PRINCIPLE AND MAIN PARAMETERS OF A HAND-HELD PINEAPPLE LEAF-TYING MACHINE

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Lịch sử bài báo

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ABSTRACT:

Due to the climatic characteristics of northern Vietnam, seasonal boundaries are sometimes unclear. When temperatures shift early from cold to warm conditions, pineapple plants tend to flower and set fruit prematurely, resulting in substandard fruit quality. To address this issue, pineapple growers apply a practice of tying pineapple leaves and crowns to inhibit early flowering, thereby maintaining vegetative growth until the main season, when plants reach the appropriate stage for flower induction. This practice contributes to increased yield, improved fruit quality, and enhanced production scheduling. At present, the tying of pineapple leaves and crowns is performed manually, which is labor-intensive and results in low productivity. To improve operational efficiency, the development of a suitable tying device is necessary. This paper presents the research results, calculations, and design of a handheld pineapple leaf-tying device. The device consists of two main components: a crown gripping unit and a wire-tying unit using a stapling mechanism. The crown gripping mechanism simultaneously performs two functions—gripping the crown and pulling it into the tying space. The wire-tying unit is driven by a cam–slider mechanism, which enables the generation of a large pressing force required for staple fastening while maintaining low power consumption.The shoot clamping mechanism performs two functions simultaneously: clamping the shoot and pulling it into the tying space. The strapping mechanism is driven by a sliding cam mechanism, aiming for low power consumption while still generating high clamping force for stapling. The stapling process's drive mechanism was simulated to determine the rotation angle of the stapling arm at approximately 45° and the required driving torque of the arm $M_{max} = 1.085$ N_m. *The power of the electric motor driving the arm is* $N_{dc} = 5$ *W.*

Keyword: *pineapple leaf tying machine; strapping mechanism; shoot clamp mechanism; staple-type tying mechanism.*

I. INTRODUCTION

Currently, pineapple is one of Vietnam's key export fruit and vegetable products and is being prioritized for expansion in many regions.

In Vietnam, pineapple is grown throughout the country from North to South and is a fruit tree with a large area after banana (147,799 ha), mango (111,582 ha), durian (71,282 ha) and dragon fruit (65,243 ha) [1]. With an area of about 45,997 ha in 2021, pineapple production reached about 737.3 thousand tons, an increase of 25.3 thousand tons compared to 2020 [2]. In general, the area of pineapple cultivation tends to increase. Compared to 2013 when the pineapple area was about 40,000 ha with a production of about 500,000 tons, the area in 2021 increased by 15% and the production increased by 47%. Thus, pineapple cultivation has not only increased but production has also increased.

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Figure 1. Technique for bundling pineapple plants to induce off-season flowering and fruiting.

Due to the climatic characteristics of Northern Vietnam, when the weather changes from the cold season to the warm season, pineapple plants often bear fruit early, so the fruit quality is not satisfactory. To overcome this, farmers use the method of tying pineapple leaves and shoots to prevent early fruiting, and at the same time can handle off-season [3] (Figure 1). This process is currently done entirely manually, with low productivity and a lot of labor. Therefore, to improve the efficiency of pineapple cultivation, it is necessary to research, design and manufacture an automatic pineapple leaf tying device suitable for production in Vietnam.

This paper presents the research results on an automatic pineapple leaf-tying machine, including the proposed principle and structure, and the determination of the machine's main parameters, as a basis for manufacturing and application in production to improve labor productivity.

II. RESEARCH METHODS

- Using information gathering and expert methods to analyze, compare, and select appropriate binding mechanism principles based on existing research results from both domestic and international sources;

- Using 3D and 2D design software Autodesk Inventor to calculate and design the binding mechanism;

- Using the Dynamic Simulation module for multiple rigid bodies in simulating the dynamics of the stapling and binding process;

- Agricultural machinery testing method.

III. RESULTS AND DISCUSSION

3.1. Analysis and evaluation of pineapple tying machine design selection

a) Pineapple leaf tying process

Currently, tying pineapple leaves is done manually. Due to the wide dispersal of pineapple leaves, before tying, workers use their hands to gather and hold the leaves together, then use string to tie the leaves and the tip. Depending on different stages, the diameter of the tied pineapple tip can vary from 50-80 mm.

Therefore, to mechanize the tying process, the following steps need to be taken:

- Gather and clamp the pineapple leaves and shoots together to form a compact bundle of suitable diameter, depending on the plant's growth.

- Feed the string and create the knot.

These steps can be performed separately or simultaneously.

