DESIGN AND MANUFACTURE A BANANA FIBER EXTRACTION MACHINE FOR SMALL AND MEDIUM-SCALE HANDICRAFT PRODUCTION

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https://doi.org/10.55250/jo.vnuf.2023.15.148-157

ABSTRACT

Currently, by-products from banana trees such as banana sheath and leaves are discarded, which is very wasteful and causes environmental pollution. However, in the world, these materials are considered a significant resource that can be used to produce natural fibers and create handicraft products that are aesthetically valuable, economically viable, and environmentally friendly. This article introduces the research results on designing and manufacturing a banana fiber extraction machine for the production of handicrafts on a small to medium scale in Vietnam. The machine was designed through calculations, model building, and software testing before being manufactured and assembled. After assembly and completion, the banana fiber extraction machine was tested under no load and under load to evaluate its fiber processing capability. Three different processing modes corresponding to different motor speeds of 750 rpm, 900 rpm, and 1,050 rpm were tested to evaluate the banana fiber extraction rate. The results showed that the machine functioned reliably across all three modes, with extraction rates of 10.1%, 11.2%, and 10.8% achieved at motor speeds of 750, 900, and 1050 rpm, respectively. Therefore, this banana fiber extraction machine can be used to extract banana fibers and meet the requirements of producing handicraft materials in Vietnam.

Keywords: banana fiber, banana sheath, fiber extraction machine, handicraft production.

1. INTRODUCTION

Vietnam's handicraft and art industry has existed for a long time, and the development of this industry has made a significant contribution to the country's socio-economic development. It has significantly impacted the economic and social situation, particularly in reducing poverty and developing rural areas. It has helped increase income in rural areas, employing about 1.35 million people in over 2,000 craft villages across the country, thereby narrowing the gap in living standards between urban and rural areas. The handicraft and art industry has also contributed to the formation of thousands of producers, exporters, and service companies in Vietnam.

Currently, the potential of using natural materials as an alternative to the production materials of handicrafts and art products is significant. This not only helps to reduce the demand for natural resources but also provides environmentally friendly materials to create high-quality handicraft and art products, fashion products, and furniture products that meet market demand and are in line with the trend of eco-friendly products.

Banana fibers are extracted from banana sheaths. The surface characteristics of banana fibers are similar to those of bamboo and jute fibers, but banana fibers have better beauty and durability. Some previous studies have shown that the chemical composition of banana fibers includes cellulose at 56-63%, lignin at 7-9%, hemicellulose at 15-17%, and inorganic matter at 3%. The diameter of the fibers ranges from 0.17 to 0.3 mm. Banana fibers have high mechanical strength compared to other fibers, making them suitable for producing handicrafts and art products. Recently, there has been attention paid to the use of banana fibers as a reinforcing material in thermoplastic composite materials due to their low density, lightweight, recyclability, biodegradability, etc [1, 2]. The traditional process of extracting banana fibers involves the breakdown of lignin, pectin, and other substances. However, these traditional plant fiber extraction methods require around 2-6 weeks for the breakdown process before the fibers can be extracted, resulting in low productivity [3].

The banana is one of the fruit trees with a vast cultivated area (>100,000 ha) among fruit trees in Vietnam. According to the Plan for Agricultural Development in Hanoi until 2020, with a vision to 2030, banana cultivation is expected to be developed in areas with a total area of over 3,176 ha, concentrating on planting banana trees in wasteland areas in districts such as Thuong Tin, Gia Lam, Ba Vi, Me Linh, and Phuc Tho, as well as neighboring areas in Hung Yen province [4]. Therefore, it can be said that this is a very abundant source of raw materials to create new products from banana fibers and reduce the pressure on the use of rattan .

According to the research conducted by the authors, there has been no published study on the design and fabrication of a banana fiber extraction machine for use in handicraft production in Vietnam. This article presents the results of the research, design, and fabrication of a banana fiber extraction machine suitable for small and medium-scale production in Vietnam, which will help increase the extraction rate of plant fibers and reduce human labor. This machine is one of the products of the scientific research project funded by the Hanoi Science and Technology program titled "Research on technology and equipment for natural fiber extraction from the banana sheath and pineapple leaves using mechanical methods to produce materials for handicraft production".

