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# DESIGN AND FABRICATION OF A BANANA FIBRE MACHINE

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**Abstract***:* The banana producing countries of the CARICOM region have been particularly challenged. The loss of preferential agreements in many major markets, exacerbated by the proliferation of pests and viruses that attack the banana plant, have led to significant losses in revenue over the past few years. With banana production being the key export in many of these countries, this has meant significant decreases in foreign exchange earnings and in general a blow to their national economies. Recognizing the significant investment in banana production infrastructure in these countries, efforts have been made to develop alternative markets based on the banana plant. It has been found that the fibre produced from the banana stalks has desirable material properties and can be used in paper production, craft creation and as an input for other bio-composite materials. Recent initiatives by some regional governments have begun to foster new markets for these fibres in the United States and Europe. However, exploitation of these markets would require significant regional capacity development, primarily in the form of increased fibre production levels. One solution is to design and construct a machine that meets the needs of the stakeholders of the region and the international market. This paper would discuss the design, fabrication and testing of a prototype banana fibre machine. The design process is unique as it uses both the standard engineering design process and an energy/impact loading analysis for the machine's critical components, permitting overall improvement in energy consumption. Testing was performed on the machine and it has been shown to produce fibres from the banana stalk more effectively, with comparable quality and at a higher production capacity per unit of energy utilized, as compared to existing designs used in other regions. This machine addresses some of the current challenges and in so doing, provides a critical component to the proposed alternative regional banana value chain.

## Introduction

Traditionally, many islands of the Caribbean region have based their livelihoods on agriculture. In particular, the production of bananas for export has been a fundamental and predominant sector in the economies of many of the smaller island states. In recent times however, the removal of preferential tariffs, amendments to existing and formalizations of new trading blocks and agreements, and a number of other globalization induced dynamics, have negatively influenced the capacity of these island states to compete in international markets. Accordingly, this has led to lower market shares and in turn lower revenue streams for these countries. In keeping with this, many of these countries have sought new markets for their banana crops, as well as to develop value added products from the bananas with the intention of accessing new markets and the associated revenues available further down the value chain.

One such product has been the production of banana fibres. Natural fibres may be categorised as cellulosed (plant based), protein (animal derived) or mineral. Banana fibre can be categorized as a natural fibre by standard designations and requires less energy to manufacture as compared to synthetic fibres [1]. Natural fibres also have other key advantages over synthetic fibres [2] and have gained commercial popularity in recent years as a result of the textile manufacturing industry. Due to its high sheen and flexibility, fabric produced from banana fibre is quite thin and light weight, as compared to other natural plant based fibres, such as jute and pineapple leaf fibre. Its high strength and low strain properties have also made it possible for banana fibre to be used as an additive in fibre reinforced, polypropylene automobile floor panels.

The banana fibres produced by the Caribbean island states has the potential to be sold to the North American market, where manufactures can utilize them in craft production, paper and bio-composite materials. Currently however, a small amount of fibre production is done by hand or by small mechanical devices, and the production levels will be unable to meet the demand of these markets. Accordingly, there is a need for increased production levels to meet this demand. However, the availability of effective and suitable machinery can prove to be a challenge. For instance, India is the largest banana producer in the world, yet most of its banana fibre production and usage is directed to cottage industry applications. The main reason for its underproduction of more refined products, may be attributed to the limited scientific testing and data available regarding the proper mechanical extraction of banana fibre and its refinement [3].

One of the earliest machines for large scale production is credited to Frederick P. Gardner and it was designed to be used for pineapples, abaca and other similar fibrous crops. In the machine, both sides of the fibrous material were subjected to a shearing force by means of a continuously spinning bladed drum and a series of fixed blades [4]. Perhaps the most commonly available machine is the banana fibre decorticator or extractor, which utilizes a combination of compressions and continuous impacting to effectively beat the pulp material away from the fibrous sheaths [5]. Another notable existing design was developed by Krishi Vidyan Kendra and employs very similar operating principles to deliver a significant increase in fibre production over manual methods. This machine has the capacity to output up to 15 kg in an 8-10 hour period. Notwithstanding this, there are known efficiency issues with many of these machines, given the generic nature of the design. Additionally, many have low production capacities and are difficult to repair and maintain. More importantly, most machines have suffered from critical safety issues which have led to serious concerns and even more serious injuries in some cases.

In keeping with this, the current work seeks to develop a banana fibre machine to address the regional situation. The approach seeks to utilize key engineering design principles to develop a more effective machine, with a suitably larger capacity. Additionally, this design seeks to incorporate mechanisms that will allow for variability in the operational components, so as to optimize its use with different strains of banana plants. Emphasis will also be placed on the safety features of the design. The subsequent sections of this paper present the approach utilized in the design of the machine and key results obtained from the testing of a prototype. Lastly, an outline of the key findings obtained and the future work intended for the machine are presented.

