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College of Electrical and Mechanical Engineering

SEMI-AUTOMATIC DECORTICATOR FOR BANANA PSEUDOSTEM WASTE

A PROJECT REPORT

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Abstract

The objective of this project was the design and fabrication of fiber extracting machine (decorticator) to extract high quality banana fibers from banana pseudostems. Advantage of use of this machine over traditional fiber extraction techniques is that the fiber extraction process becomes less time consuming and labor intensive. Extracted fiber output is increased and they are of higher quality. For every cycle of banana fruit production, four times greater biomass waste is produced as compared to banana fruit yield. About half of this waste accounts for pseudostems which can be used to extract fibers and the solid waste can be utilized as bio-fertilizer for next banana plantations. The machine proposed consists of rotating cutting drum with several blades mounted on it which will provide the crushing, beating and pulling operation on the pseudostem when it is fed to the machine through the feed rollers. The fibers and waste residual material are collected separately. After validation of design through Ansys analysis, the machine was fabricated. The testing of machine resulted in good fiber extraction efficiency.

Keywords: Decorticator, banana, fiber, fiber extraction, FEA

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We are thankful to Allah Almighty for blessing us through the difficult phases experienced during the project and providing us the resources and associations that helped complete our project. We are grateful to our supervisors Dr. Sajid Ullah Butt and Asst. Prof. Rehan Ahmed Khan for their continued support, guidance and recommendations from the initial stages of the project. We would also like to thank Mr. Nadeem Baig, Mr Faiz Alam and Mr. Rameez for their help and professional work during the fabrication stage. At the successful completion and testing of the project, we are eternally grateful to our parents for their prayers and encouragement throughout the project span.

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Chapter 1 Introduction

Humans have been using natural fibers, since prehistoric times when they were living a nomadic life, to serve their clothing needs. Earliest accounts include use of wool and dyed flax fibers by cave dwellers in Swiss Lake region. Although nowadays natural fibers face competition from synthetic fibers but the importance of natural fiber has not decreased. During the last decade, the production of natural fibers has ranged between 28 million tons and 35 million tons and accounted for nearly 30% of all fiber production [1]. These natural fibers are used in making of clothes, carpets, papers and other handicraft products. They have now also found utility in making of composite materials for wide range of applications in automobile, aerospace, military and construction industries [2]. Research and development work is being done on extraction and treatment methods of natural fibers and their properties which will help natural fibers gain more application and usage. Natural fibers provide benefits of being strong, cheap, abundantly available, recyclable and biodegradable.

Fibers derived from plants are the largest contributors to the total natural fiber production share. Fibers from the fruits, stems, leaves of cotton, jute, sisal, hemp are extensively used worldwide. Although having a small share in the fiber market, the use of cellulose fibers derived from banana plant is gaining popularity. Banana is a major fruit crop in the world which had production amounting to 116.78 million metric tons in the year 2019 [3]. This plant can be grown in diverse climatic conditions but they are primarily found in the tropical regions. India and China are the leading producers of the fruit with 36% share followed by Ecuador, Brazil, Colombia, Philippines. Figure 1 shows the banana production by country in 2018 [4].

In the recent years, banana fibers have been used by the paper industry to make paper, cardboard, notepads and notebooks, packaging material, files and covers. They have found use as absorbents for oil slippage in refineries [5]. Handicrafts, tea bags, string thread, high quality fabric material, paper for currency notes and rope have also been made using these fibers. Clothes, bags, curtains, rugs are also being made using banana fibers. Banana pseudostem fibers have good modulus of elasticity, tensile strength, and stiffness which has made it good raw material for many industries [6]. Banana pseudostem fibers are also biodegradable and flexible and can be spun by any method.

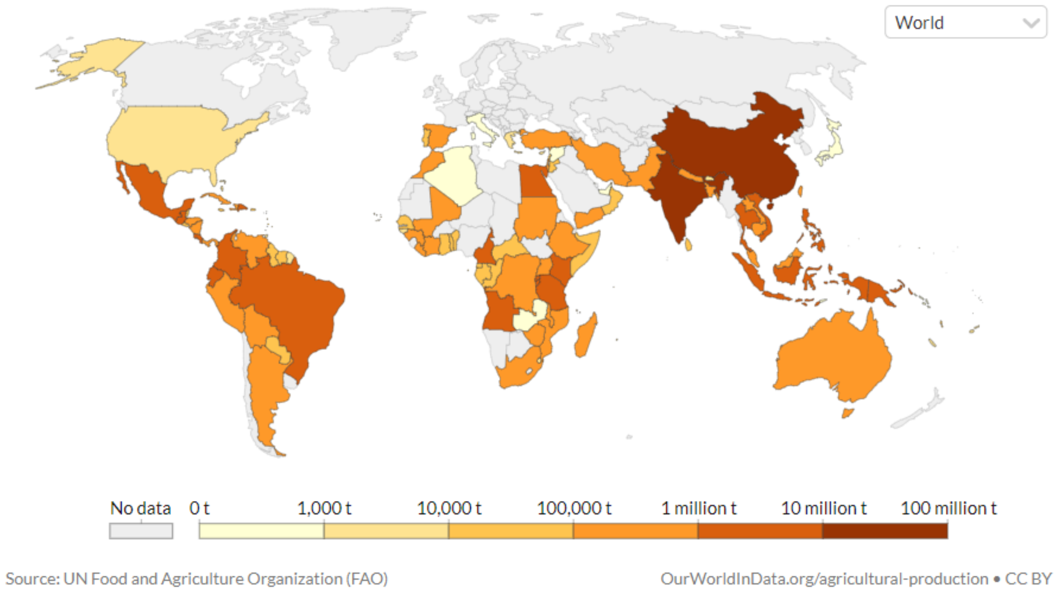


Figure 1. Annual Banana Production in 2018 [4]

The objective of this project is to develop an indigenous decorticator machine at affordable price for banana farmers in Pakistan. This will help to create a secondary source of income for these farmers by making of value added products from extracted fibers and help in reduction of environmental pollution caused by burning of banana pseudostems and associated waste.

Chapter 2 Literature Review

2.1 Banana Plant and Associated Waste

The banana plant as shown in Figure 2 [7] has a pseudostem (apparent trunk) which is the stem that provides and transports nutrients from the soil to the fruits. The pseudostem is made up of large leaves closely rolled up one over the other. The pseudostem contains buds which produce leaves and flowers. Flowers appear in spring and give way to fruit in late summer. The time for a plant to grow from the corm and bear fruit varies, depending on climate and specie, but generally can take anywhere from 10 to 15 months. Alongside the main stem it has young stems (suckers) sprouting from the corm (underground plant stem). When the plant produces fruit, the pseudostem is cut down as it cannot bear fruit for second season. These stems then grow into fruit bearing plants for next cycle.

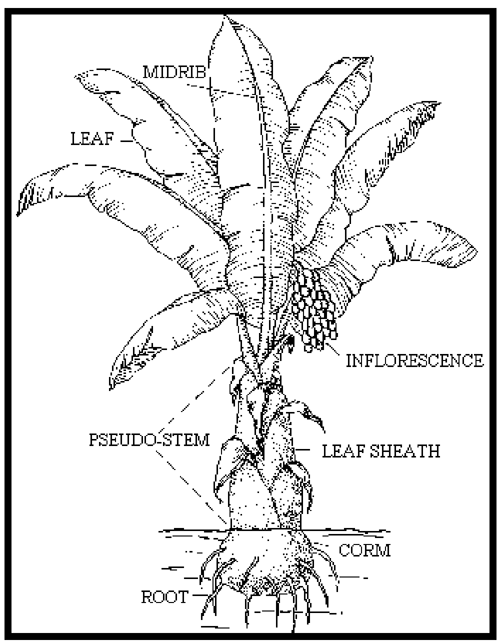


Figure 2. Parts of Banana Plant [7]

Banana plantation sites produce large amounts of organic waste in the form of banana peel, pseudostems, leaves, pulp, rejected fruit [8]. The ratio of banana waste and its product (fruit) is estimated to be 4:1. Half of the global waste produced by banana industry comprises of pseudostems. The pseudostem and leaves are commonly left to rot in farms to replenish some of the nutrients in the soil. Some farmers throw away the pseudostem from the plantation site or burn it because it takes a long time to rot.

2.2 Banana Pseudostem Fiber Extraction Process

Banana pseudostems are a rich source of fibers that can be extracted by different techniques that include immersion, biological and mechanical methods. In immersion method, the pseudostems leaf sheaths are submerged in water for 7-10 days that results in natural decomposition of non-fibrous material holding the fibers together and as a result fibers become separated. Biological method involves use of chemicals and enzyme solution in which leaf sheaths are submerged. Mechanical method involves use of a mechanism to continuously strike leaf sheaths in order to expose the fibers. The resulting fibers are then washed and dried to remove impurities. Immersion and biological methods for extraction of fibers are time consuming, labor intensive and cannot provide for the needs of large scale production. Average fiber quality is also reduced during these processes.

2.3 Decorticator Machine

Decorticator machine is a type of mechanical method for fiber extraction. The extracted fibers can then be cleaned using chemical and enzymatic processes for further processing.