2. RESEARCH METHODOLOGY

2.1. The principles of design

Currently, India is a leading producer of banana products. It is estimated that after harvesting the fruit, a huge amount of residual biomass is left behind, consisting of sheath, leaves, etc. Therefore, there is great potential to extract fiber from banana sheath. It is estimated that 17,000 tons of fiber can be extracted annually from this waste and has a value of about 11.7 million USD [5]. Although manual extraction processes yield good quality fiber, it is not economically efficient due to the labor-intensive nature and low output (20kg/person/day) (Figure 1). Therefore, efficient extraction of banana fiber can only be achieved through mechanized equipment.

In the field of handicraft production, banana fibers are mechanically extracted using specialized fiber separating machines [6]. In India and China, machines for producing banana fibers using mechanical methods such as crushing and separating banana sheath on specially designed rollers have been developed. The productivity of small-scale automatic machines is 70-100 kg of banana sheath per hour, while industrial-scale automatic machines can reach 1-2 tons per hour. The fiber separating equipment using mechanical methods reduces labor costs and increases fiber yield by 20-25 times compared to manual fiber extraction. In addition, to improve productivity and fiber quality, some semi-automatic devices have been developed. These devices are used to extract fibers from banana sheath and can also be used for some other types such as pineapple, agave, etc (Figure 2).

Figure 1. Handmade Banana Fiber Extraction process [7]

Figure 2. Automatic banana fiber extraction machine [8]

In this study, the selection of the operating principle of the banana fiber extraction machine must be suitable for the production conditions. Therefore, based on the results of the survey of production conditions in Vietnam as well as the requirements of banana fiber used for producing handicrafts, this study selects the principle of banana fiber extraction machine in small and medium-scale production conditions as shown in Figure 3.

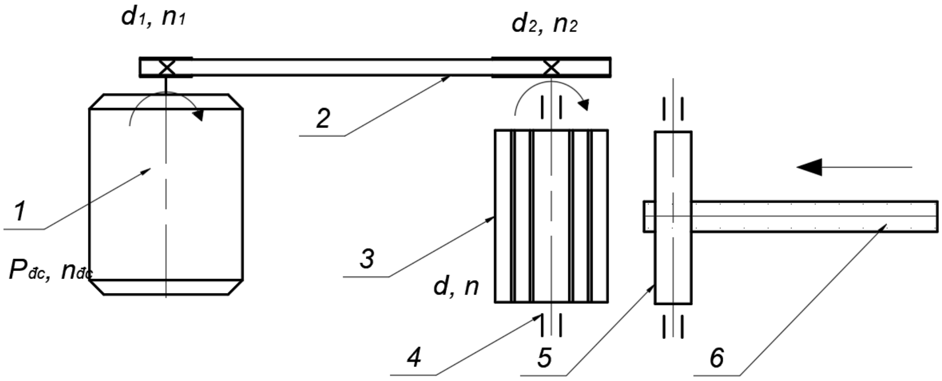

Figure 3. Working principle of banana fiber extraction machine

The main principle of fiber extraction is to create an impact to remove any residual materials on the sheath, while also separating the water to make the banana fibers separate from each other. The fiber stripping drum (3) is mounted on two bearing supports (4) and is driven by a belt transmission system (2). The power source is a motor (1). During operation, the banana sheath (6) is fed into the fiber-separating blades, and the impact force removes the unwanted parts such as fiber residue and debris. After passing through the feed roller (5), the banana sheath is pulled back, and the movement of the upper roller removes some of the residual materials on the banana fibers.

2.2. Main Component Design and Calculations

2.2.1. Determine the force and torque required to extract fiber

The elastic modulus E can be expressed as formula (1): [1, 9].

$$E = \frac{fl^3}{48yI} \tag{1}$$

where E is the modulus of elasticity; y is the deviation in mm; *f* is crushing force/load (N); I moment of inertia and *l* is the length of the banana sheath.

$$I = \frac{BH^3}{12} \tag{2}$$

Where, B and H are the width and thickness of the banana sheath. This study preliminarily selected B = 150mm, thickness H=10mm, y=5mm, and used the elastic modulus of banana fiber E=29 GPa [10]. According to formula (1), the force can be determined to be f=169.9N.

