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Design And Construction Of Automatic Safety System Potato Stick Cutting Machine

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Abstract

This research aims to develop a potato stick cutting machine with an automatic safety system, which is a crucial step in supporting the sustainable growth and development of the French fries industry. The methodology used includes a literature review, needs identification, conceptual design, machine fabrication, and testing. In determining the allowable tensile stress of the material, the value used is 120 N/mm², while for the torsional stress and bending stress of the shaft, the values are 96 N/mm² and 120 N/mm² respectively. Planning the pulley involves using a pulley with a diameter of 76.2 mm, while belt selection involves using a type A V-belt with a length of 48.50 inches. The shaft axis distance is also determined with a correction of 503 mm. Test results show that the machine is capable of achieving a production capacity of 84 kg/hour when equipped with an automatic safety system. This machine also facilitates further processing and opens opportunities for small and medium-sized enterprises (SMEs) to utilize it in potato stick production. This research contributes significantly to the development of the potato processing industry by providing a reliable and efficient solution for potato stick production. Thus, this study is crucial for advancing the overall French fries industry sector.

Keywords: Design, cutting machine, potato, automatic safety

INTRODUCTION

The potato industry begins with the production process in agriculture, where farmers plant, cultivate, and harvest potatoes [1]. Potato production can be carried out on various types of land, ranging from small plots for small-scale farmers to large tracts for commercial farmers. Potatoes can be processed into various food products, such as french fries, mashed potatoes, potato chips, frozen potatoes, potato flour, and many more [2]. This processing involves various technologies and machines to process potatoes into finished products ready for consumption. Potato products are distributed to various local, national, and international markets [3]. Distribution can be done through various channels, such as wholesale, retail, restaurants, and other food industries [4]. Transportation and logistics play a crucial role in maintaining the freshness of potato products during distribution. The potato processing process can be carried out using advanced modern potato cutting machines or manually by slicing potatoes using a knife [5].

The purpose of this research is to reduce the risk of work accidents that may occur due to direct contact between workers' hands and knives during the potato cutting process [6]. Additionally, this research also aims to increase production capacity by efficiently cutting potatoes in large quantities and saving time by speeding up the cutting process. French fries, or shaped potato snacks, are one of the most popular and preferred potato snacks [7]. However, making french fries is not as simple as buying them from restaurants or fast food stores

The process involves human hands slicing fresh potatoes into blocks of varying lengths, depending on the size of the potatoes used. To produce uniform-sized potato sticks, facilitate further processing, and open opportunities for small and medium-sized enterprises (SMEs) to utilize this machine in potato stick production [8].

The implementation of the potato stick cutting machine with an automatic safety system is expected to provide a practical solution to address the challenges faced in the potato processing industry. With the automatic safety system in place, it is expected to reduce the risk of work accidents and improve the welfare and productivity of workers. This machine is also expected to enhance overall production process efficiency, thus making a positive contribution to the development of the food industry. Therefore, the design and construction of the potato stick cutting machine with an automatic safety system will be a significant step in supporting the sustainable growth and development of the French fries industry.

RESEARCH METHODS

The aim of this research is to develop a potato stick cutting machine with an automatic safety system, which is a crucial step in supporting the sustainable growth and development of the french fries industry. With the introduction of this machine, it is expected to enhance efficiency in the french fries production process and reduce the risk of work accidents during potato cutting. Additionally, this machine can ensure consistency in the size of potato pieces, which is a vital factor in producing high-quality products [9]. Therefore, the development of this potato stick cutting machine not only provides benefits in terms of productivity enhancement and workplace safety but also has the potential to drive the growth of the french fries industry. The methodology employed in the research to design and construct the potato stick cutting machine may involve several steps or stages, as illustrated in **Fig. 1.**

