Fabrication of Lotus Fibre Spinning Machine

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***Abstract*—Lotus thread is usually collected to make a lotus silk and is high-quality material in fashion field. Lotus is commonly planted in Southeast Asian countries such as Vietnam, Cambodia, Myanmar, and some parts of India. Up to now, the lotus fibre is still gathered manually and this process takes at least two months to collect thread enough for making a scarf. As a result, the products made by lotus silk are usually expensive. Besides, the quality of fibre in lotus stalk will decreases after 24 hours of cutting down and is easily broken, thus, lotus fibre spinning process needs implementing quickly. To promote the development of traditional products made by lotus silk and enhance effectiveness of the lotus fibre spinning process, this paper introduced the first design of lotus fibre spinning machine which solves all shortcomings of manually spinning process.**

***Keywords*—machine, spinning, lotus fibre, design, silk**

I. Introduction

Lotus fibre is a natural and highly sustainable material, one of its popular application is to make high-quality textiles, including clothing, scarves, and shawls. In recent years, lotus fibre has become increasingly focusing on because of its good characters such as durability and versatility [1, 2]. The lotus plant has a stem that is composed of long, slender fibres that are known for their strength and durability. Until now, the lotus fibre is still extracted manually, this process is time-consuming and requires a great deal of skill and patience. It consists of three main stages as shown in Fig. 1. Firstly, a prepared lotus stem is gently cut through the outer part. The second step is to gently pull the two ends of the lotus stem to release the bast fibres. The final stage is to twist the two stem ends to weave the lotus fibre into a thread which will be woven into silk then. To overcome the above-mentioned shortcomings of manual method and promote the development of lotus fibre-made products, the automation of fibre spinning process needs studying on. It will enhance the productivity and the quality of the lotus thread.

In the field of agriculture, some fibre extracting machine have been developed and reached the impressive results. For illustration, Omoniyi and Ayodele proposed a coir fibre extracting machine [3]. This machine helps save time-consuming and labour cost in comparison with the traditional method. Adam [4] A developed a Pineapple Leaf Fibre Machine 1 (PALF M1) for small scale industry. Naik and Kar [5] studied on a portable sisal fibre extractor for small scale growers. This machine reduced cost and saved energy consumption of sisal leaf processing. Ajay *et al.* [6] designed and fabricated a banana fibre extracting machine which is very simple and can be manually operated by everyone even unskilled labour. Likewise, Poudel *et al.* [7] developed a banana fibre extraction machine that combined roller and a decorticator for fibre extraction. Their machine improved the production efficiency up to 180% in comparison with available ones. Recently, Karim *et al.* [8] introduced a machine to reduce the production cost of jute fibre extracting process in Bangladesh. The performance evaluation on their machine confirmed that it saved 90% of labour cost.

Fig. 1. Lotus fibre spinning process of craftsman.

All above-mentioned machines are only applied for specific fibre and could not used for lotus fibre extracting process due to the difference of the lotus stem. Therefore, to promote lotus silk-made products, this paper introduced a design of lotus fibre spinning machine which is the first prototype in the world, simulates the lotus thread extracting process of a craftsman. The proposed machine consist of two modules: workpiece supplying and fibre spinning. Its operation is automatically controlled by PLC S7-1200. The remaining of this paper is organized into three parts such as the next section describes the structure design of the proposed machine. The simulation result of lotus fibre spinning process and validation is expressed in the second section. The final section includes some conclusions.

II. Design of Lotus Fibre Spinning Machine and Working Principle

A. Workpiece Feeding Module

This module is to provide the lotus stem continuously and implement cut around at the end of the lotus stem before spinning fibre. It composed of five primary parts such as ball screw (1.1), guide chute (1.2), air cylinder (1.3), cone bushing (1.4) and 3-claw gripper (1.5) as shown in Fig. 2. The green lotus stem is cut into 400 segments and positioned on the guide chute. Through the motion of the ball screw, the lotus stem will progressively move towards the working zone. Subsequently, the cone bushing moves forward and acts on the 3-claw gripper to grasp the lotus stem by an air cylinder as described in Fig. 3.