## Methodology

The methodology utilized in the design and development of the proposed banana fibre machine, follows six key stages. The first stage of the process involved conducting a review of existing literature, research documentation and patent documents. During this stage, the key issues of the work were identified and the core emphases refined. The second stage of the process entailed the development of design concepts. Data obtained from the first stage as well as from interviews conducted with key personnel, was used to identify the critical functional requirements of the machine, via a functional decomposition approach. This data was also used to obtain critical selection criteria, which was in turn used in a morphological approach to the development of various machine design concepts. The design concepts developed were evaluated via a pugh chart and the highest scoring design was selected for prototyping. The third stage of the process entailed the design of the selected concept. This is the subject of the subsequent section. Upon completion of the design, a bill of material quantities was developed. In the fourth stage, the selected design was fabricated. A full scale prototype was fabricated in the engineering workshop, of the Faculty of Engineering, University of the West Indies, St. Augustine Campus, utilizing standard machine shop practices. Stage five of the process involved testing of the manufactured prototype. The two key aims of the testing process were to optimize the machine parameters for a given strain of banana pseudostems and to identify key aspects of the design that required further improvement. An outline of the testing process is given in Section 3.3. The final stage of the process is iterative and involves the continuous improvement of the design via testing and re-engineering. Currently, this stage is ongoing.

Description of design

The prototype features a beater roll similar to some existing machines, but differs significantly in the manner in which pseudostem sheaths are fed to the system, as well as how the fibres are removed post processing. Pseudostem sheaths are sent in at the top of a bed plate, leading to a pair of horizontal squeezing rolls. The clearance between these rolls is adjustable, depending on the size of the feed stock. At the very end of the bed plate, a beating roll is restricted to spin on a horizontal axis, where it beats the pulpy material out of the sheaths, separating it to obtain the long banana fibres, while concurrently drawing the feed stock into the machine. The bed plate ends in a downward acute angle, to allow the banana fibres to fall freely downward, between two closely spaced rolls. A fixed rubberised plate is positioned to the closest allowable position to the spinning blades to prevent waste material from going down with the fibres into the rolls. The speed of these rolls will serve two main purposes. Firstly, since it will spin at a slightly higher speed than the feed rolls, it will maintain a degree of tautness in the fibres during processing. This also aids in directing them towards the conveyor system which finally allows the user to remove the processed fibres safely by hand. The design is powered by two independent, variable speed motors and power is also transmitted by an intermediate belt drive between the first motor and the drum. Figure 1 shows a drawing of the prototype.

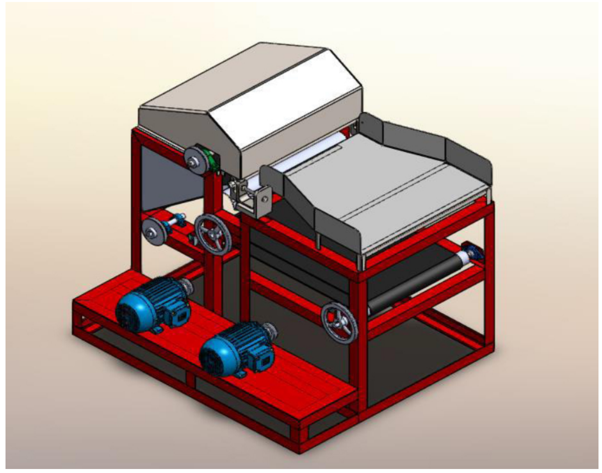

Figure 1: Design drawing of the prototype

Testing Procedure

Testing of the device was conducted using banana pseudostems obtained from the Faculty of Food and Agriculture's field station, at the University of the West Indies, St. Augustine Campus. The tests were conducted using one strain of banana species. The primary aim of the tests were to determine the optimal parameters for fibre yield of the given banana plant species. The main steps of the testing process were as follows:

1. The feed system was adjusted to an initial blade clearance of 0.61mm, and the nuts of the carriage assembly secured.
2. The motor supplying power to the drum was started and its speed slowly increased to approximately 500 rpm.
3. Two pseudostem sheaths were weighed and fed into the drum separately, for a period of 8s each. For safety reasons, only a portion of the sheaths were processed, while the remaining piece served as a handle. To account for the unprocessed material, the remaining stumps were cut free from the fibres and the difference in mass measured.
4. Steps 1-4 were repeated at 550 rpm, 600 rpm and 640 rpm respectively.
5. The motor was then switched off and the clearance adjusted. The entire procedure was repeated for clearances of 0.457mm and 0.12 mm.