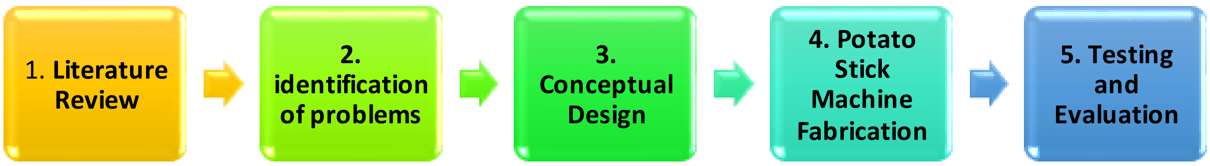


Fig. 1. Research Scheme

1. Literature Review
   The initial step is to conduct a literature review to gain in-depth understanding of existing potato cutting machines, the technologies utilized, operational principles, and safety devices commonly employed in similar machines. Literature review also aids in staying updated with the latest advancements in potato cutting machine technology [10].
2. Needs Identification
   After comprehending the basics of potato cutting machines, the next step is to identify specific requirements that need to be fulfilled by the machine to be designed. These include factors such as desired production capacity, desired potato piece sizes, workplace safety, energy efficiency, among others.
3. Conceptual Design
   Once these requirements are identified, conceptual design is carried out to generate the initial design of the potato stick cutting machine.
4. Machine Fabrication
   After the conceptual design is completed, the subsequent step is to construct or fabricate the potato stick cutting machine based on the design. This prototype is usually constructed using readily available materials and relatively simple manufacturing processes.
5. Testing and Evaluation
   Upon completion of the prototype, the potato stick cutting machine is subjected to testing to ensure that it functions as expected. This testing involves evaluating various features and functions of the machine, including safety, cutting accuracy, and efficiency.

The methodology employed in the research to develop the potato stick cutting machine encompasses these steps to ensure that the resulting machine meets market requirements and safety standards.

RESULTS AND DISCUSSION

In response to the increasing demands of the food industry, the potato stick cutting machine emerges as a solution to facilitate human labor in efficiently cutting potatoes into sticks. Equipped with an automatic safety sensor system, this machine is designed to provide several benefits, ranging from increased production to better product quality. In the effort to enhance the productivity of the potato stick business, this machine promises effective and efficient work, as well as uniform cutting results, making it a valuable investment for the food industry. Previous studies on the design of potato stick cutting machines have indeed been conducted by several researchers and companies. For instance, a study conducted by Manuel Michael Beraún-Espíritu, et al. in 2023 [11] discusses the design and development of a potato cutting machine based on a PLC (programmable logic controller) with an automatic safety sensor. In this study, the designed potato cutting machine can produce potato stick pieces with uniform and accurate sizes while minimizing the risk of work accidents. Another relevant study was conducted by Bo Liu, Min Zhang, et al. in 2019 [12], which discusses the design and testing of a prototype potato stick cutting machine with an automatic safety system using light sensor technology. This study shows that the designed potato cutting machine can improve production efficiency and reduce the risk of injuries caused by manual knife use.

The implementation of a potato stick cutting machine with an automatic safety system can serve as the basis for this research. The design of the potato stick cutting machine with an automatic safety system can be observed in the design results shown in **Fig. 2.**