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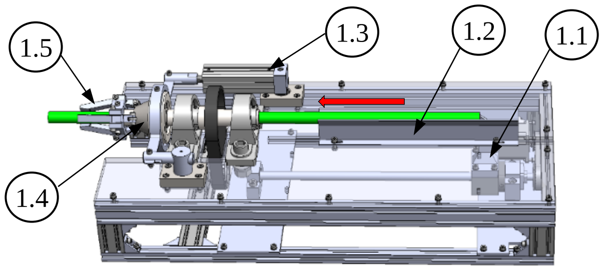
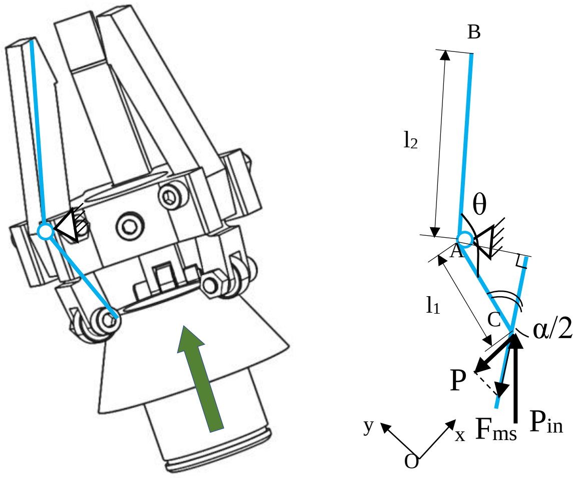


Fig. 2. Workpiece supplying module.



a) b)

Fig. 3. The 3-claw gripper: a) 3D design; b) Kinematic diagram with design parameters.

In order to assess the effectiveness of the suggested gripper, the Grasping Index (*GI*) described in [9] is used as a design criterion, *GI* expresses the correlation between the input and output forces, thereby providing a measure of the gripper's performance. *GI* is defined in Eq. (1).

$$GI = \frac{F}{P_{in}} \quad (1)$$

where P_{in} is the force exerted by the cylinder on the cone bushing, while the grasping force is represented by F and θ represents the configuration angle of the gripper. Figure 3b describes the structure parameters of the gripper. The equilibrium conditions for moments around point A as described in Eq. (2).

$$F.l_2 = P.l_1 \quad (2)$$

where l_1 and l_2 refer to the dimensions of the first and second links of the gripper, respectively. P is a normal force component generated by the cylinder acting on the first link of the gripper and determined by Eq. (3).

$$P = F_{ms}.\sin(\beta) \quad (3)$$

with

$$F_{ms} = \frac{P_{in}}{3\cos\frac{\alpha}{2}} \quad (4)$$

where P_{in} is input force, α denotes the angle of the bushing cone, while β represents the contact angle between the first link and the cone bushing during the grasping process. The value of β is varies depending on the position of the first link.

After substituting Eqs. (3) and (4) in Eq. (2), we obtain Eq. (5).

$$F.l_2 = \frac{P_{in}}{3\cos\frac{\alpha}{2}}.\sin(\beta).l_1 \quad (5)$$

This equation gives.

$$F = \frac{P_{in}.\sin(\beta)}{3\cos\frac{\alpha}{2}}.\frac{l_1}{l_2} \quad (6)$$

Then, substituting Eq. (6) in Eq. (1), the Grasping Index for the suggested gripper can be described as Eq. (7).

$$GI = \frac{\sin(\beta)}{3\cos\frac{\alpha}{2}}.\frac{l_1}{l_2} \quad (7)$$

As indicated by Eq. (7), the Grasping Index (*GI*) depends on various factors. These factors include the ratio (l_1/l_2) of the length of the first link to the second link, the contact angle between the first link and the cone bushing (which varies with the position of the first link), and the configuration angle of the gripper. The parameters of the links are determined based on the diameter of lotus stem, which ranges from 15 mm to 20 mm.