The structure of the stripping drum is shown in the Figure 4. The necessary torque for fiber extracting is calculated according to formula (3) [9]:

$$T = f \times r \quad (3)$$

where r is the radius of the stripping drum (mm).

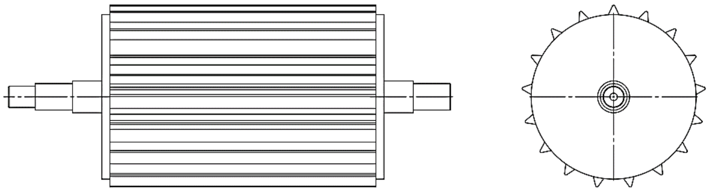

Figure 4. Structure of the stripping drum

According to [11], the number of blades should be selected from 17 to 27. Preliminary research on selection of stripping drum radius r=175 mm. Thus, the torque is determined T= 29.7 Nm.

2.2.2. Calculating motor power

In this study, the belt transmission was initially selected d_1=0.08 m; d_2=0.2 m; Also, preselect the number of revolutions of the motor n_1=1420 rpm, so n_2=568 rpm.

The stripping drum is driven by an electric motor, with the motor power transmitted by a belt. Accordingly, the engine power is calculated as formula (4) [12, 13]:

$$P = \frac{2\pi nT}{60} \quad (4)$$

In which, P is the motor power (W), T is the torque (Nm) and n is the number of revolutions (rpm). From formula (4), P = 1.8 kW. Therefore, the motor selected according to the standard has a power of $P_{\text{đc}}$=2.2kW, and $n_{\text{đc}}$=1420 rpm.

2.2.3. Required Tension on Belt

Figure 5 is a schematic diagram for the belt drive mechanism indicating the tight and slack sides. Let T_1 and T_2 be tensions in Newton on the tight and slack side of the belt, respectively.

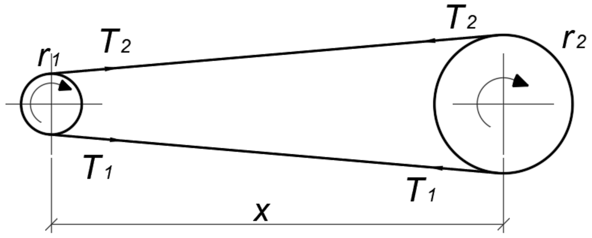

Figure 5. Belt Drive Mechanism

The belt length is calculated by the formula (5):

$$L = \pi(r_2 + r_1) + 2x + \frac{(r_2 - r_1)^2}{x} \quad (5)$$

Where, r_1 and r_2 are the radius of the small and large pulley, respectively, and x is the distance between the centers of the two pulleys.

Preliminary selection of the distance between the two centers of the pulley x=600 mm, then the belt length is 1.65 m.

The angle of lap on the small pulley is calculated by the formula (6):

$$\theta = 180 - 2\left(\frac{r_2 - r_1}{x}\right) \times 57 \quad (6)$$

Thus, the small pulley angle θ=168.6°=2.94 rad

The speed of small pulley is calculated by the formula (7):

$$v = \frac{\pi d_1 n_1}{60} = \frac{\pi.0{,}08.1420}{60} = 5{,}95\ m/s \quad (7)$$

On the other hand, the relationship between the required power transmitted by the belt can be expressed by the formula (8):

$$P = (T_1 - T_2).v \qquad (8)$$

Where v is the belt velocity in meters per second. According to [9], this ratio can be expressed by the formula (9):

$$23\ln\left(\frac{T_1}{T_2}\right) = \mu\theta \qquad (9)$$

In which, μ is the coefficient of friction between the belt and the pulley, ($\mu = 0.3$). Hence, the calculation results are obtained $T_1 = 572.8N; T_2 = 236.7N$

2.3. Banana fiber extraction machine model design and simulation

In today's mechanical design field, computers support all tasks in the design, production and production organization. The work is carried out automatically, greatly reducing the design and manufacturing effort for mechanical engineers [14, 15]. In this study, SolidWork software was applied to model three-dimensional details. This software is developed by SolidWorks, one of the most reputable design software companies in the world. This software allows users to build 3D models of details, assemble them together into a complete machine part (machine), check kinematics, provide material information, etc.