Therefore, the pineapple leaf tying device must have two main parts:

- The part that gathers and clamps the pineapple leaves into a compact bundle (referred to as the clamping part);

- The part that feeds the string and creates the knot (referred to as the tying part).

Based on the above analysis, the overall principle of the machine is proposed as shown in Figure 2. This is a highly automated system, and one that does not yet exist in practice. Further research into the principles and operating parameters is needed before design and manufacturing.

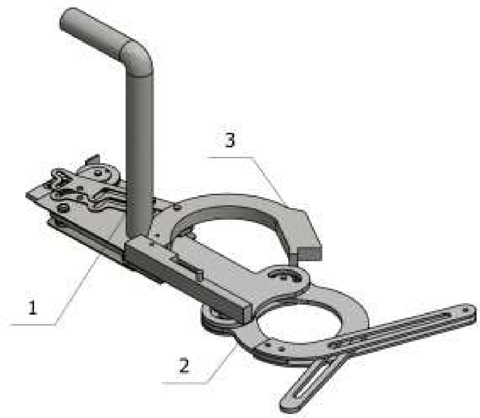


Figure 2. Overall construction of the pineapple leaf tying machine.
1. Support bracket, handle; 2. Clamping mechanism; 3. Tying mechanism

To select a suitable tying mechanism for the handheld tying machine, we will evaluate the advantages and disadvantages of several common tying mechanisms currently on the market.

b) Pineapple leaf tying mechanism.

* Heat sealing tying device:

Vegetable bundling machine;

Figure 3. Heat-sealed vegetable bundling machine

Features:

- Uses ribbon-type plastic cord;

- Connections are made using heat sealing;

- The cord guide frame is a fixed closed loop. Not suitable for bundling pandan leaves.

- The machine is heavy (30 kg) and not suitable for handheld use.

* The cord tying device creates knots.

Figure 4. Knot-tying machine for vegetables

Features:

- The tying device uses a complex knot-tying mechanism [4,5];

- Operates statically;

- Large weight, unsuitable for hand tools.

* Twisting knot making device [7,8].

The knot is created by twisting steel wire or plastic-coated steel wire. For tying tree trunks, plastic-coated twisted steel wire is commonly used. The advantage of this principle is its simple mechanism. The disadvantage is that the wire has a small cross-section, and when tightened around the pineapple leaf, it can easily damage the pineapple leaf.

* Stapler-type tying device [6]

A hand-held plant tying device (Tape tool) is a gardening tool used to staple tape onto branches, used to staple strings onto tomatoes, grapes, potatoes, etc., used in combination with staples and rolls of plastic ribbon.

Figure 5. Handheld Tapetool

This is a lightweight tool, weighing only about 250g, suitable for application in the design of handheld or shoulder-mounted machines. This project will use this principle for the design of a pineapple leaf tying machine.

c) Pineapple Leaf Clamping Mechanism.

This is a completely new approach in principle and involves two stages:

- Gathering and clamping the pineapple leaves into a bundle;

- Moving the clamped bundle relative to the tying mechanism into the tying space to perform the tying.

The above steps can be performed by two separate mechanisms and motors. However, from the perspective of the requirements for a lightweight, compact handheld machine, a lightweight mechanism and a motor are needed to perform both steps.

The sliding clamp mechanism is designed as shown in Figure 6.

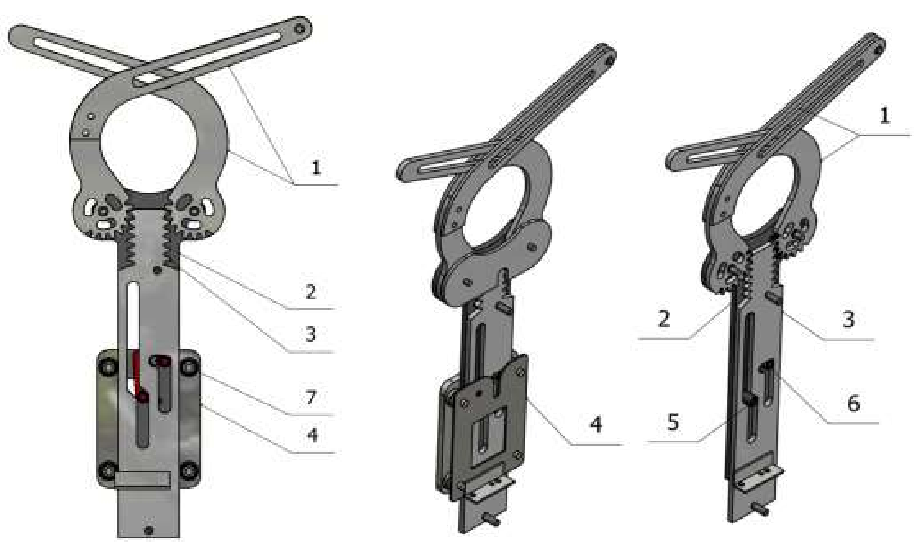
This mechanism performs the following operations in sequence:

- Clamping the pineapple leaves in a circular space similar to a hand-operated clamp;

- Pulling the clamp into the binding space;

- Performing the above two steps in reverse to release the plant after binding.