Design Approach and Analyses

The design of the prototype was perhaps the most critical component of the work. The low efficiencies in some existing machines can be attributed to the ineffective design process. More specifically, though the fibres are flexible they can be damaged during the extraction process. Additionally, the force or energy required to separate the fibres may vary depending on the fibre composition and size [6]. Key to the extraction process is the use of a method that delivers sufficient force to separate the pulp from the fibres in a manner that allows for easy removal, while not damaging the fibres themselves. Machines that cater for several varieties of crops generally do not have enough specificity in the design of the separation process and can be either too harsh destroying some of the fibres in the process or inadequate leading to insufficient fibre removal. In addition, machines that are geared to one species of banana plant also run the risk of decreased efficacy when using other species. Accordingly, the current prototype seeks to optimize the separation process by varying the machine speed and clearance distances, allowing for variations in the separation force applied.

Accordingly, the most crucial aspect of the design process was the determination of the energy requirement for the separation process. The first stage in this process involved determining the failure stress of the banana pseudostems. Pseudostem samples were acquired and underwent compression testing using a Tinius Olsen compression testing machine. During the tests, the samples were compressed until the pulp began to separate from the fibrous material. The values of the force applied at that point were recorded for several samples, in addition to the magnitudes of the compression of the material. This data was then used to calculate the value of the work done or strain energy via the expression: $U = \int_0^x F dx$, where x represents the displacement through the material, F represents the applied force and U the strain energy. Subsequently, the strain energy absorbed per unit volume was calculated. An average value of the strain energy per unit volume was further calculated from several samples, and represents the amount of energy that must be applied to a unit volume of pseudostem material to achieve successful separation. Considering the proposed dimensions of the blade that would strike the pseudostems, the angular velocity required to achieve a sufficient impact force and deliver the required strain energy was then calculated. Subsequently, the torque required for a given angular velocity was then calculated, and ultimately, the power requirement of the machine.

The other components of the prototype were designed based on the strain energy and power requirement values previously calculated. This included the design of the belt drive system to transfer power from the motor to the requisite power shafts; the main emphasis here was the determination of belt tension and speed. The other key aspect of the design process involved the determination of component dimensions and material types, for all of the load bearing components of the design. This included the blades, drum plate, shafts and the frame. This was primarily done utilizing the finite element analysis capabilities of the software package SolidWorks but was also corroborated by hand calculations. Figure 2 depicts some of the analysis results provided by the software.

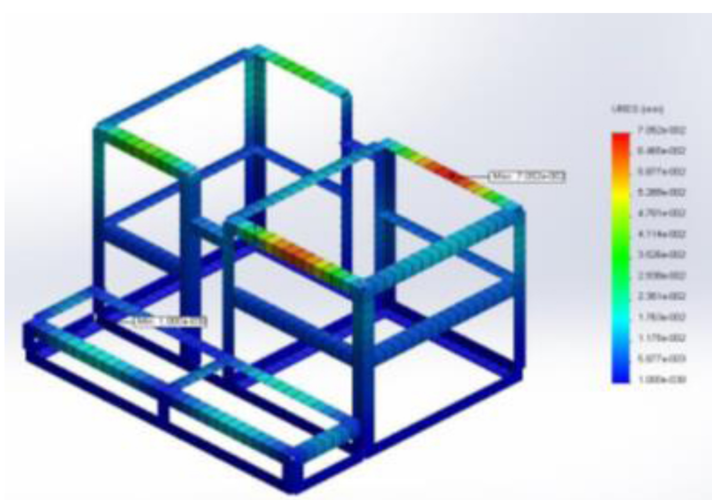

Figure 2: Finite element modelling and analysis of the prototype frame via SolidWorks

**Results and Discussion**

A summary of the results obtained from testing the fabricated prototype, are presented in Table 1. Additionally, Figure 3 shows a photo of the prototype and some separated fibres.