Based on the operating principles and theoretical calculations, the study uses the Weldments tool to construct the frame structure of the machine from standard steel sections, and the frame model is presented in Figure 6.

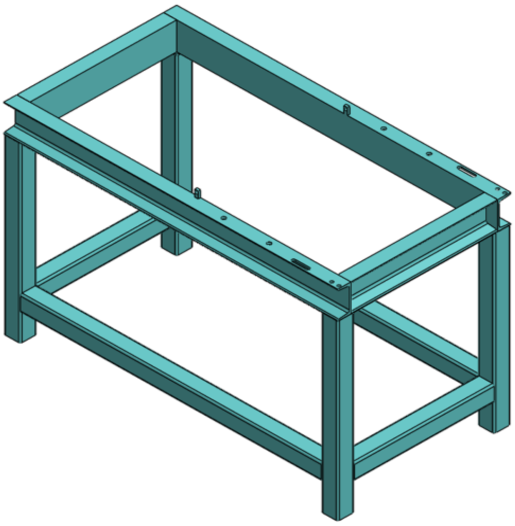

Figure 6. 3D model of the machine frame structure

The fiber-separating blade is the most important factor in the banana fiber extraction machine. It applies the necessary force to the banana sheath to separate the pith and leave the fiber. Some studies have shown that when comparing the efficiency of fiber separation, the type of blade with a toothed structure is likely to damage the structure of the fiber, while a circular blade can separate the fiber structure of the banana sheath effectively [16]. Therefore, in this study, a normal blade with rounded edges was used and mounted on the stripping drum (Figure 7).

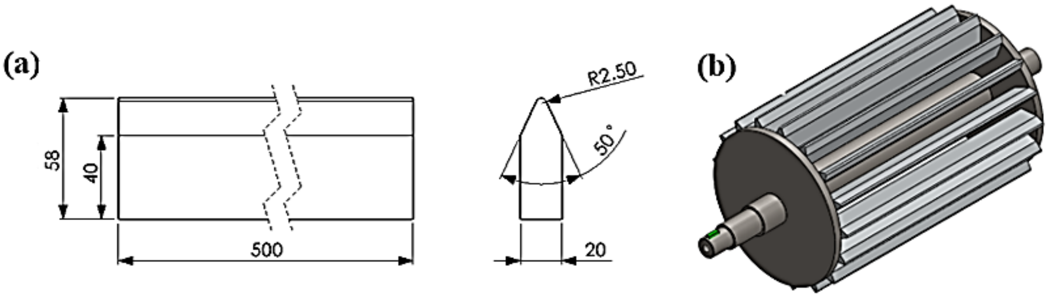

Figure 7. Fiber-separating blade (a) and stripping drum (b)

The machine components designed in the Part module were assembled in the Assembly module to create the machine parts assembly and the overall machine model Figure 8.