The internal working of decorticator machine can simply be represented by Figure 3 [9]. It consists of a rotating drum mounted on a shaft. On the surface of the drum, blades are attached which provide the crushing and beating action. As the drum rotates by help of electric motor, the pseudostem leaf sheath is fed by a worker through the feeding roller to the drum and stationary beater bar. As the distance between the drum and beater bar is small, the pseudostem is continuously crushed and beaten and the non-fibrous material (residue) holding the fibers in their place is removed. The residual material is collected under the machine while the fiber is withdrawn by the worker.

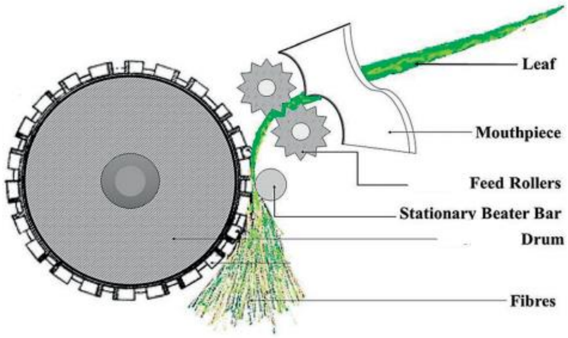


Figure 3. Simplified Decorticator Operation [9]

The fibers then undergo degumming operation that is used to remove the remaining non-fibrous matter from the fibers. This is achieved by boiling the fibers several times in alkaline solution and washing them with water. They are then dried at room temperature conditions and mechanically spun into yarn. The residual material from the decorticator machine comprises of solid biomass. It can be used directly as plant feed or can be synthesized into bio-fertilizers to improve growth and yield of crop.

2.4 Pre-Decortication Process

The pre-decorticator process includes turning the banana pseudostems into input for the machine. The pseudostem is round in shape and made up of a soft central core and tightly wrapped leaf sheaths and cannot be directly used in the machine. The pseudostem is cut in the center throughout its length. The soft central core is taken out and used for cooking purposes. The leaf sheaths are unwrapped. These are then cut into appropriate length and width. The length of the sheaths is determined by the desired length of fiber and width is adjusted for optimal operation. And then the sheaths are fed into the decorticator machine. Pre-decorticator operation can be represented by Figure 4.

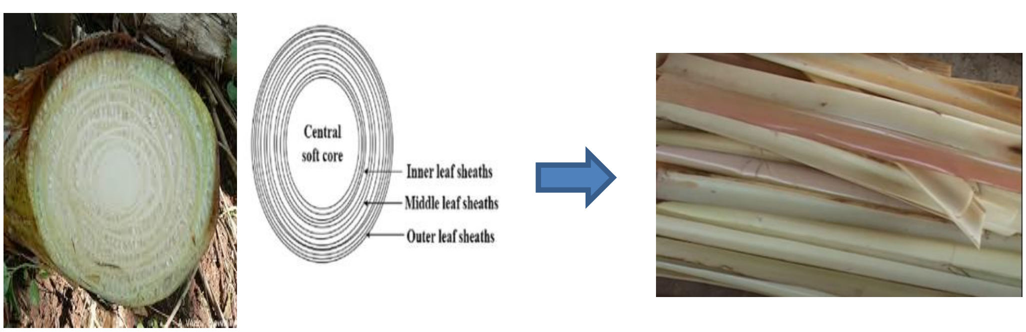


Figure 4. Banana Pseudostem is converted into individual leaf sheaths

2.5 History of Decorticator Machines

Fiber extraction machines have been invented as early as 1900s and have been known by different names like decorticator, abstractor and defibrator. Initially flax, kenaf and hemp were used for these machines. Yusof, Y. et. al. [10] while reviewing published journals and patented machines determined that most extraction machines used crushing and bending of plant leafs as part of extraction process. Some machines utilized fluid power to rotate the crushing and grinding wheels of machine while at the same time wash the fibers. After World War 2, natural fibers met reduced demands in favor of synthetic fiber due to which research work on these machines decreased.

However nowadays fibers from natural sources like banana, pineapple leaf and sisal have found attraction due to environmental awareness and economical prices. Decortication process for most plants is the same due to which some machines found in literature can be used as multi plant fiber extraction machine. These machines are used at small and large scale in all major banana producing countries with considerable success. Some of the unique machines used in these countries were studied.

Nigeria is among the largest banana fiber producing countries on the African continent. To provide an alternative for the traditional water retting technique of fiber extraction, Oreko, B. U. et. al. [11] developed a decorticator machine that was powered by 2 hp electric motor that could extract fibers from pseudostems of varying thickness and length with average extracting time of 26 seconds.

To provide a means to overcome raw material shortages for Ethiopian Textile industry, work started on utilizing fiber potential of different plant stems and leaves which are usually cast aside as waste. In this regard, Ahmed, F.E. et. al. [12] developed a multi plant fiber extraction machine as a pilot project in Ethiopia. It consisted of horizontally placed drum with two different surfaces. On one side of the drum surface, small nails were closely welded in order to be used to extract fiber from flat plant stems like banana plant and sisal while second half side of drum is grooved to extract fibers from circular shaped plant stems like papyrus. The machine was effective and 3-4 times cheaper as compared to the imported machines available in market.

Philippine is generally regarded as the country to first utilize banana fibers for use in fabric and handicraft development. Today, it has been surpassed by India and China in terms of banana and associated fiber production. Tenerife Jr, P. M. et. al. [13] brought a new concept for the fiber industry in Philippine by developing a banana fiber extraction machine which used an auto feed system for fiber input and conveyer belt for transporting extracted fibers. The machine was worked at different motor rpms and torque with variable feed roller distance to extract fibers. 4mm gap between feed rollers was found to be optimum for fiber production. Effect of motor speed on extracted fiber quality was also studied. The machine could be utilized at large scale in farms to increase the production rate of fibers.

Institute for Social and Environmental Transition – Nepal with the collaboration of Poudel S. et. al. [14] developed a banana fiber extraction machine with a production efficiency of 54 kg of wet fiber per day. In this machine an arrangement was made for storing of pulp removed during feed roller operation. Gear and belt and pulley mechanism was used to drive the machine whose efficiency was highest when the roller gap was 5 mm and length of leaf sheaths fed was 1m. Change in number of decorticator blades and their profile was recommended with use of adjustable feed roller gap mechanism in decorticator machine.

For the purpose of developing a small scale machine for processing sisal which is the sixth largest cash crop of Kenya, Brasa N. W. [15] developed a sisal decorticator machine for use in small scale farming estates. The decorticator machine used wire brushes and steel combing pins in between the cutting blades to remove the non-fibrous material and straighten the fiber. It provided an alternative for the large machines already used that consumed large amount of water in already water scarce Kenya.

Banana fibers and residue material from decortication process represent an important opportunity for banana cultivators in Pakistan. Similar to other agricultural economies of the world, Pakistan also produces banana on a large scale. Cultivation area accounts to 30 thousand hectares (about one-third the size of Islamabad) with a total production of 135 thousand tons giving an average yield of 4 tons per ha [16]. Majority area (93%) and production (83%) of banana in Pakistan lies in Sindh province as shown in Figure 5.

Figure 5. Major and Minor Banana Cultivation Areas in Sindh [16]

Haripur, Bannu, Mansehra, DI Khan districts in Khyber Pakhtunkhwa (KPK) are major growing areas. Lasbela district in Balochistan produces nearly 46 000 tons of bananas annually. Khanewal, Sahiwal, Narowal districts in Punjab are major banana plantation sites. The major variety grown is Cavendish Dwarf which accounts for about 90% of bananas grown in Pakistan.

Traditionally thousands of tons of associated waste is burnt in fields every year by the farmers which contributes to pollution and greenhouse gases harmful to surrounding [17]. By using gasoline or electric motor powered decorticator machines at these farm sites, extraction of natural fibers can take place. It would be a source of income and saving for the farmers through selling of fibers and reutilization of liquid sap and solid waste biomass as plant feed. An indigenously developed machine would cater for needs of local people and be far less costly than an imported machine. Fiber extraction machines have been developed in Pakistan in agricultural and textile universities as well as government organizations. Some of the recent developments in this field in Pakistan were studied.

National Agricultural Research Center (NARC) developed a portable sisal decorticator machine in collaboration with Lok Sanjh Foundation. The machine was used equipped with 7.5 kW engine and tires and could be towed with help of tractor. The sisal plants were sourced from Rawalpindi while testing was done at NARC. The machine had production capacity of 15.94 kg/hr of dry fiber while the operating cost of the machine was determined as Rs. 507.9 per hour by Ahmad, T. et. al. [18]. It was determined that clearance gap between feed rollers and decorticating drum and decorticating drum speed had effect on fiber breakage and quality of fiber extracted and for sisal plant the optimal clearance gap was 2 mm with speed of decorticating drum being 1250 rpm.

To develop jute and banana fiber reinforced composites Awais H. et. al. [19] developed a decorticator machine for banana pseudostem in National Textile University, Faisalabad. The extracted fibers were then reinforced and the obtained composite's properties were measured.

A decorticator machine for use on banana plantation sites was developed by Dr. Shoukat Ali Abro from Sindh Agriculture University, Tandojam in 2021. It was a pilot project made with a cost of greater than 0.1 million. The machine was tested in plantation sites in Hyderabad, Sindh. Textile industry stakeholders and farmers expressed hope on project's initiation that it could serve as an alternative to cotton as cotton yields have showed decreasing trends in last few years due to climate change related factors.