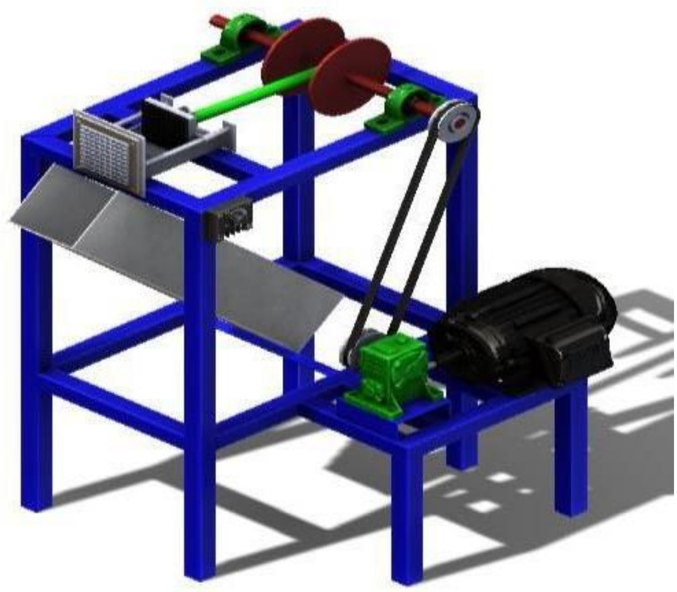


Fig. 2. Design of Potato Stick Cutting Machine

The principle of operation of this machine is quite simple. Firstly, an electric motor generates rotation, which is then transferred to a crankshaft. This crankshaft is connected to a pusher that pushes the potatoes towards the blade. When the machine is turned on, the electric motor will rotate a shaft connected to a gearbox, which is used to change the rotation. From the gearbox, the motor's rotation is connected to two pulleys using a belt [13].The rotation from the first pulley to the second pulley will experience a reduction in speed, resulting in the output rotation being slower than the motor's rotation. The second pulley is connected to the crankshaft that rotates the pusher. This pusher moves up and down to push the potatoes towards the blade for cutting. To ensure user safety, the machine is equipped with a control system. When potatoes are inserted into the cutting table, the pusher will automatically stop moving to prevent work accidents.

In this research, the analysis of the potato stick cutting machine involves a comprehensive exploration and evaluation of several key components, such as the cutting force required for the potato cutting process, the motor power required to operate the machine, the cutting speed produced by the machine, and the technical characteristics of the shafts, keys, pulleys, and belts used in the machine's operation [14]. Additionally, buckling force calculations are performed to determine the structural stability of machine components, while the use of automatic sensors is integrated to monitor and control machine operations accurately and efficiently. Several calculations for the potato cutting machine components can be seen in the equations provided [13].

Determining Potato Cutting Force

The cutting force in the potato stick cutting machine can be determined using Equation 1 [13].

$$Tg = \frac{F}{A} \quad (1)$$

$$F = Tg.A$$

Where:

T = Shear stress (kg/mm²)

F = Potato cutting force (Kg)

A = Cross-sectional area of the potato (mm²)

The testing was conducted with 5 experimental trials. Below is the **Table 1** of data resulting from the potato cutting tests.

Table 1. Results of Potato Cutting Force Testing

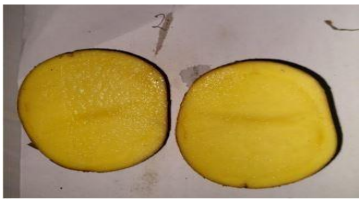
No	D(mm)	F(kg)	$A=\pi r^2$ (mm^2)	$\tau g = \frac{F}{A}$
1.	57 mm	4,3 kg	2550 mm^2	0,001686 kg/mm^2
2.	55 mm	3,9 kg	2374,6 mm^2	0,001642 kg/mm^2
3.	59 mm	4,5 kg	2732,5 mm^2	0,001646 kg/mm^2
4.	51 mm	3,2 kg	2041,7 mm^2	0,001567 kg/mm^2
5.	57 mm	4,15 kg	2550,4 mm^2	0,001627 kg/mm^2

For the results of potato cutting in this test, please refer to Fig. 3.

Potato 1

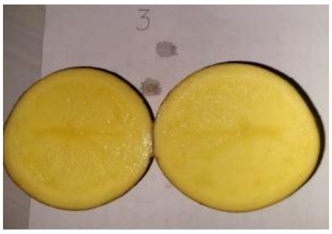
Potato cutting result 1

Potato 2



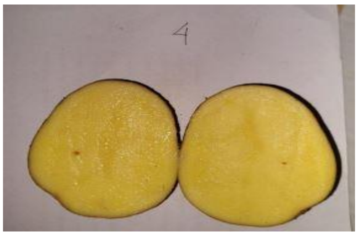
Potato cutting result 2

Potato 3



Potato cutting result 3

Potato 4



Potato cutting result 4

Potato 5

Potato cutting result 5

Fig. 3. Potato Cutting Results

Thus, the highest cutting stress value in the potato cutting experiment is 0.001686 kg/mm². After obtaining the potato cutting stress, next is to determine the potato cutting force (F1):
Where:

F = Potato cutting force (N)

τg = Potato cutting stress = 0.001686 kg/mm²

A = Cross-sectional area of the potato (mm²) = 2732.5 mm²

Therefore,

$$F1 = \tau g \times A \quad (2)$$

$F1 = 0{,}001686\ kg/mm^{\wedge}2 \times 2732{,}5\ mm^2$

$F1 = 4{,}60\ kg$

$F1 = 4{,}60\ kg \times 10\ m/s2$ $F1 = 46\ N$

So, the potato cutting force (F1) is 46 N.