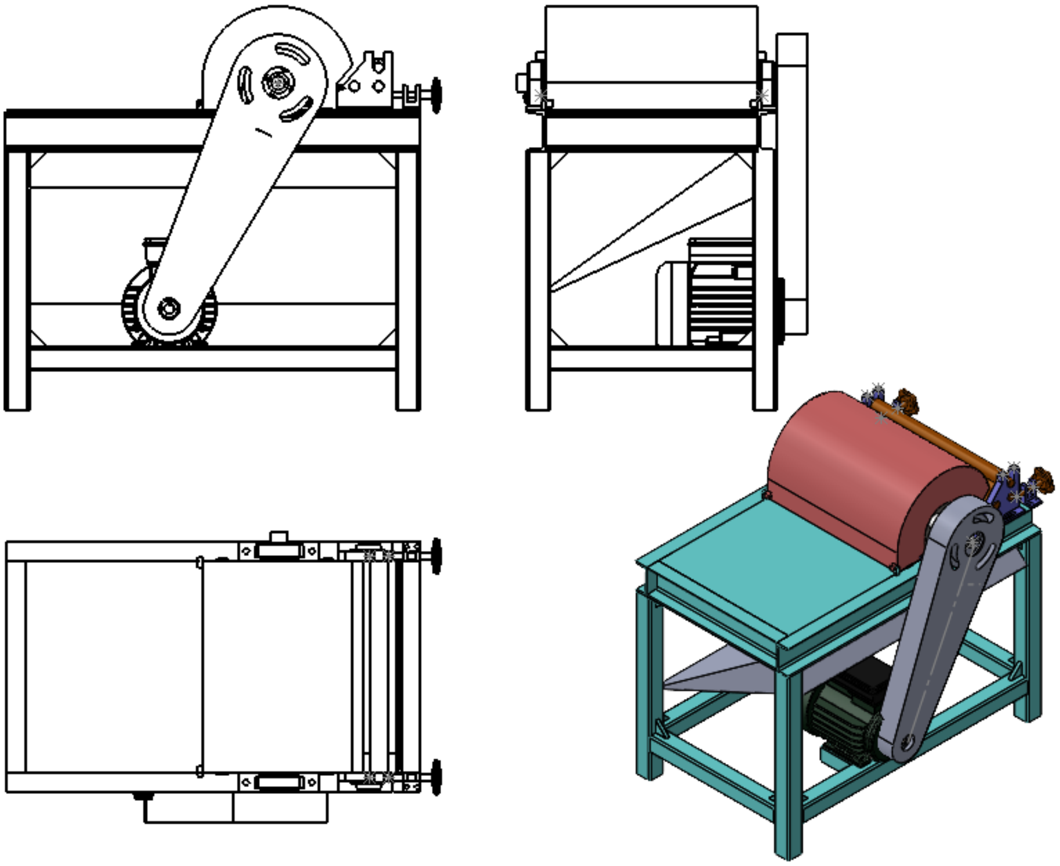

Figure 8. 3D model of banana fiber extraction machine designed by Solidworks

2.4. Simulations result

Testing the system's durability often conducts analysis and breaks down specific problems for calculation. However, it is not possible to calculate all the details, but it is necessary to analyze and select important details and parts for calculation. This equipment needs durability for components such as the frame system, the durability of the shaft system, etc. Based on the analytical calculation results to optimize the design.

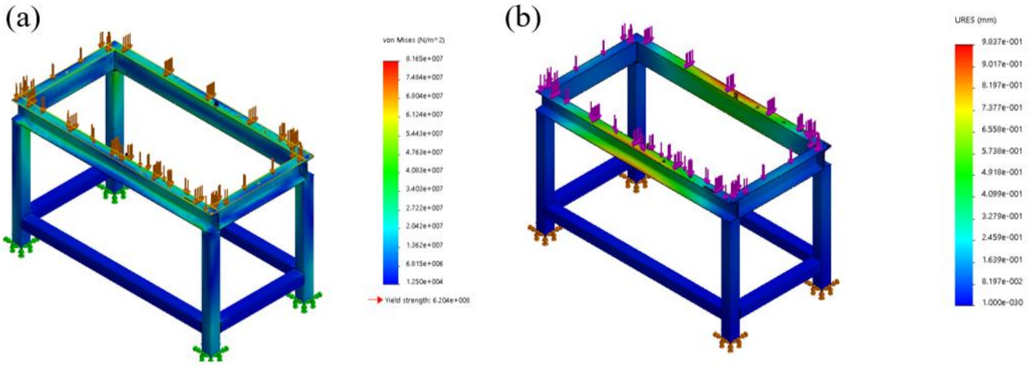

Figure 9. Vonmis stress (a) and displacement (b) results of the frame structure

In this study, the frame structure is very important because it will bear the entire load during operation. After establishing constraints, applying loads, and conducting simulations, the results show that the frame in working condition with the established load has a maximum stress value of 38.06 MPa at node 30938 ($< [\sigma] = 160$ MPa), which is less than the elastic deformation limit of the steel. The maximum displacement value is 0.9 mm, which is not significant since the device does not require high accuracy, so the structure of the frame still meets the working conditions (Figure 9). Therefore, it can be concluded that the structural strength of the machine frame is safely ensured during operation.

2.5. Electric control system

The drive of the stripping drum from the motor is through the belt drive. According to the calculation in the principal calculation, the motor used is 3 phase, capacity 2.2 KW, voltage 220/380V, 50Hz, speed 1420 rpm. Therefore, research and choose the IG5A inverter to adjust the speed of the stripping drum (Figure 10).