To make decortication machines viable for banana farming community in Pakistan, the machine should not only have better efficiency in terms of quantity and quality of fibers extracted but also cost effective. Factors determined during literature review that affect efficiency of decorticator machine include having variable feed roller gap, variable clearance gap between cutting drum and feed roller, change in decorticator cutter profile and use of cutting disc for bisecting banana pseudostems. These factors will be important designing features for this project's proposed decortication machine design.

Chapter 3 Design of Decorticator Machine

3.1 Sub-Assemblies of Decorticator Machine

Major components of the designed decorticator machine as shown in Figure 6, include rotating feed rollers, cutting drum, pulley and belt mechanism, electric motor, bearings and cutting disc. Pseudo-stem sheaths are sent to a pair of horizontal squeezing rollers. The motor driven cutting drum while continuously striking the sheaths extracts the fibers and the residue falls in the collector bucket.

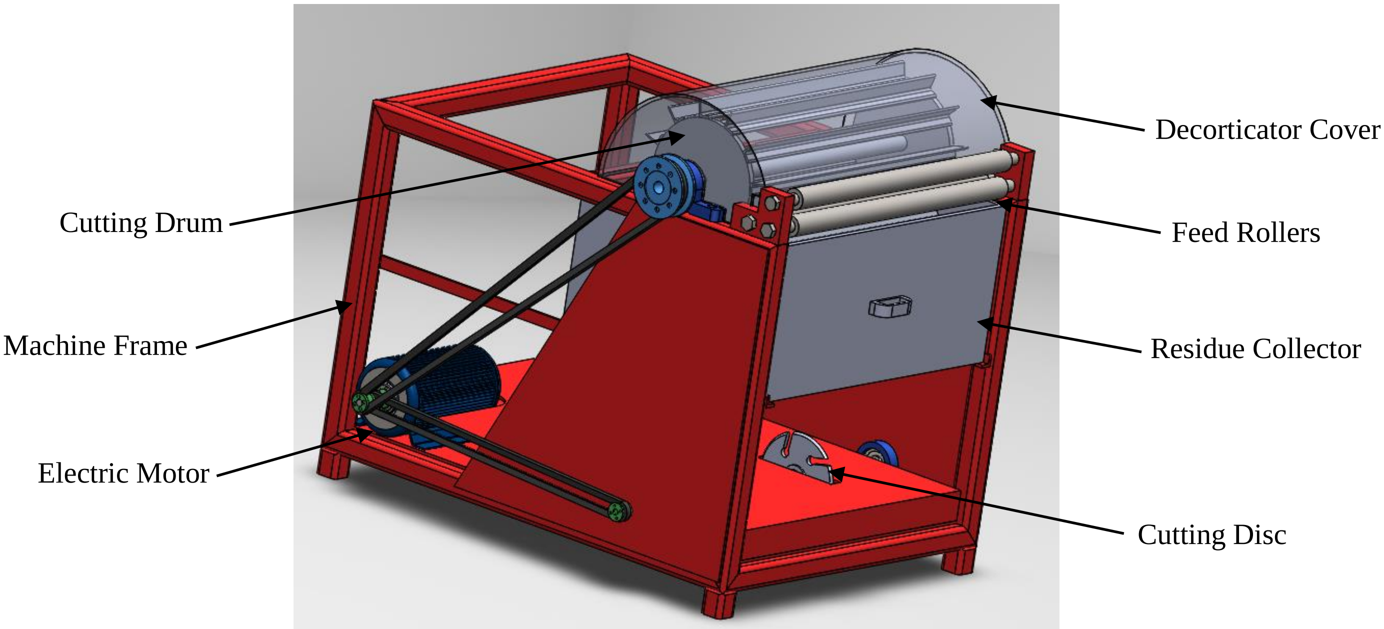


Figure 6. Banana Pseudostem Decorticator

The purpose of important parts of decorticator machine are discussed in the following sections.

3.1.1 Machine Frame

Machine frame is the base structure on which all other components of decorticator are to be attached. It is to be made of mild steel and will weigh such that it allows for easy mobility. The height of machine is designed to allow working upright for the workers to be easy. The width and length of machine is designed to allow proper space for bisecting of pseudostems and fiber extraction.

3.1.2 Feed Rollers

The rollers apply the necessary squeezing force on the banana sheaths for separating the pulp. Two feed rollers are used and they are able to rotate about their axis. They are not connected to motor and rotate when the leaf sheaths are pulled by the cutting drum as it strikes them.

3.1.3 Beater Bar

As the leaf sheaths move through the feed rollers they fall onto the beater bar and move beyond it. Beater bar, attached adjacent to feed rollers, serves the purpose of trapping the sheaths between the rotating cutting drum and itself while cutting drum continuously strikes them. It has the same dimensions and shape of feed rollers but it does not rotate and remains fixed. The distance between the beater bar and cutting drum is kept between 2mm to 5 mm for low fiber breakage and good extracted fiber quality.

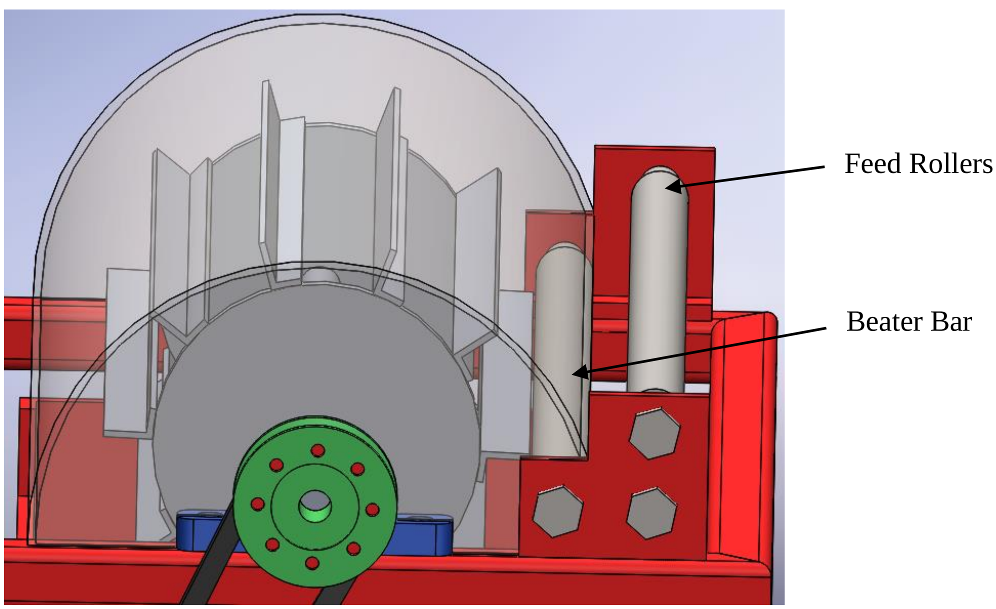


Figure 7. Feed rollers and Beater bar Assembly

3.1.4 Cutting Drum

It consists of angle bar shaped blades that are permanently joined between two metal discs. One side of angle iron that will come in contact with leaf sheaths is made sharp while the other end is welded on the circumference of the two metal discs on either sides. A concentric solid shaft will pass through this assembly which will be attached with pulley to electric motor. 8 - 12 number of blades have been determined from literature review to provide efficient extracting.

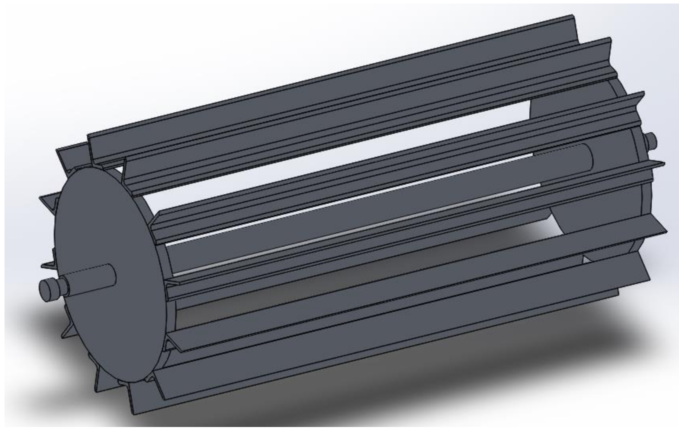


Figure 8. Cutting Drum

3.1.5 Electric Motor

A single phase motor will be used to rotate the cutting drum and the cutting disc. This electric motor is used to rotate the heavy cutting drum assembly while overcoming the resistance of pseudostem sheaths. The power and torque from the motor attached to the bottom of the machine frame will be transmitted to the two components with the help of belts and pulleys.

3.1.6 Belt and Pulley

Three pulleys and two V-belts will be used for transmitting the power from the motor to cutting roller and cutting disc. One of the belts is used to connect the cutting drum and motor and another used to connect the motor and cutting disc.

3.1.7 Cutting Disc

Cutting disc is used for the pre-decorticator process of fiber extraction. This involves cutting through the center of banana psuedostems to separate the leaf sheaths enclosed within it to be used as input for the decorticator machine.