Figure 6 shows the pineapple top clamping and pulling mechanism, which includes a clamping arm 1, attached to a rod 2 via a revolute joint; a driving 3; and a support 4. The clamping arm 1 and the clamping arm are connected to the support by a prismatic joint via rollers 7. This mechanism performs two consecutive tasks: clamping the pineapple top and then pulling it into the binding space by 1 motor through a mechanism with locking pins.



a) b) c)

Figure 6. Design of the clamping assembly.

1. Clamp; 2. Clamp attachment bar; 3. Drive rack; 4. Support bracket;

5. Connecting pin between the clamp attachment bar and the support bracket;

6. Connecting pin between the clamp attachment bar and the drive rack.

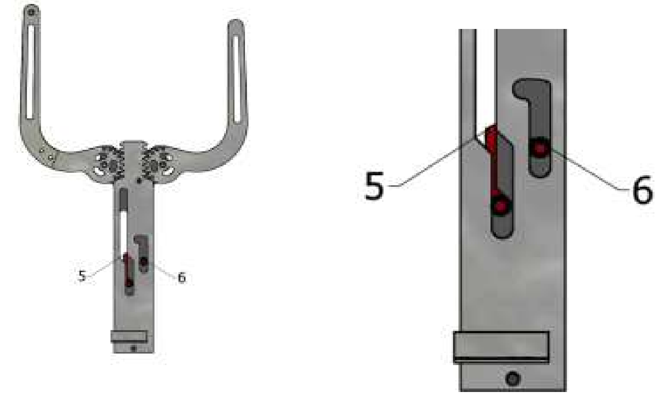


Figure 7. Position of the locking pin for the clamping arm and support.

Initially, the clamping arm is held stationary with support 4 via locking pin 5. One end of pin 5 (figure 7) is connected to the support, while the other end is in the locking slot 4 of the clamping arm. When the rack 3 moves downwards, the rack-gear linkage rotates the clamping arm, gathering and squeezing the pineapple top. This process ends when the locking pin 5 contacts the inclined groove 2 of the rack.

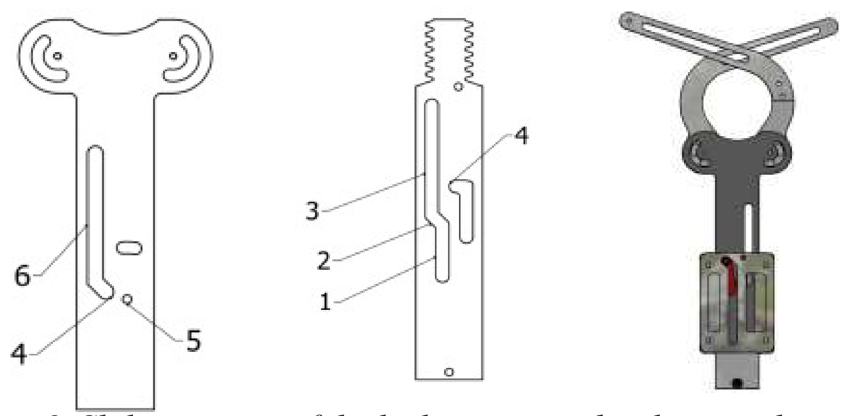


Figure 8. Sliding groove of the locking pin on the clamping bar, rack, and pin release plate.
a) Clamping bar; b) Rack; c) Pin release plate.

At this point, the inclined groove 2 of the rack and the inclined groove of the clamping bar will move together through pin 5. Simultaneously, the inclined groove of the pin release plate will push pin 6 into the locking slot 4 of the rack (Figure 8), creating a connection between the rack and the clamping bar. At this point, these two bars will move together without the need for the inclined groove base and will bring the binding mechanism into the clamped area to tie the rope. The process of releasing the tree is similar in the reverse direction of the two processes above.