| Clearance used (mm) | Stem before processing (kg) | Stem after processing (kg) | Stump (kg) | Shredded material (kg) | % fibre yield | drum rpm | rate of shredding (kg/hr) | Average rate (kg/hr) |
|---|---|---|---|---|---|---|---|---|
| **0.61** | 0.389 | 0.221 | 0.178 | 0.043 | 20.38 | 554 | 0.32 | |
| | 0.264 | 0.125 | 0.09 | 0.035 | 20.11 | 554 | 0.26 | 0.29 |
| | 0.493 | 0.178 | 0.135 | 0.043 | 12.01 | 605 | 0.32 | |
| | 0.443 | 0.177 | 0.121 | 0.056 | 17.39 | 605 | 0.42 | 0.37 |
| | 0.309 | 0.125 | 0.104 | 0.021 | 10.24 | 645 | 0.16 | |
| | 0.204 | 0.091 | 0.065 | 0.026 | 18.71 | 645 | 0.2 | 0.18 |
| **0.457** | 0.361 | 0.265 | 0.238 | 0.027 | 21.95 | 554 | 0.2 | |
| | 0.357 | 0.183 | 0.156 | 0.027 | 13.43 | 554 | 0.2 | 0.20 |
| | 0.406 | 0.258 | 0.223 | 0.035 | 19.13 | 602 | 0.26 | |
| | 0.296 | 0.179 | 0.147 | 0.032 | 21.48 | 602 | 0.24 | 0.25 |
| | 0.149 | 0.082 | 0.061 | 0.021 | 23.86 | 641 | 0.16 | |
| | 0.252 | 0.135 | 0.106 | 0.029 | 19.86 | 641 | 0.22 | 0.19 |
| **0.12** | 0.273 | 0.171 | 0.128 | 0.043 | 29.66 | 557 | 0.32 | |
| | 0.2 | 0.103 | 0.069 | 0.034 | 25.95 | 550 | 0.26 | 0.29 |
| | 0.219 | 0.147 | 0.125 | 0.022 | 23.4 | 600 | 0.17 | |
| | 0.164 | 0.111 | 0.096 | 0.015 | 22.06 | 600 | 0.11 | 0.14 |
| | 0.335 | 0.12 | 0.097 | 0.023 | 9.66 | 641 | 0.17 | |
| | 0.259 | 0.123 | 0.098 | 0.025 | 15.53 | 640 | 0.19 | 0.18 |

Figure 3: Prototype with tested samples resting on the feed tray

Table 1 shows results for drum speeds of 550, 600 and 650 rpm. Tests were also carried out at speeds of 500 rpm and lower. However, it was found that at those speeds, there were incomplete or low levels of fibre separation. This can be attributed to the inadequate transference of energy to the pseudostem samples at these speeds; at these speeds the blades were unable to transfer the required levels of strain energy. Accordingly, this places a lower limit on the speeds that can be used for effective operation.

The results show the highest rate of fibre production during the tests to be 0.37 kg/hr. This was obtained at a drum speed of 600 rpm and a clearance of 0.61 mm. This result suggests that this combination was the optimum arrangement for the pseudostem samples tested. Of particular interest were the trends observed in the results. Firstly, it can be seen that for the 0.61 mm and 0.457 mm clearance widths used, the highest production rates occurred at 600 rpm and decreased at higher speeds. A second trend of interest was that generally production rate decreased with decreasing clearance width used; the notable exception to this would be the 0.12mm width, 550 rpm combination. Collectively, the results indicate that there exists an optimal value of energy that must be imparted to the pseudostems to ensure the most effective fibre separation process. As this energy is primarily imparted via impact, a variation in the distance between the blades and the pseudostems (changes in clearance widths) must be balanced by changes in the blade speed. At the same time, these parameters represent the machine configuration for which its energy is best utilized and least wasted. Accordingly, an effective banana fibre extracting machine must be able to vary its parameters to achieve this.

In general, the tests demonstrated that the machine was capable of achieving its primary function effectively. During testing, one key problem observed concerned the waste removal conveyor system, which suffered from a shifting belt drive. With the exception of this, the machine functioned as designed. For the purposes of the tests, small samples of pseudostems were used, leading to low fibre production rates. This limited use of material was to facilitate observation and analysis of the machine's basic components and overall performance. However, the machine was capable of processing several pseudostems at once. In keeping with this, current work includes the redesign of the machine's waste removal system to facilitate better functionality. In addition, further testing is to be done using large feed rates and longer operational times, to determine the implications of long term operation. This work is currently ongoing.

## Conclusion

Changing market conditions have made it necessary for the banana producing small island developing states of the Caribbean region to explore the production of value added banana products. Some of the products being considered require banana fibres as the feedstock. However, these are generally made by hand in quantities that are unable to support the market's demand. The current work seeks to design a banana fibre extraction machine that has a production capacity suitable for the regional banana fibre producers.

A prototype was designed using standard engineering principles. Critical to the design process was the utilization of a strain energy approach in the determination of the energy requirement for successful fibre removal. Additionally, the design sought to incorporate the capacity to vary the machine's parameters, so as to optimize the fibre separation process for varying banana plant strains. The prototype design was fabricated and tested at the University of the West Indies' St. Augustine Campus. The tests confirmed that the design was successfully able to meet its primary objectives. Further, the variation of the prototype's operational speed and clearance distance verified that there is an optimal value of force or energy that must be applied to the pseudostems for optimal fibre yield. This variation in the prototype's parameters allows it to be further calibrated for optimal fibre production for various banana plant strains. Despite the machine's general success, problems with one of its subsystems were identified. Additionally, the testing process did not assess the prototype's capacity to process large capacities of pseudostems, or the impact of long term machine operation. These concerns, as well as the examination of the machine's yield for various strains of banana plant, are currently the focus of ongoing work by the research and design team.

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