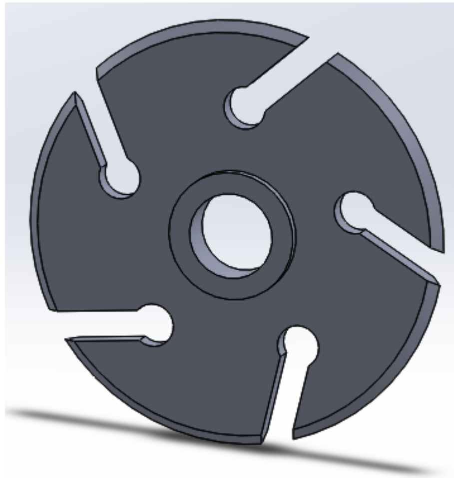


Figure 9. Cutting Disc

3.1.8 Residue Collector

Container attached directly below the rotating cutting roller in which the residue from the decorticating operation will fall and which can be used for used as raw material for further processes.

Chapter 4 Selection Consideration for Decorticator Machine Components

4.1 Decortication Resistance

The resistance faced during decortication process can be approximated by applying cantilever model for banana pseudostem sheaths. One end of the sheath will be held by labor feeding it to the machine while on the other end force will be applied by cutting drum. We know that for a cantilever beam the deflection on free end is given by

$$\delta = \frac{FL^3}{3EI}$$

E, L, I represent the modulus of elasticity, length and moment of inertia of banana pseudostem sheaths that are being input to the machine. And F represents the force required to deflect the pseudostem. Conversely F represents the resistance that the cutting drum blades will face.

The modulus of elasticity of banana sheaths was determined by Indira et. al. [20] to be 29 GPa. To determine the reactive force, the slightly curved cross-section of the sheaths is approximated as rectangular. Values of thickness and width of sheath cross-section were determined directly from pseudostem using measuring tape. The thickness varies from 6 mm to 15 mm for sheaths closer to pseudostem core and those at outer periphery whereas the width varies from 60 mm to 150 mm. The maximum deflection is found as

$$\delta = 15/2 = 7.5 \text{ mm} = 0.0075 \text{ m}$$

$$I = \frac{b\,h^3}{12} = \frac{0.15 \text{ x } 0.015^3}{12} = 4.22 \text{ x } 10^{-8} \text{ m}$$

For decortication process banana sheath are cut into smaller lengths according to desired length of fiber to be extracted. For length of 600 mm, decortication resistance is determined to be

$$F = \frac{3 \text{ x } 29 \text{ x } 10^9 \text{ x } 4.22 \text{ x } 10^{-8} \text{ x } 0.0075}{(0.6)^3} = 127.479 \text{ N}$$

4.2 Torque and Power Required for Decortication

The cutting blades are to be mounted on the circumference of metal disc. The metal discs have a diameter of 200 mm. The circumference of these discs comes out to be

$$\text{Circumference} = 2\,\pi\,r$$

$$= 2 \times 3.14 \times 100$$

$$= 628 \text{ mm}$$

MS angle iron 25mm x 25 mm x 3 mm are to be attached. One side (25 mm) will be completely welded along the circumference while the other side will act as cutting blade. For 12 blades, 300 mm space is required which is less than the total circumference of discs so the angle iron can be easily attached with space in between them.

For impacting a force of 127.479 N to banana sheaths, the torque needed to be provided to cutting drum should be

$$\text{Torque} = F \times r$$

$$= 127.479 \times 0.100$$

$$= 12.75 \text{ Nm}$$

The speed of cutting drum should be at least 800 rpm for effective decortication. The power of motor that can supply this torque at 800 rpm can be found as

$$\text{Power} = \frac{2\pi NT}{60}$$

$$= \frac{2 \times \pi \times 800 \times 12.75}{60}$$

$$= 1068.14 \text{ W} = 1.068 \text{ kW}$$

This power and torque can be provided by a 1.5 hp motor whose 1450 rpm can be reduced by use of larger pulley at cutting drum end.

4.3 Belt and Pulley Selection

The electric motor selected has a power of 1.5 hp (1.118 kW) and operates at 1450 rpm. The desired speed of cutting drum is at least 800 rpm.

For **cutting drum and electric motor**, the speed ratio is

$$\frac{N1}{N2} = 1450/800 = 1.81$$

The minimum pitch diameter for pulley is 75mm. This will act as driver motor pulley, the pulley diameter for cutting drum side can be obtained as

$$D = d \times 1.81 = 75 \times 1.81 = 135.75 \text{ mm}$$

Standard pulley diameter available is 127 mm so this is selected. Through this pulley combinations, on driven side 855 rpm value is achieved which is greater than the minimum desired rpm.

The peripheral speed of belt is

$$V = \pi \times d \times n = \pi \times 0.075 \times \frac{1450}{60} = 5.69 \text{ m/s}$$

B belt section is selected for this belt speed and 1.118 kW power. From the design of CAD model the center distance between the drive and driven shafts is 735mm.

Contact angle for open belt drive can be found as

$$\theta_d = \pi - 2\sin^{-1}\left(\frac{D - d}{2C}\right)$$

$$\theta_d = 3.07 \text{ rad}$$

Gates Rubber Company declares that its effective coefficient of friction is 0.5123 [21].

$$\exp(0.5123 \times 3.07) = 4.189$$

From Table 17-16 of Shigley's Mechanical Engineering Design, Kc for B cross section V belt comes out to be 0.965. The centrifugal tension can be found as

$F_c = K_c (V)^2 = 31.24$ N

We know that nominal power is 1.118 kW. For service factor K_s of 1.2 for uniform driven machinery with normal torque characteristic and factor of safety of 1 the design power is calculated

$$H_d = H_{nom} \times K_s \times n_d = 1.3416 \text{ kW}$$

From the design of CAD model the center distance between the drive and driven shafts is 735mm. Belt length required for can be determined from the formula

$$L = 2C + \frac{\pi}{2}(d + D) + \frac{(D - d)2}{4\,C}$$

$$L = 2\,(0.735) + \frac{\pi}{2}(0.127 + 0.075) + \frac{(0.127 - 0.075)2}{4 \times 0.735}$$

$$L = 1.788 \text{ m} = 1788 \text{ mm}$$

The standard belt length available is 1750mm. We can decrease the center distance between two shafts which will in turn decrease the required belt length to standard length. This can be done by moving the electric motor closer to the cutting drum.

From Table 17 – 13, angle of contact factor is 0.99 and from Table 17 – 14, belt length correction factor is 0.95. The tabulated power from Table 17 - 12 for belt speed of 5.69 m/s is 0.8 kW.

$$H_a = 0.7524 \text{ kW}$$

The power transmitted per belt is

$$\Delta F = \frac{Hd/Nb}{\pi\, n\, d}$$

$$\Delta F = 0.1324 \text{ kN} = 132.4 \text{ N}$$

The largest tension in the belt can be found by

$$F_1 = F_c + \frac{\Delta F \exp(f\phi)}{\exp(f\phi) - 1}$$

$$F_1 = 205.157 \text{ N}$$

Least tension in the belt can be found from

$$F_2 = F_1 - \Delta F$$

$$= 72.57 \text{ N}$$

For connecting **cutting disc and electric motor,** B cross-section V belt type is used. Higher rpm of cutting disc will facilitate in the better bisection of banana pseudostem. For this reason smaller pulley is used on the cutting disc shaft as compared to electric motor. For electric motor 75 mm pulley was used so for cutting disc 50 mm pulley is used.

The distance between the two shafts as determined from CAD model is 352 mm. The belt length required can be determined from

$$L = 2C + \frac{\pi}{2}(d + D) + \frac{(D - d)2}{4\ C}$$

$$L = 2\ (0.352) + \frac{\pi}{2}(0.05 + 0.075) + \frac{(0.075 - 0.05)2}{4 \times 0.352}$$

$$L = 0.9007 \text{ m} = 900.7 \text{ mm}$$

The closest standard belt available is 875 mm so the position of electric motor can be adjusted in such a manner that both cutting drum and cutting disc shaft belts can be fixed properly with the driving shaft.

4.4 Cutting Drum Shaft Selection

The shaft is to be fixed at both ends with bearings. One side of the shaft will also have a pulley attached to it. A simple schematic diagram for the shaft is shown in Figure 10. The weight of the drum will act on the shaft as well as the weight of pulley and tension due to electric motor rotating it. As the drum pulley is attached to the motor pulley with belts that are at 45^o (determined from CAD design) with the horizontal, we will have two components of force (vertical and lateral) acting on pulley and shaft.