3.2. Calculation main parameters of a hand-held pineapple leaf-tying machine

a) The travel and traction of the rack of the clamping mechanism

The travel *l* of the rack includes the travel to rotate the clamp *l1* and the travel to pull the pineapple tip clamp l2 into the tying position.

The travel *l1* will rotate the clamp as designed at 700 with the gear pitch radius re=22,5 mm calculated using the formula:

$$l = \frac{70}{180}.\pi.r_e = \frac{70}{180} \times 3{,}14 \times 22{,}5 = 27{,}5\ mm \quad (1)$$

(1)

The l2 travel distance will need to be larger than the diameter of the pineapple bundle, which is designed to be 80 mm

Thus, the stroke length l > 27.5 + 80 = 117,5 mm. We choose l = 125 mm.

The required pulling force of the rack to grip the pineapple leaf is calculated using the formula:

$$F_T = \frac{2.F_k.h}{r_e} \quad (2)$$

Where Fk is the clamping force on the pineapple leaf, Fk = 15 N; h – the distance from the center of the pineapple top to the line connecting the centers of rotation of the two clamps. According to the design, h = 60 mm. Thus

$$F_T = \frac{2.F_k.h}{r_e} = \frac{2\times15\times60}{22{,}5} = 80\ N \quad (3)$$

The power of the motor pulling the rack during a stroke of T=1s is

$$N_T = \frac{F_T.l}{T} = \frac{80\times0{,}125}{1} = 10\ W \quad (4)$$

We choose NT = 15 W for the motor driving the rack.

b) Calculation the driving torque of crank handle of Stapler strapping mechanism.

As mentioned above, the stapler strapping mechanism is very common on the market; however, when designing the machine, some parts need to be modified to suit the machine's control. In commercially available devices, the wire feeding and stapling mechanism is manually controlled. The knot formation is done in two stages: Stage 1: the stapling bar 5 is pushed towards the stapling unit; Stage 2: the staple is pressed to create the knot. In stage 1, the torque acting on the crank 2 only needs to overcome the spring force; in stage 2, it is necessary to overcome the stapling resistance force.

A necessary requirement is to generate a sufficiently large stapling force to create the knot. Measurements have determined the stapling force to be approximately 100 N at the final stroke of 8 mm. In order to select a suitable structure with low motor power for a shoulder-mounted device, this section will design a mechanism that generates high clamping force despite low power consumption.

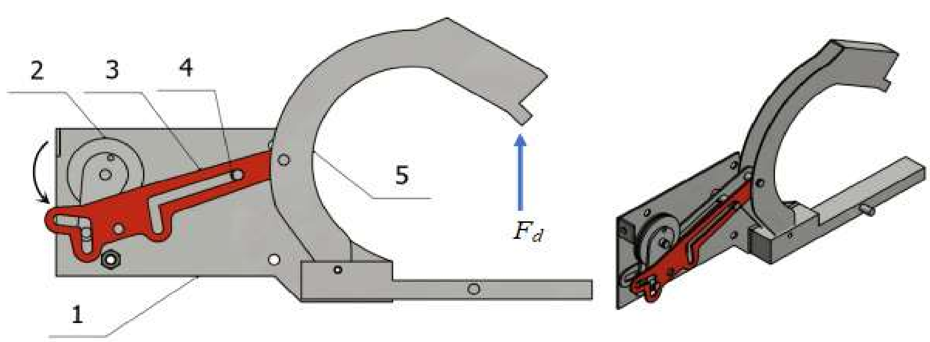


Figure 9. Stapler strapping mechanism.
1. Base; 2. Crank handle; 3. Connecting rod; 4. Fixing pin; 5. Stapler arm.

The stapler strapping mechanism is shown in Figure 7. The stapler arm 5 is controlled by the movement of the crank handle 2, via the connecting rod 3. The simplest way to control the clamping force is by changing the speed of the crank handle using a sliding cam mechanism. In stage 1, the fixing pin 4 slides along the longitudinal groove, while the crank handle's pivot pin 2 slides along the transverse groove. With a suitable angle of inclination of the transverse groove, the speed of the stapler arm can be adjusted to be faster or slower. In stage 2, the fixing pin 4 slides in the transverse groove, and the crank handle's pin slides in the longitudinal groove.

Using Autodesk Inventor's Dynamic Simulation program, the rotation angle of the stapler arm 5 and the required actuating torque of the crank arm 2 were simulated.

The simulation process was divided into two stages.

- Stage 1: The external force acting on the stapler arm 5 is a spring force with a stiffness of 1 N/mm; Stapling force Fd = 0;

- Stage 2: The external force acting on the stapler arm 5 is a spring force with a stiffness of 1 N/mm; Stapling force Fd = 100 N;

The simulation was performed with friction at the rotating joints with a friction coefficient f = 0.3.

