiffness on the clamping force, an experiment is set up as shown in Figure 9. The loadcell will be placed in the middle of the two pulleys. The force data are collected by an Arduino Uno board and are displayed in Microsoft Excel.

Two types of rubber linings were used to wrap the pulleys which consist of nitrile and silicone rubber as shown in Figure 10. The experiment results are presented in Figure 11. It can be seen that with silicone rubber, the generated clamping force is bigger than the one created with nitrile rubber. When the stiffness of the spring is bigger than 3000 N/m, the workpiece breaks, as shown in Figure 12. As a result, this research selected the silicone rubber to wrap the pulleys and the stiffness of the spring was chosen as 1000N/m for fabrication.

Fig. 9. Experimental set up.

(a)

(b)

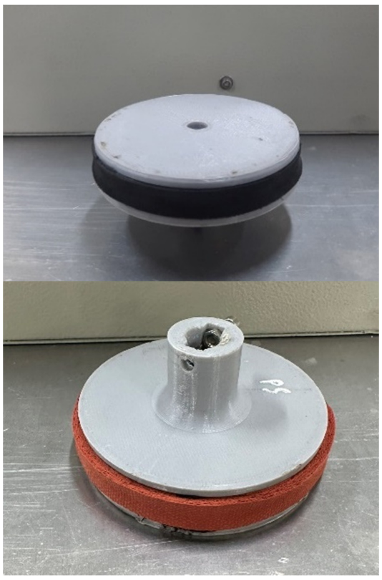


Fig. 10. Rubber linings: (a) nitrile rubber, (b) silicone rubber.

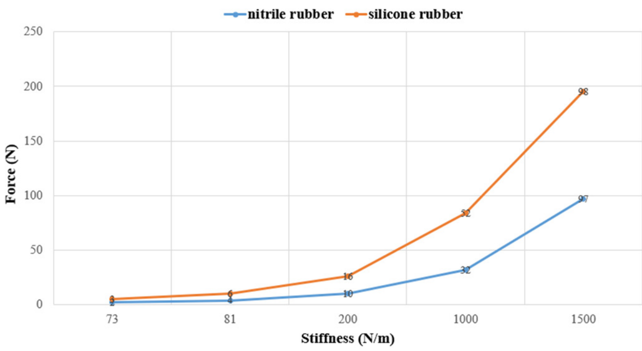


Fig. 11. Force depending on the stiffness of the spring.

D. *Machine's Frame System Design*

The machine frame serves as the standardized assembly unit for mounting various components, necessitating high rigidity during operation due to the precision requirement in the process of drilling the workpiece. The specific technical requirements are that the maximum stress in the working process is less than the yield stress of the material and the maximum displacement is smaller than 0.1 mm. Additionally, the machine frame should be compact in size and lightweight for easy transportation and assembly. In accordance with the requirement of integrating four modules, the machine frame was designed with dimensions of 970×550×510 mm.

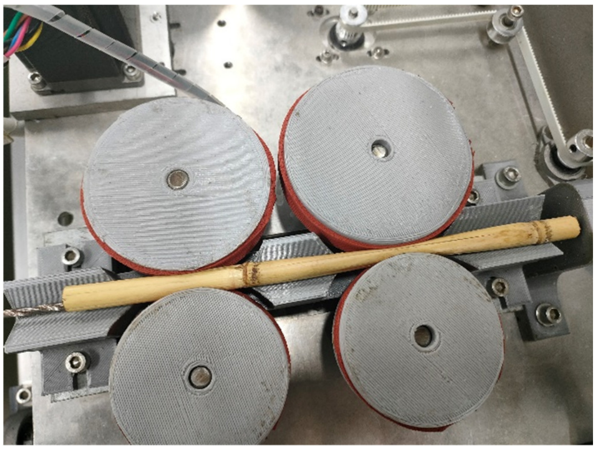


Fig. 12. Experiment with broken straw at stiffness of 3000 N/m.