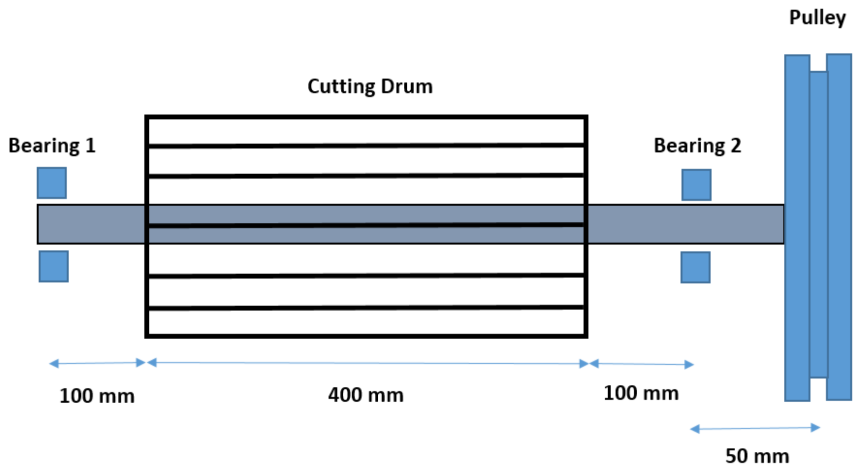


Figure 10. Cutting Drum Schematic Diagram

The vertical free body diagram for this system is shown in Figure 11. R_1 and R_2 are the reaction forces from the bearings while W_d is the weight of cutting drum and W_p is weight of pulley and the force exerted on it due to motor. The weight of the drum will be equally divided and act through the two side discs attached to the shaft.

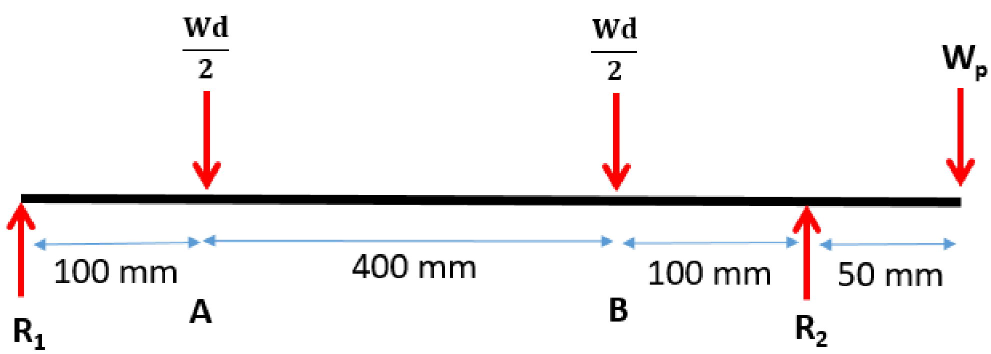


Figure 11. Vertical Free Body Diagram

The shaft will be subjected to combined twisting moment and bending moment. The torque on the shaft due to motor can be found from the following formula

$T = (F_1 – F_2)$ (Pulley Radius)

$T = 16.84$ Nm.

The force on the pulley due to motor tension can be found by using motor power and the belt velocity.

$P = F \times v$

$F = \frac{P}{v} = \frac{1118}{5.69} = 196.4$ N

This force is divided into vertical and horizontal components. The weight of a 127 mm A-1 Classical SFK V-belt pulley is 2 kg. The total force on pulley comes out to be

$W_p = (196.4 \cos45 + 2 \times 9.82) = 158.51$ N

Weight of drum can be calculated from weight of blades and side metal discs. The extraction blades will be fabricated from angle bars measuring 25 mm by 25 mm by 3 mm with mass distribution of 1.19 kg/m. For 12 number of blades, the total blade weight will be

$= 1.19$ kg/m x 0.4 m x 12

$= 5.712$ kg = 56.09 N ($g = 9.8$ m/s^{-2})

The side discs will be fabricated from mild steel and will have a diameter of 0.2 m and thickness of 0.008m. Density of mild steel is 7860 kg/m^3. So the weight of side discs comes out to be

$= 7860 \times \frac{\pi}{4} (0.2)^2 \times 0.008 \times 2$

$= 3.95$ kg = 38.78 N

So weight of drum assembly is determined as

$W_d = 56.09 + 38.78 = 94.87$ N

From the FBD we can see that

$$\sum F = 0$$

$$R_1 + R_2 = 47.4\ N + 47.4\ N + 158.5\ N = 253.3\ N$$

Summation of moments about Bearing 1 will give us

$$47.4 \times 0.1 + 47.4 \times 0.5 - R_2 \times 0.6 + 158.51 \times 0.65 = 0$$

$$R_2 = 219.1\ N$$

$$R_1 = 34.2\ N$$

The bending moments at points A and B where the cutting drum is attached to the shaft and R2 where Bearing is attached experience highest bending moment

$$M_A = 3.42\ Nm$$

$$M_B = -1.86\ Nm$$

$$M_{R2} = -7.92\ Nm$$

For the lateral direction the weight of drum will not act. Only the pulley weight will act. The free body diagram for lateral direction can be shown as

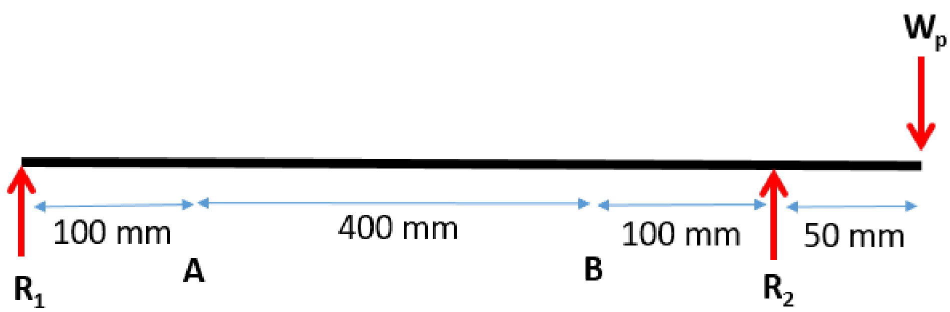


Figure 12. Lateral Free Body Diagram

The reactions force from summation of forces and summation of moments come out to be

$$R_2 = 171.72\ N$$

$$R_1 = -13.21 \text{ N}$$

Resulting bending moment at points A, B and R_2 are

$$M_A = -1.321 \text{ Nm}$$

$$M_B = -6.605 \text{ Nm}$$

$$M_{R2} = -7.926 \text{ Nm}$$

Resultant bending moment for the lateral and vertical directions is

$$M_A = \sqrt{3.42^2 + (-1.321)^2} = 3.67 \text{ Nm}$$

$$M_B = \sqrt{(-1.86)^2 + (-6.605)^2} = 6.86 \text{ Nm}$$

$$M_{R2} = \sqrt{(-7.92)^2 + (-7.926)^2} = 11.2 \text{ Nm}$$

Using the maximum shear stress theory minimum diameter of shaft required is calculated for the critical bending moment at R_1 and torque of 16.84 Nm.

$$\frac{\pi}{16} \times \tau_{max} \times d^3 = \sqrt{M^2 + T^2}$$

The maximum permissible shear stress for shaft without allowance for key ways is taken as 56 MPa according to ASME Code for design of transmission shafts.

The allowable diameter comes out to be 12.25 mm. For standard shafts, the minimum shaft diameter available is 25 mm so it will be used in the fabrication process.

Chapter 5 FEA Analysis of Machine Components

5.1 Machine Frame

The frame structure supports 15 kg mass of cutting drum (including weight of shaft and bearing) and 10 kg of motor placed on the lower frame structure. The induced stresses and strain are determined from Ansys to determine the safety of structure.

von-Mises Stress

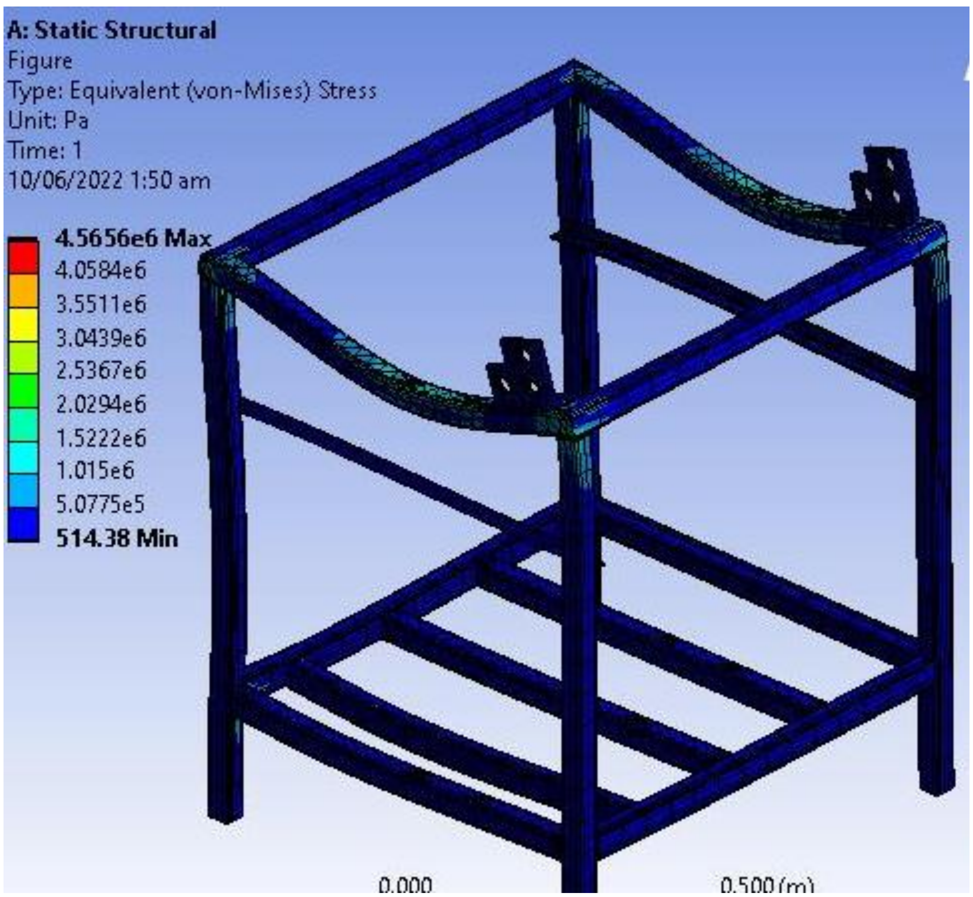


Figure 13. von-Mises Stress in Machine Frame

The yield strength of the above frame structure is 250 MPa while the maximum stress developed in above model is 4.5 MPa, so as a result material is safe from permanent deformation.