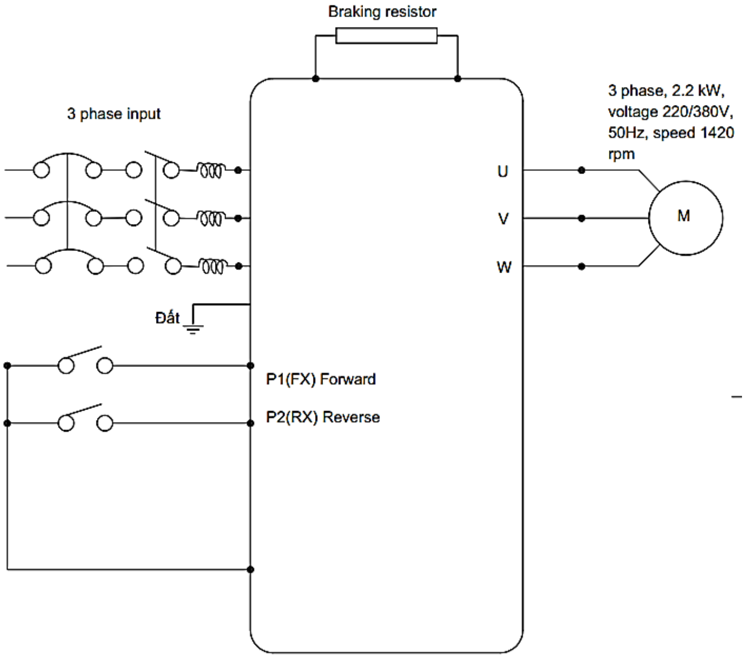

Figure 10. Wiring diagram for controlling motor with IG5 inverter

3. MANUFACTURING, ASSEMBLY AND TESTING RESULTS

3.1. Testing the machine under no-load conditions

After being manufactured (Figure 11), the banana fiber extraction machine was tested for its performance. The technical specifications of the banana fiber extraction machine are presented in Table 1.

Figure 11. Banana fiber extraction machine

Table 1. Specifications of banana fiber extraction machine

No	Parameter	Unit	Value
1	Dimensions (Length × width × height)	mm	1,080 × 620 × 1,230
2	Motor power	kW	2.2
3	Control		Manual
4	Stripping drum speed control type		Inverter
5	Feeding system		Manual

To preliminarily evaluate the banana fiber extraction after manufacturing and assembly, a study was conducted by running the machine under no-load conditions. Before the operation, the assembly joints, such as bolts, belt transmissions, connections, power supply... were checked. The no-load test was carried out to check if the device operates stably. During the trial run, if any issues such as noise or vibration are detected, the machine is stopped to identify and resolve the problem.

3.2. Testing the machine under loaded conditions

The experiment was carried out with one variable (motor speed) at three levels, corresponding to three experimental modes. To reduce the influence of the heterogeneous nature of banana stem materials, the following sampling method was carried out in this study: From each banana plant, 1 or 2 sections were cut with a length of 800-1000 mm, with the section close to the root (near the ground) being 200 mm away from the root. These parts of the banana stem were split into three parts with nearly equal weights. These three parts were used as three experimental samples. Splitting and dividing the banana stem was continued until each sample reached a weight of 30-35 kg, then the sample was tied and labeled with a sample code. This sampling method was performed with a total of 10 samples per experimental mode. The experimental results are presented in Table 2.

Table 2. Experiment results

N. o	Experiment condition		Weight of banana sheath (kg)	Weight of fiber (kg)	Percentage (%)
	Sample	Motor speed (rpm)			
1	I.1	750	32.72	3.096	9.5
2	I.2		32.64	3.335	10.2
3	I.3		31.95	3.422	10.7
Average			32.44	3.284	10.1
4	II.1	900	32.63	3.796	11.6
5	II.2		32.83	3.657	11.1
6	II.3		32.4	3.516	10.9
Average			32.62	3.656	11.2
7	III.1	1050	32.66	3.764	11.5
8	III.2		32.38	3.516	10.9
9	III.3		31.78	3.183	10.0
Average			32.27	3.487	10.8