To evaluate the strength of the frame structure prior to fabrication, using simulation tool is the best choice that helps reduce manufacturing cost and time saving [20, 21]. This paper estimates the performance of the frame structure based on two criteria, stress and displacement. The simulation is implemented in SolidWorks as shown in Figure 13. The used CPU is AMD Ryzen 9 3900X (3.8 GHz, 70 MB cache, 12 cores 24 threads), with 64 GB Ram Corsair Vengeance 3200 MHz. The material chosen for the machine frame is shaped aluminum with a density of 2.7 g/cm³. The external force acting on the frame consists of the self weight of the proposed machine and straws' weight which equals 54 kg. This research applied a safety factor of 1.6 for the most dangerous situation, equal to 86.4 kg.

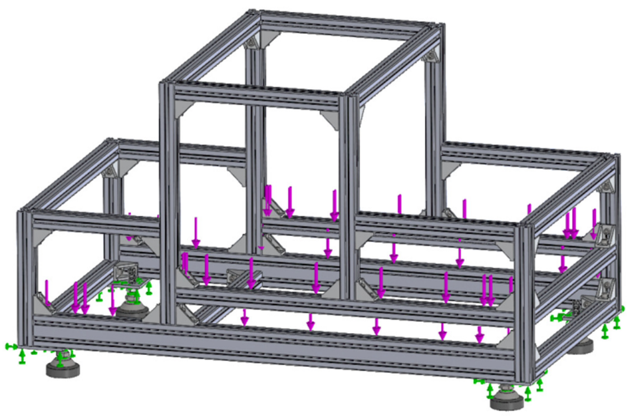


Fig. 13. Simulation in SolidWorks.

Based on the simulation results shown in Figures 14 and 15, the stress analysis confirms the frame's strength, with the highest stress recorded at 2.58 MPa, far below the yield strength of 95 MPa, ensuring the machine's durability. The maximum observed displacement is 0.07 mm and the maximum strain is 1.38×10^{-4}, indicating negligible movement. These findings demonstrate that the frame's structure meets the technical requirements effectively.

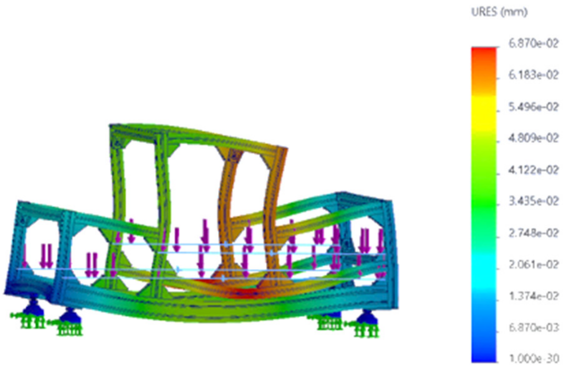


Fig. 14. Displacement simulation results.

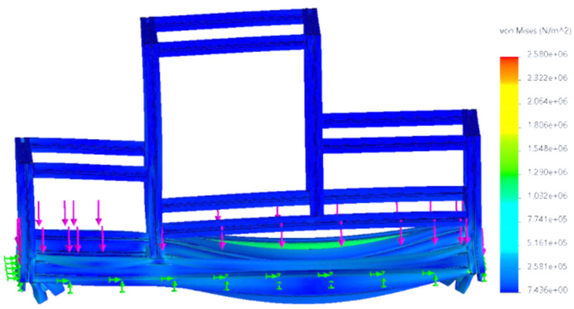


Fig. 15. Stress results.

III. FABRICATION OF THE STRAW CORE CLEANING MACHINE

A. *Design of the Control System*

Originating from the technological process of manufacturing straws and the designed working modules, a control system was planned as shown in Figure 16. The electrical control system comprises a Mitsubishi FX3U 32MT PLC controller, which controls 4 stepper motors through 4 drivers and 4 DC motors through intermediate relays. Additionally, two DC 775 motors are speed-controlled through a pressure-reducing circuit.