Total Deformation

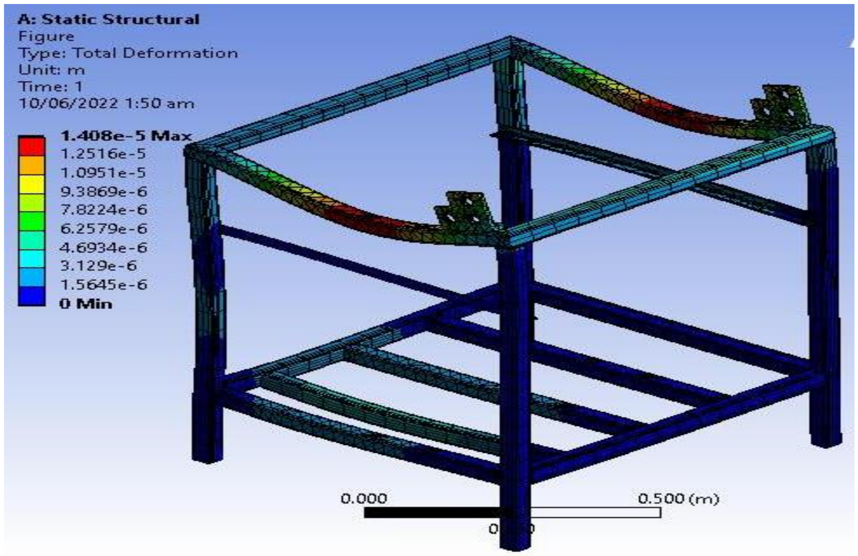


Figure 14. Total Deformation of Machine Frame

The maximum total deformation due to the loads applied on frame structure is 1.4e-5 m, which is negligible as compared to the total size of structure.

Maximum Shear Stress

The theory is applied to triaxial states of stress which predicts that the yielding will occur whenever one half of the algebraic difference between maximum and minimum stress is equal to one half of the yield stress.

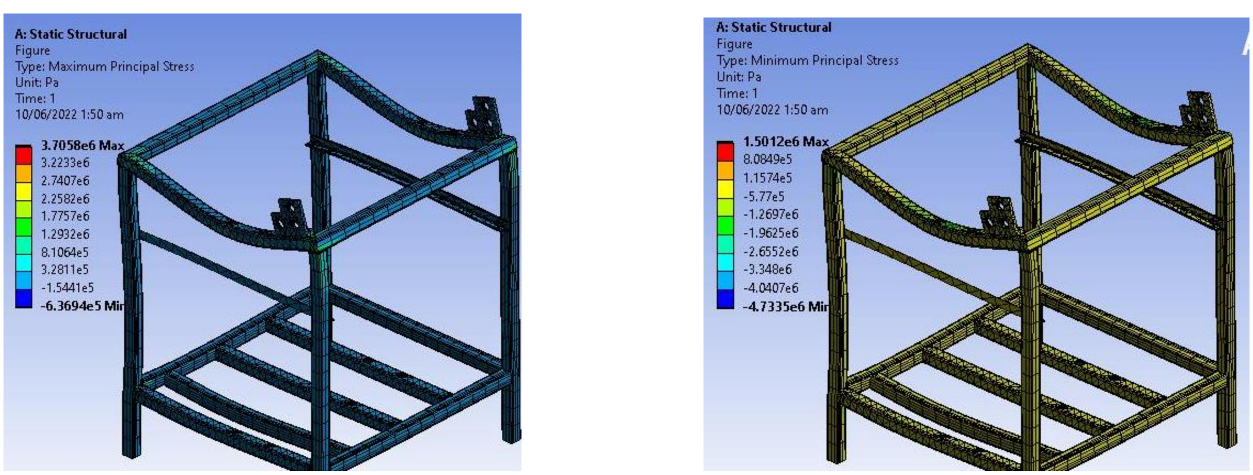


Figure 15. Maximum and Minimum Principle Stress developed in Frame

$$(3.7\text{-}1.5)\text{MPa}/2 \ll 250\ \text{MPa}/2$$

So according to maximum shear stress theory, the structure is safe.

5.2 Cutting Drum

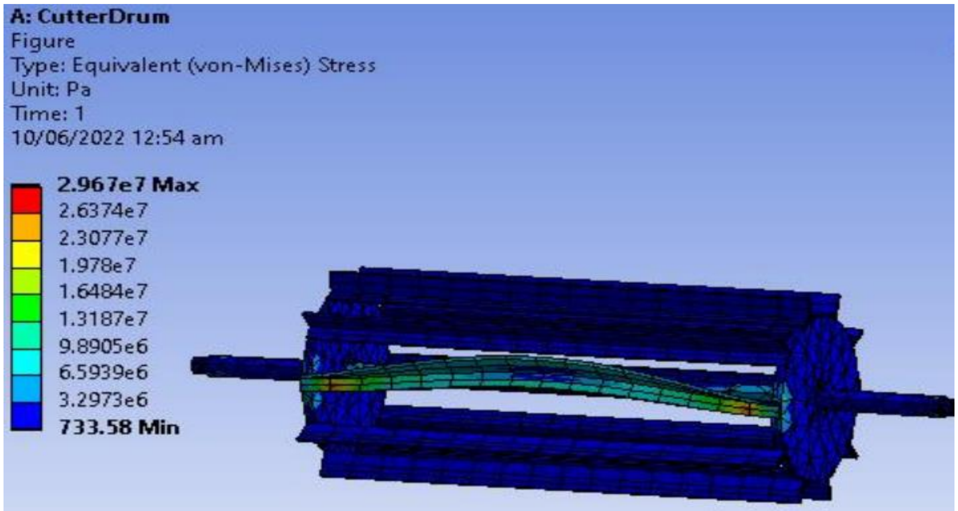


Figure 16. von-Mises Stress in Cutting Drum

The maximum stress developed in the drum cutter is 29.6 MPa, which is less than the yielding stress of Mild Steel (250 MPa), so by von-Mises criteria, the model is under safe limit for applied loads.

Safety Factor

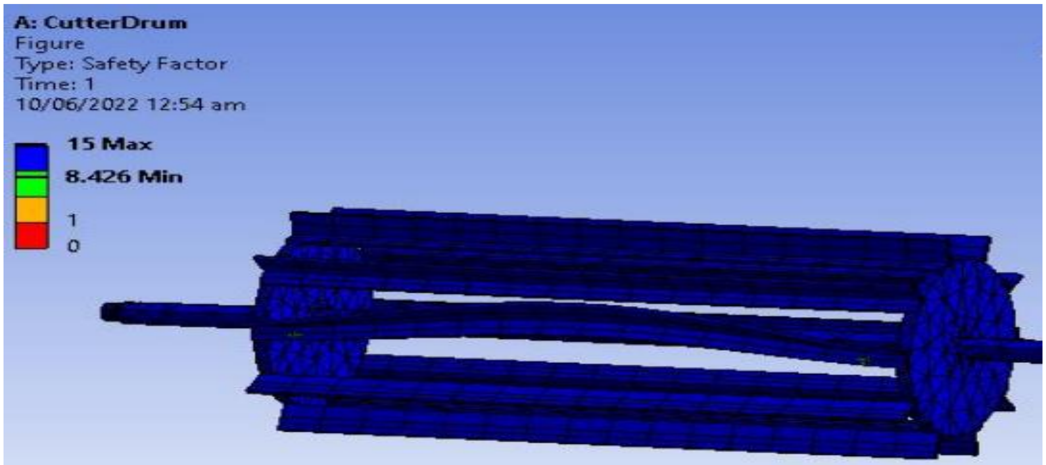


Figure 17. Safety Factor of Cutting Drum

For static structural analysis, safety factor for the applied loads is 8.5, which shows that the model is under safe limits. Any additional or unexpected load other than the design load can be supported.