For the purpose of practicality and operational efficiency, we selected the length of the first link, l_1 = 20 mm, and the length of the second link, l_2 = 40 mm. These geometric parameters have been chosen with consideration on manufacturing feasibility and the gripper's working capacity. It is worth noting that according to Eq. (7), the grasping index (*GI*) reaches its maximum value when the contact angle between the first link and the cone surface, β = 90°. In this study, we set the angle of the bushing cone, α = 20°, resulting in *GI* = 0.169.

B. *Lotus Fibre Spinning Machine*

This module is to twist the lotus fibre into thread, comprises five primary components, namely ball crew 1 (3.1), ball crew 2 (3.2), upper spinning hand (3.3), lower spinning hand (3.4), eccentric pin (3.5), and rope drum (3.6) as depicted in Fig. 4. This module simulates the spinning process executed by the laborers. The upper spinning hand is capable of both horizontal and vertical movements (indicated by the green arrow), facilitated by ball screw 1 and 2. The lower spinning hand driven by the eccentric pin moves solely in horizontal direction (represented by the red arrow). Following the spinning operation, the lotus thread is gathered and wound onto the rope drum.

C. *Simulation of Spinning Process*

To set up operation of the lotus fibre spinning machine, the simulation process is implemented to define velocity of spinning hand, it is based on the allowable stress (torque) of the lotus fibre. The tensile properties of lotus fibre were explored by Chen *et al.* [10] as shown in Table 1. These properties will be used to model the lotus fibre in the simulation.

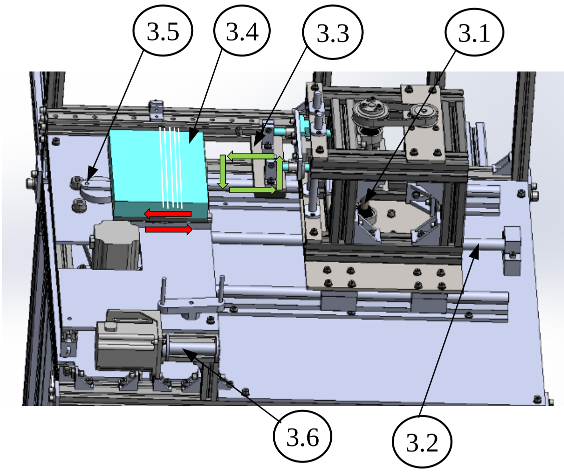


Fig. 4. Fibre spinning module.

Table 1. Properties of lotus fibre

	Density [g·cm^{-3}]	**Modulus [cN·dtex $^{-1}$]**	**Breaking tenacity [cN·dtex $^{-1}$]**	**Breaking elongation [%]**
Value	1.1848	146.81	3.44	2.75

In the next stage, we will investigate the effect of velocity of spinning process on the effective stress of the lotus fibre. This is to define the reasonable velocity of the spinning hand. We set up the simulation model as shown in Fig. 5. Velocity of spinning process is in range of (10/150) (rad/s).

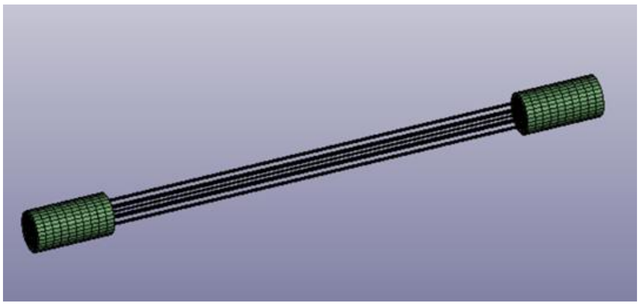


Fig. 5. Setting up the simulation model.

III. Simulation and Validation

A. *Modelling of Spinning Process*

The results of simulation are shown in Table 2. As mentioned in [10], initial yield stress of lotus fibre is 30 MPa, thus the optimal velocity of spinning process is 140 rad/s and this velocity will be used for spinning hand. The final state of the simulation of spinning process is shown in Fig. 6.