B. *Structure of the Machine*

The fabricated straw core cleaning machine is illustrated in Figure 17. The machine has dimensions of 970 mm (length) × 550 mm (width) × 510 mm (height). It weighs 52 kg and achieves 15 products in one minute. The diameter and length of the workpiece are 9±1 mm and 150÷200 mm, respectively. The produced grass straws meet the quality criteria when their core is removed entirely. The machine was tested and could produce grass straws with a completely cleaned core. The operation process of the straw's core cleaning machine is depicted in Figure 18.

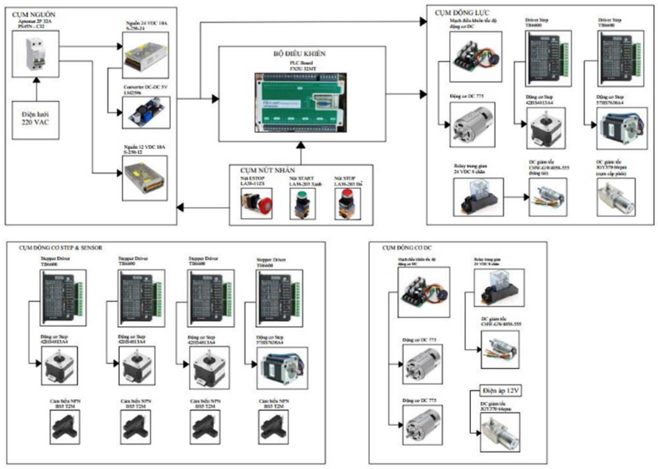


Fig. 16. Diagram of the control system.

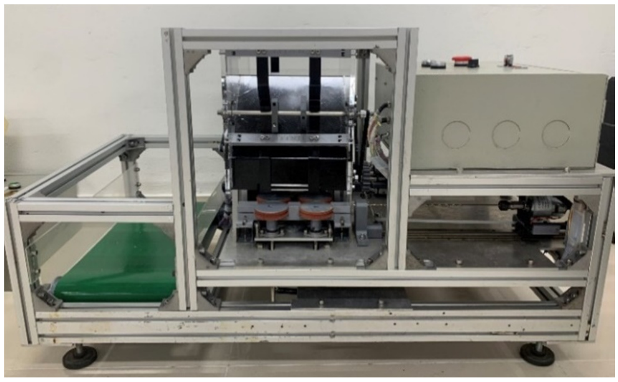
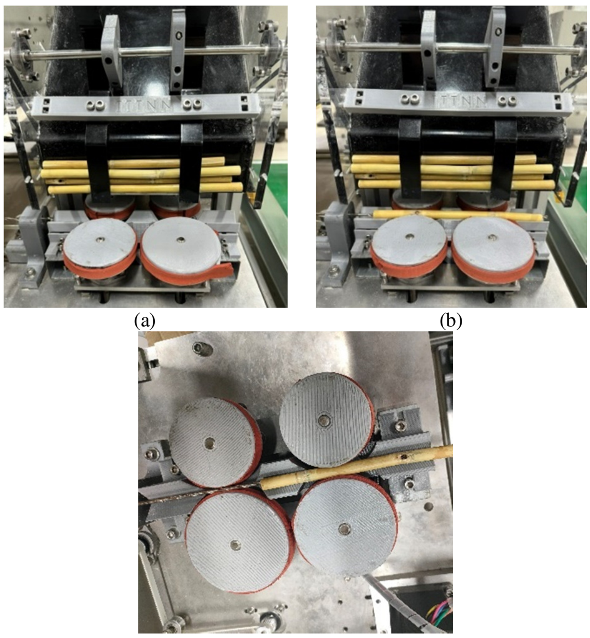


Fig. 17. The fabricated straw core cleaning machine.



(a) (b) (c)

Fig. 18. Working process of the core cleaning machine: (a) Feeding, (b) clamping, (c) drilling.

IV. CONCLUSION

This article presents the world's first grass straw core cleaning machine. The design of the proposed machine is modularized to easily repair, assemble, and upgrade. There are four main modules of the machine: feeding, clamping, drilling, and releasing. The machine can work effectively with a workpiece with a diameter of 9.0±1.0 mm and a length ranging from 150 to 200 mm. Its productivity is 15 products per minute, which is three times as much as the rate of the manual production.

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