Total Deformation

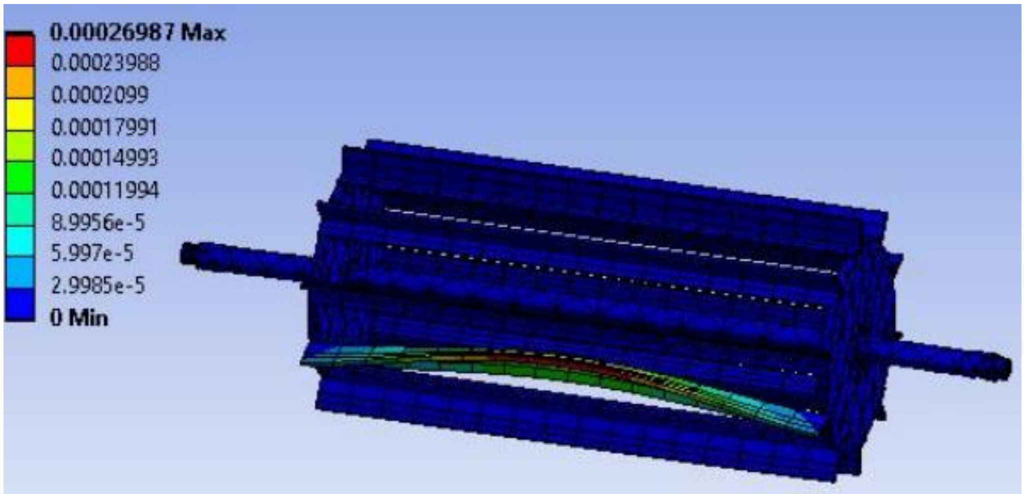


Figure 18. Total Deformation of Cutting Drum

Maximum total deformation developed in the system is 2.7*10^-4 m which is very small.

Fatigue Analysis

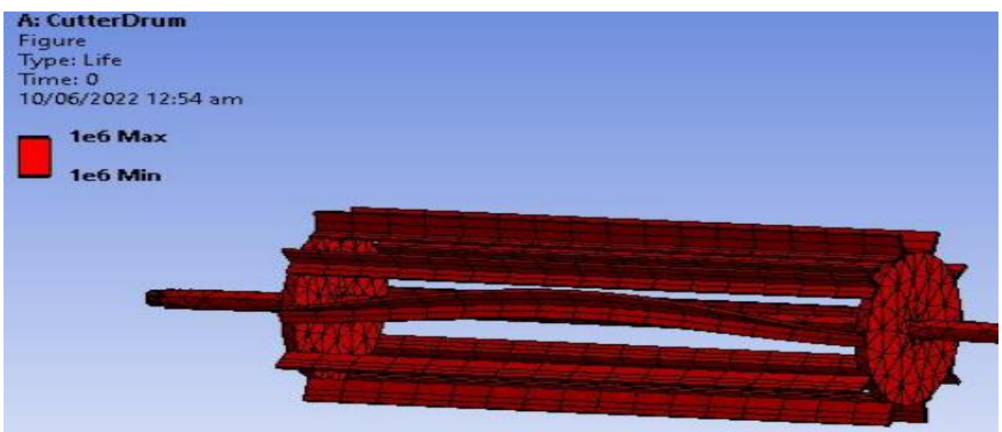


Figure 19. Fatigue Analysis of Cutting Drum

Fatigue life, at a given alternating stress level and mean stress, is the number of cycles required to cause failure due to fatigue. The number of loading (stress) cycles of a specified character that cutting drum sustains before failure of a specified nature occurs is over millions of cycles. Thus the number of stress cycles required to cause failure is practically infinite.

Safety Factor

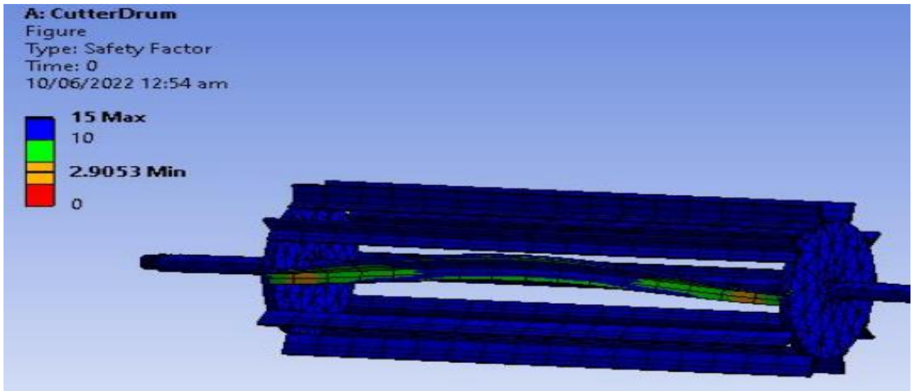
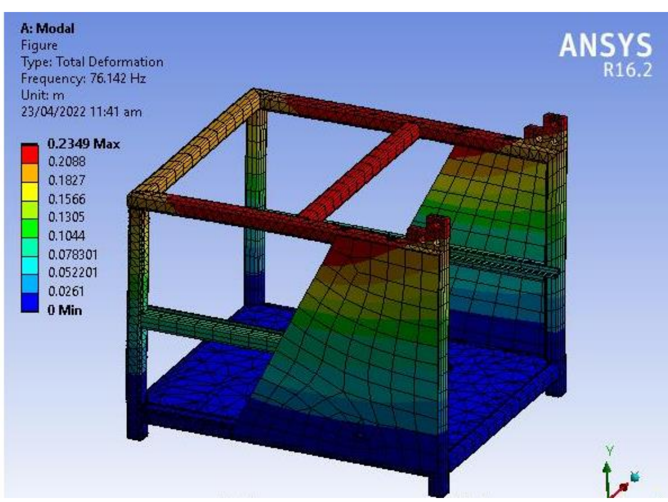


Figure 20. Safety Factor under Fatigue Load

The factor of safety with respect to a fatigue failure at a given design life is around 3, which means that material is under safe range for applied cyclic loads.

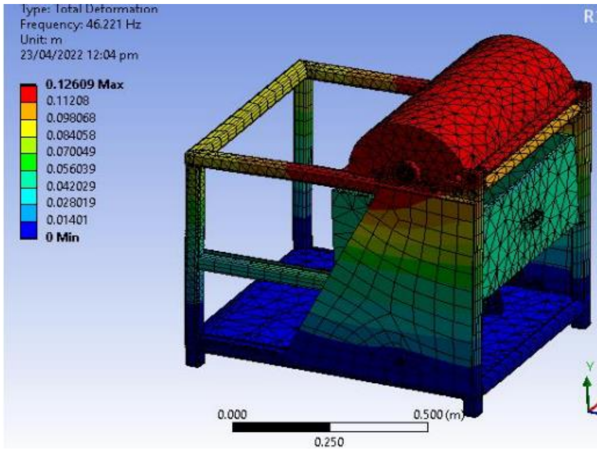
5.3 Modal Analysis

Vibrational analysis is carried out through two cases as shown in Figure 21 and Figure 22. In first case natural frequency of machine frame and in second case natural frequency of complete assembly is found out. The first natural frequency of both cases is 76 and 46 Hz respectively whereas the Driving or forced frequency due to electric motor is 23 Hz (due to the 1450 rpm). As natural frequency is higher than the forcing frequency, our structure will be stable from resonance. For achieving first mode shape we would have to run the machine at least 3000 rpm which cannot happen as highest rpm for motor is 1450.



Mode	Frequency [Hz]
1.	76.142
2.	150.18
3.	151.65
4.	182.22
5.	216.69
6.	236.51

Figure 21. Modal Analysis of Machine Frame



Mode	Frequency [Hz]
1.	46.221
2.	93.157
3.	98.404
4.	117.68
5.	118.6
6.	132.25

Figure 22. Modal Analysis of Complete Assembly

Chapter 6 Fabrication and Assembly of Decorticator Machine

After the completion of CAD design and analysis, fabrication of machine is started. This phase includes making of different parts of machine and buying of components and assembling them together. After successful running of machine, finishing is done by using air compressor paint spray machine. The fabrication stage is explained in chronological order in the following sections.

6.1 Cutting Drum

The cutting drum is made of side discs, cutting blades and shaft. In the first step, MS side discs of 200 mm diameter and 8 mm thickness are obtained and facing is done with help of lathe machine.

Figure 23. Side Discs for Cutting Drum

MS Angle of 20 ft (6000 mm) was obtained for making of cutting blades. The angle was cut into 12 equal pieces of 400 mm length. One side of the angle iron that was going to come into contact with the pseudostem sheaths was chamfered by using grinding wheel so that the process of extracting the fibers could be made more efficient.

Figure 24. Cutting Drum Blades

Markings were made on the side discs so that the cut angles could be attached at equal intervals. The marks were made after every 30^0 with the center of rotation being the center of discs.

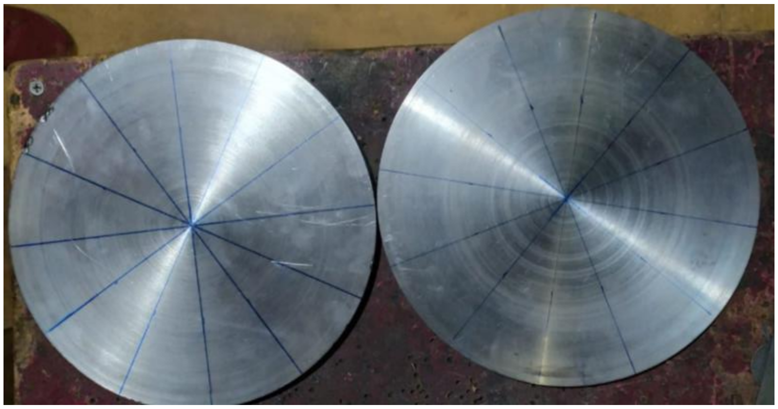


Figure 25. Markings for Blades

MS Rods of 1800 mm length and 25 mm diameter were bought for making shafts for both cutting drum and cutting disc. 25 mm diameter hole was made in both side discs with help of lathe machine. The rod was cut equal to required shaft length. The side discs were placed on required position of shaft and welded in their place. Then one by one the blades were welded keeping the chamfered side faced outside. The final assembly of cutting drum is shown in Figure 26.