Table 2. Simulation results on spinning process

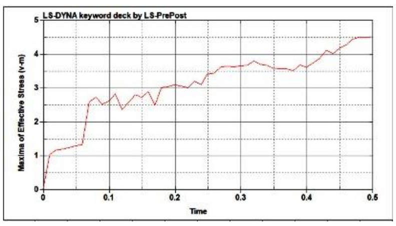
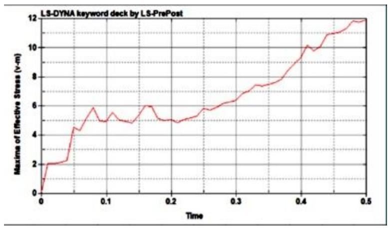
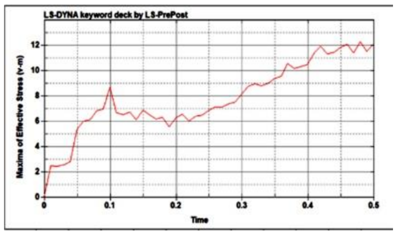
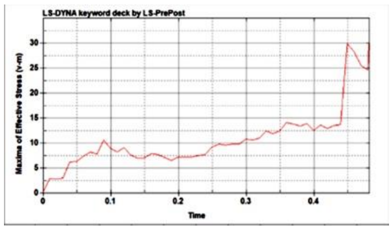
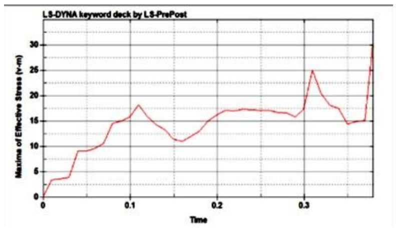
Velocity of spinning process (rpm)	**Maximum effective stress (MPa)**
450	
500	
550	
600	
650	

Table 2 shows that when the velocity of the motor reach 600 (rpm), the effective stress of the lotus fibre is maximum. It is recommended that the velocity of the motor should not exceed 600 (rpm). In the next experiment, we will investigate the effect of the velocity on the success rate of spinning process. Firstly, we use Success Rate (SR) of the spinning as described in Eq. (8).

$$SR = \frac{N_S}{N_t} \tag{8}$$

where N_t are the number of the experiments, we implemented 30 tests; N_s represents the count of successful tests, where all lotus threads are tightly spun. The experiment was considered at speed of 450, 500, 550, 600 and 650 rpm. Each speed was conducted with 30 tests and the experiment results were shown in Fig. 7. When the speed of the motor is 450 rpm, the success rate is about 96.67% (29/30). When the speed of the motor is 650 rpm, the success rate is about 80% (24/30). The experiment results recommended that reducing the speed of the motor will improve the success rate and the working performance of the proposed machine.

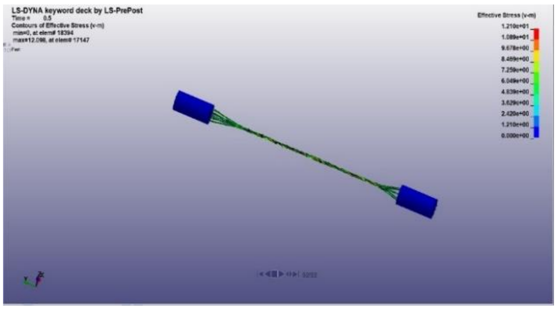


Fig. 6. Final state of simulation process.

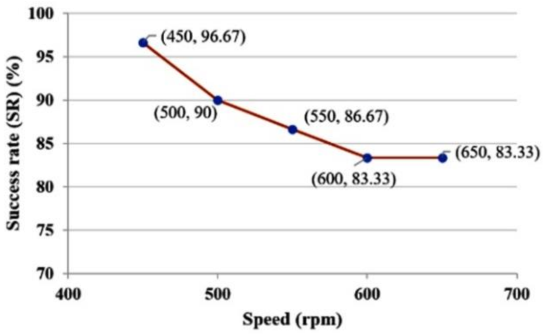


Fig. 7. Success rate at various motor speeds.