The simulation results determining the actuating torque of the crank arm 2 and the rotation angle of the stapler arm are shown in Figure 10. The simulation results show that stage 1 ends when the rotation angle of the crank arm 2 φ1 is approximately 970, and stage 2 ends when φ1 = 1450. The driving torque in stage 1 is quite small because it only has to overcome the spring resistance. Meanwhile, the driving torque of crank 2 is much larger in stage 2 when the resistance force Fd = 100 N. The maximum resistance torque in this stage is 1085 Nmm.

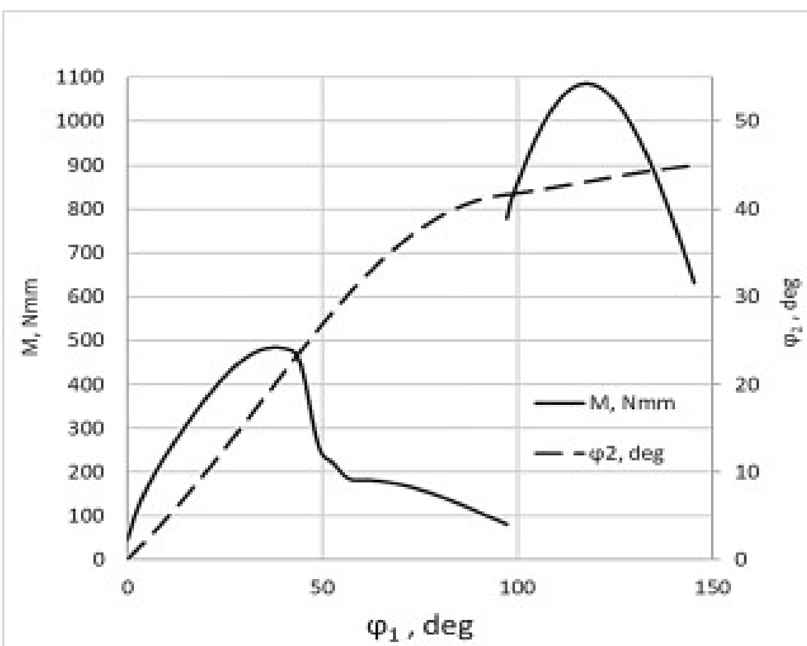


Figure 10. Kinematic simulation results of the staple binding mechanism.

Regarding the rotation angle of the stapler arm, in stage 1, the rotation angle of the stapler arm 5 increases rapidly (high rotation speed) and reaches a value of φ2 = 420 at the end of the phase. Meanwhile, the rotation speed in stage 2 is much lower, and the maximum rotation angle of the stapler arm at the end of phase 2 is φ2 = 450. This is advantageous for increasing the staple pressing force without requiring an excessively large driving torque of the crank arm 2. The maximum driving torque of the crank arm is Mmax = 1.085 Nm.

IV. CONCLUSION

1. Based on the analysis of the pineapple vine tying process used by farmers, a tying machine structure consisting of two parts has been selected: a vine gathering and clamping unit and a knot-forming unit;

2. A vine gathering and clamping mechanism has been synthesized and designed to perform two functions simultaneously: clamping the vine and pulling it into the tying space with the travel and traction of the rack of the clamping mechanism respectively l=125 mm; FT = 80 N and motor power 15 W.

To ensure the productivity of the equipment, the estimated time for creating the staple binding is 1 second, equivalent to the angular velocity of the crank arm 2.

$$\omega = \frac{145\times\pi}{180} = 2{,}53\,\frac{rad}{s} = 24\ min^{-1} \tag{5}$$

With that amount of time, the power of the motor creating the knot will be

$$N_{dc} = \frac{M.\omega}{\eta} = \frac{1{,}085\times 2{,}53}{0{,}7} = 3{,}92\ W \tag{6}$$

In which η=0,7 is the efficiency of the geared motor.

We choose a geared electric motor with a power of Ndc = 5 W.

3. A staple-type tying mechanism has been selected for the pineapple vine tying unit, and based on that, a sliding cam drive has been designed with the aim of low power while still generating a large clamping force for stapling.

4. Based on Autodesk Inventor's Dynamic Simulation software, the stapling process's drive mechanism was simulated, determining the stapling arm's rotation angle to be approximately 45° and the required driving torque for the arm Mmax = 1.085 Nm. The power of the electric motor driving the arm Ndc = 5 W.

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