The results showed that, when the motor speed was set to 750 rpm, the fiber extraction roller rotated slowly, and the blades did not separate the soft tissue surrounding the banana fiber bundles effectively. As a result, many pieces of banana flesh remained stuck to the fiber bundles after passing through the equipment, which could not be washed or separated from the obtained fibers, leading to a low fiber yield. When the motor speed was increased to 1,050 rpm, the fiber extraction roller rotated too fast, and the blades acted too quickly and powerfully on the banana sheath, causing more fibers to break compared to when the roller ran at a slower speed. This significantly reduced the amount of fiber obtained. At a motor speed of 900 rpm, the speed of the fiber extraction roller was sufficient to separate the fibers from the sheath effectively but without causing fiber breakage. This resulted in a significantly increased amount of fiber obtained compared to the previous two cases.

4. CONCLUSION

In this study, a compact banana fiber extraction machine suitable for small- to medium-scale production was designed, fabricated, and tested. After fabrication, the machine was evaluated under no-load and loaded conditions using three different processing modes. The test results showed that the machine operated stably and achieved the best fiber separation efficiency at a motor speed of 900 rpm. Therefore, this motor speed can be a reference for processing selection in actual production. The product of this research could replace the labor-intensive and inefficient manual fiber extraction process, thereby improving the efficiency of utilizing waste materials from banana trees to create aesthetically valuable, economically viable, and environmentally friendly handicraft products.

ACKNOWLEDGEMENTS

This study results from a project funded by the Hanoi Science and Technology program titled "Research on technology and equipment for natural fiber extraction from the banana sheath and pineapple leaves using mechanical methods to produce materials for handicraft production." The authors would like to sincerely thank the Department of Science and Technology in Hanoi Science and Technology.

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THIẾT KẾ VÀ CHẾ TẠO MÁY TÁCH SỢI CHUỐI ỨNG DỤNG SẢN XUẤT HÀNG THỦ CÔNG MỸ NGHỆ QUY MÔ VỪA VÀ NHỎ

Trần Công Chi, Tạ Thị Phương Hoa, Vũ Huy Đại, Phạm Văn Tỉnh
Trường Đại học Lâm nghiệp

TÓM TẮT

Hiện nay các phụ phẩm từ cây chuối như bẹ chuối, lá chuối bị bỏ đi, rất lãng phí và gây ô nhiễm môi trường. Tuy nhiên, trên thế giới, các phụ phẩm này được coi là nguồn tài nguyên rất lớn có thể sản xuất sợi tự nhiên, từ đó chế tác ra các sản phẩm thủ công mỹ nghệ có giá trị thẩm mỹ, kinh tế cao và thân thiện môi trường. Bài báo này giới thiệu kết quả nghiên cứu thiết kế và chế tạo máy tách sợi chuối sử dụng để sản xuất hàng thủ công mĩ nghệ quy mô vừa vả nhỏ tại Việt Nam. Máy đã được tính toán thiết kế, xây dựng mô hình, kiểm nghiệm bằng phần mềm trước khi đưa vào chế tạo, lắp ráp. Sau khi lắp ráp và hoàn thiện, máy tách sợi chuối đã được khảo nghiệm không tải và có tải để đánh giá khả năng gia công tách sợi. Ba chế độ gia công khác nhau tương ứng số vòng quay của động cơ là 750 vòng/phút; 900 vòng/phút; 1050 vòng/phút đã được khảo nghiệm để đánh giá hiệu quả của máy thông qua tỷ lệ tách sợi chuối. Kết quả cho thấy máy hoạt động ổn định ở cả 3 chế độ với tỷ lệ tách sợi là 10,1%, 11,2% và 10,8% tương ứng với các cấp tốc độ động cơ lần lượt là 750, 900 và 1050 vòng/phút. Do đó máy này có thể được sử dụng để tách sợi chuối, đáp ứng tốt yêu cầu làm nguyên liệu sản xuất hàng thủ công mỹ nghệ tại Việt Nam.

Từ khóa: bẹ chuối, máy tách sợi, sản xuất hàng thủ công, sợi chuối.

Received : 22/3/2023
Revised : 24/4/2023
Accepted : 09/5/2023