B. Fabrication of Spinning Module

From 3D model of spinning module, we fabricated the real structure as shown in Fig. 8. The material of spinning hand is rubber which is soft and has a high friction coefficient. The experiment result is shown in Fig. 9. As can be seen that the spinning module worked well, the lotus fibre is spined into a thread. The experiment result is similar to the simulation.

Fig. 8. Fabrication of spinning module.

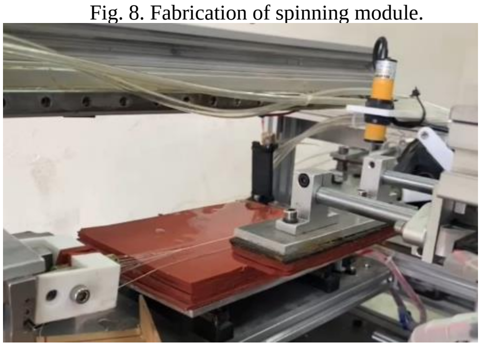


Fig. 9. Experiment results.

IV. Conclusion

This paper introduced a lotus fibre spinning machine which simulated the working process of the craftsman, comprised workpiece supplying and fibre spinning modules. The motion velocity of the proposed machine is defined through the simulation in LS-DYNA under the condition of the stress limit of the lotus fibre. In addition, the confidence of the machine is evaluated by experiment results with the various motor velocities. The result confirmed that reducing the speed of the motor will improve the success rate and it reaches the maximum value of 96.67% at the motor speed of 450 rpm.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Van-Tinh Nguyen conducted the research and wrote the original paper; Ngoc-Kien Nguyen analyzed the data; Ngoc-Tam Bui commented and edited the paper; all authors had approved the final version.

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References

[1] Y. Pan, G. Han, Z. Mao, Y. Zhang, H. Duan, J. Huang, and L. Qu, "Structural characteristics and physical properties of lotus fibres obtained from Nelumbo nucifera petioles," *Carbohydrate Polymers*, vol. 85, issue 1, 2011.

[2] D. S. Chen, Y. J. Gan, and X. H. Yuan, "Research on structure and properties of lotus fibres," *Advanced Materials Research*, vol. 476–478, pp. 1948–1954, 2012.

[3] T. E. Omoniyi and E. B. Ayodele, "Development of a coir fibre extracting machine," *International Research Journal of Engineering and Technology*, vol. 7, pp. 3776–3787, 2020.

[4] A. Adam, "Design and development of Pineapple Leaf Fiber Machine 1 (PALF M1) for small scale industry," Master's thesis, UTHM University, Malaysia, 2016.

[5] R. K. Naik and G. Kar, "Development and testing of a portable sisal fibre extractor for small scale growers," *Int. J. Curr. Microbiol. App. Sci.*, vol. 9, no. 10, pp. 2467–2472, 2020.

[6] C. V. Ajay, K. Vignesh Ramamoorthy, V. Subash *et al.*, "Design and fabrication of manually operated banana fiber extracting Machine for agriculture applications," in *Proc. Materials Today*, 2021, pp. 1–4.

[7] S. Poudel, S. Chapai, R. K. Subedi, T. R. Giri, and S. Adhikari, "Design, fabrication and testing of banana fibre extraction machine," *Journal of Innovation in Engineering Education*, vol. 2, iss. 1, 2019.

[8] M. R. Karim, M. A. Hoque, A. Chawdhury, F.-Ul-Islam, S. Ahmed, A. E. Sabagh, and A. Hossain, "Design, development, and performance evaluation of a power-operated jute fibre extraction machine," *AgriEngineering*, vol. 3, no. 2, pp. 403–422, 2021.

[9] M. Ceccarelli, "Fundamentals of mechanics of robotic manipulation," *Springer Science & Business Media*, vol. 27, 2013.

[10] D.-S. Chen, Y.-J. Gan, and X.-H. Yuan, "Research on structure and properties of lotus fibres," *Advanced Materials Research*, vol. 476–478, pp. 1948–1954, 2012.