Figure 26. Assembled Cutting Drum

6.2 Machine Frame

Machine frame was made using MS Square pipes measuring 38 mm x 38 mm x 5 mm. The frame is made to have width of 750 mm, length of 800 mm and height of 900 mm. After welding of complete assembly, grinding and buffing is done at the welded surfaces to make it clean and smooth surface.

Figure 27. Machine Frame

6.3 Feed Rollers and Beater Bar

For the feed rollers and stationary beater bar, a hollow pipe of outer diameter 38 mm with a thickness of around 4 mm are used. It was cut into three lenghts of 650 mm. A small 40 mm lenght solid MS rod was used on both sides of sectioned hollow pipes to help so can be attached to side supports and rotated through their central axis. One side of the solid rod was welded into the pipe while the other side was placed in side supports.

Figure 28. Feed rollers and Beater bar

Side supports for the feed rollers and beater bar were made from MS sheets. A L cross-section was created. On one surface holes for fixing the feed rollers and beater bar were created while one other surface a slot was created for nuts and bolts that would hold the assembly to machine frame. Slot was created to allow the assembly to have variable clearance from cutting drum blades. The final assembly mounted on the machine frame is shown in Figure 29.

Figure 29. Feed Roller Assembly

6.4 Decorticator Cover

For the cover of decorticating cutting drum, metal sheet was given a circular cross-section with help of roll bending machine. Side cover was cut out with clearance for the bearing and feed roller side supports. Then they were welded to form the upper cover. Two metal hinges were welded to the end of its curved surface and a handle was attached to its front surface. Rubber edge guard was attached to the sharp side cover ends for safety and noise reduction.

Figure 30. Fabricated Decorticator Cover

6.5 Residue Collector and Cutting Disc Platform

After the position of cutting drum and cutting disc is determined on the machine frame, the dimensions for these components is measured. MS sheet is used to fabricate both these parts. For the collector, a height of 200 mm was selected. After cutting of metal sheets into required dimensions, they were welded together to create the assembly shown in Figure 31. A handle was also attached for ease of use. Cutting disc platform is the assembly on which the pseudostem will be moved as it is bisected by the cutter. A slot was created for the cutting disc on the platform during fabrication. The complete fabricated assembly is shown in Figure 32.

Figure 31. Fabricated Residue Collector

Figure 32. Fabricated Cutting Disc Platform

6.6 Cutting Disc Shaft

To hold the cutting disc during its operation, two washers are used on its either sides. These are held in place with chuck nut. Washer and chuck nut are custom made for the shaft diameter. They are made from MS circular and hexagonal bars respectively with the help of lathe machine. Threading on shaft for chuck nut was done using lathe machine.

Figure 33. Cutting Disc Shaft Assembly

6.7 Assembly of Decorticator Machine

As the required parts were fabricated, assembly phase started. On the machine frame, at the position of attachment of parts, holes were drilled. For the shafts UCP bearings were used. Required diameter pulleys were bought and holes were drilled according to shaft diameters. V belts were used to connect the pulleys. Then remaining components were affixed.

Figure 34. Decortication Machine

After testing and experimentation of machine was completed and results were obtained, final finishing was done using air compressor assisted spray paint and bottle spray paints. The finished assembly is shown in Figure 35.

Figure 35. Final Decortication Machine Assembly

Chapter 7 Testing and Results

Once the assembly phase was completed, test run of machine resulted in no problem in running of cutting drum and cutting disc. In the next phase, testing of machine for decortication process was carried out. For this purpose three pseudostems were arranged with heights of approximately 1500 mm.

The first process carried out was bisecting of the pseudostems. The cutting disc successfully performed the operation. The cut pseudostem are shown in Figure 36.

Figure 36. Bisected Pseudostems

Individual leaf sheaths were separated out and inner core was removed. To have standard testing, the sheaths were cut into equal lengths. The sides of the leaf sheaths were also trimmed. The removed sheaths and test sheaths are shown in Figure 37.

Figure 37. Creation of standard pseudostem sheaths

The lengths, thickness and width of test pseudostem sheaths were measured using Vernier caliper and measuring tape. The leaf sheaths were then input one by one into the decorticator machine. The slightly curved cross-section of the leaf sheaths becomes flat while passing through the feed rollers and due to squeezing action the pulp is removed. The continuous striking from the cutting drum extracted the fibers. Figure 38 shows the leaf sheath during decortication and the extracted fibers.

Figure 38. Decortication and Extracted Fibers

By changing the clearance between the cutting drum blades and stationary beater bar, two tests were performed. For Case 1 the clearance gap was 3 mm and for case 2 the clearance gap was 4 mm.

7.1 Case 1 (3 mm gap)

By adjusting clearance to 3 mm, 12 sheaths of equal length of 500 mm of pseudo stems were tested. The dimension of those sheaths are listed in Table 1.

	Thickness (mm)	Width (mm)
1.	7.9	130
2.	10.14	110
3.	9.15	90
4.	9.47	80
5.	14.8	90
6.	11.53	70
7.	8.28	110
8.	6.67	75
9.	14.09	80
10.	13.09	90
11.	10.69	85
12.	9.34	120

Table 1. Pseudostem Sheath Dimensions for 3 mm gap

Some part of total pseudostem length was held, so effective decortication took place for lengths of less than 500 mm. The average length of fibers extracted was determined to be 400 mm. Non-fibrous material was removed and the quality of extracted fibers was good. Some of the fibers extracted from leaf sheaths are shown in Figure 39.

Figure 39. Extracted Fibers for 3mm gap (Case 3)

Once all of the sheaths were tested out, the extracted fibers were washed as some residue was still attached to it and dried in sun light. The washed, dried and combed fibers are shown in Figure 40.

Figure 40. Washed and Cleaned Fibers

7.2 Case 2 (4 mm gap)

In order to observe the effect of clearance gap on quality of fibers extracted, testing was done by adjusting clearance between stationary beater bar and roller drum to 4 mm. 7 sheaths of equal length of 500 mm were tested. The dimension of those sheaths are listed in Table 2.

	Thickness (mm)	Width (mm)
1.	14.36	100
2.	7.93	85
3.	12.04	120
4.	8.7	40
5.	12.6	90
6.	11.7	73
7.	7.7	130

Table 2. Pseudostem Sheath Dimensions for 4 mm gap

By increasing clearance to 4mm, the decortication process was not as effective to extract fibers out of it. The skin of pseudostem and non-fibrous material was not fully removed therefore, fibers remained held within the sheaths. Due to increase of gap the cutting blades were not able to properly strike the sheaths. The outer surface came in contact with the blades while the lower surface did not. As a result the sheaths after the decortication process have the appearance as shown in Figure 41.

Figure 41. Extracted Fibers for 4mm gap (Case 2)

7.3 Case 3 (Machine Efficiency at 3mm gap)

To determine the efficiency of the machine, decortication operation is performed on the third pseudostem. After bisecting the pseudostem, the sheaths were made into proper shapes. 18 pseudostems of 700 mm length were made. Dimensions of the sheaths are listed in Table 3.

	Thickness (mm)	Width (mm)
1.	8.8	75
2.	5.5	80
3.	8	70
4.	6.5	80
5.	6	85
6.	8	83
7.	5.5	50
8.	6	65
9.	8	105
10.	9	78
11.	8	80
12.	7	110
13.	6	50
14.	6.2	80
15.	9.4	80
16.	7	60
17.	6.5	70
18.	7.6	65

Table 3. Pseudostem Sheath Dimensions for measuring machine efficiency

The average length of extracted fibers as shown in Figure 42 is about 700 mm. The efficiency of machine is determined by the formula

$$\text{Efficiency} = \frac{\text{Dry Fiber Weight}}{\text{Pseudostem Weight}}$$

Sample Size	Pseudostem Weight	Extracted Fiber Weight	Dry Fiber Weight	Extraction Efficiency of Dry Fiber
18 pieces	2 kg 300 g	350 g	55 g	2.39 %

Figure 42. Extracted Fibers for Case 3

7.4 Residue Collection

Once all the testing was completed, the collector was taken out of machine and residue was collected which can be used as organic fertilizer after further processing.

Figure 43. Residue collected during decorticator operation

Chapter 8 Conclusion and Recommendations

The decorticator machine was fabricated and during the testing phase two functions of machine were checked. After the bisection of banana pseudostem, the pseudostem samples were created and fiber extraction was carried out. During testing the gap between the cutting drum blades and beater bar was varied to see the effect of variation on the extracted fibers. The fibers which were extracted with gap more than 3mm were not clean and their gummy material was not completely removed. The thickness of pseudostem being fed into the machine also affected the decortication process.

Further research work can be carried on the machine to understand other factors that can improve its efficiency. Different blade profiles and variable cutting drum speed can be used during decortication process to determine the effect on extracted fibers. The bisection operation of the machine can be changed to function like that of vertical band saw machine so that cutting of larger diameter banana pseudostems is easy.

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