Therefore, to determine the potato cutting force is:

F = F1 × lots of knives

F = 46 N × 16

F = 736 N

To calculate torque, we can use equation 3.
Where:

T = Torsi (Nmm)

r crank 75 mm = 0,075 m

F = 736 N

Therefore,

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

$T = 736\ N \times 0{,}075\ m$

$\boldsymbol{T = 55,2\ N.m} = 55200\ N.mm$

So, the torque on the crankshaft is 55.2 N.m.

To calculate the angular velocity, equation 4 can be used

$$\boldsymbol{\omega = 2 \times \pi \times n / 60} \quad (4)$$

Where:

ω = angular velocity (rad/s)

n = crankshaft rotation 46 rpm

So,

$\omega = 2 \times \pi \times n/60$

$\omega = 2 \times 3{,}14 \times 46{,}66\ rpm / 60$

$\omega = 4{,}81\ rad/s$

So, the angular velocity is 4.81 rad/s.

This study examines the machine analysis of the design of a French fry cutting machine, we can see the machine parameters in **Table 1**.

Table 1. French Fry Cutting Machine Analysis

No	Parameter	Value
1	Determining motor	Power torque on the crankshaft is 55.2 Nm
2	Electric motor used	Electric motor 0.5 HP = 0.37 kW
3	Determining force on the pushrod shaft	Force on the inclined rod is 758 N
4	Buckling force on the pushrod shaft	269.3 N and buckling force (Pcr) is 161077.7 N
5	Determining shear stress	Shear stress is 480 N/mm^2
6	Determining force on the pin shaft	Force to prevent breakage or displacement is 54259.2 N
7	Determining allowable tensile stress	The material allowable tensile stress is 120 N/mm2
8	Determining torsional stress	Torsional stress is 96 N/mm2
9	Determining bending stress on the shaft	bending stress on the shaft is 120 $N/mm2$
10	Pulley planning	diameter of the driven pulley is 76.2 mm
11	Belt selection	belt used is type A V-belt
12	Belt length 48.50 inches	Belt length 48.50 inches
13	Determining shaft axis distance 14	correction of shaft axis distance is 503 mm
14	Machine performance testing	Test data production capacity of the French fry cutting machine using automatic safety system is 84 kg/hour

The analysis of the parameters conducted demonstrates a thorough effort in designing an efficient and reliable French fry cutting machine. In determining the motor power, the torque on the crankshaft of 55.2 Nm has been carefully considered to ensure that the machine can operate with sufficient strength. The use of a 0.5 HP electric motor, or equivalent to 0.37 kW, indicates a suitable power selection for the operational needs of the machine. Determining the force on the pushrod shaft, including the force on the inclined rod of 758 N and the buckling force of 269.3 N, as well as the buckling force (Pcr) of 161077.7 N, reflects meticulous calculations in handling the loads received by the machine. Planning the pulley with a diameter of 76.2 mm and selecting type A V-belts provide a solid foundation for choosing suitable components to efficiently drive the machine. Additionally, performance testing of the machine conducted using an automatic safety system has proven that the machine is capable of achieving a production capacity of 84 kg/hour, demonstrating the alignment between the design and the expected results of this French fry cutting machine. Overall, this analysis confirms that the selected parameters have significantly contributed to ensuring the optimal performance of the designed French fry cutting machine.

As for the results of this research, testing was conducted on the French fry cutting machine that was fabricated. It was found that some potatoes did not fall from the cutting blade, but most of the potato parts had already been cut. Although the potatoes stuck on the blade could be removed manually, the remaining parts were already cut. The cause of this issue is that the lever used to push the potatoes is not long enough, so the cut potatoes do not immediately fall out of the hopper. Images of the machine and the testing conducted can be seen in **Fig. 4.**

Fig. 4. Assembly Design and Testing of a French Fry Cutting

The most significant aspect of this research is that the French fry cutting machine has been equipped with sensors to enhance its functionality. The use of sensors can be customized to specific needs, and to implement them, a program needs to be input into the Arduino Uno. Furthermore, this machine utilizes an electric motor with the primary purpose of facilitating human labor through manual processes. The integration of sensors and electric motors is a crucial step in improving the efficiency and accuracy of the French fry cutting machine, thereby enabling more consistent and overall efficient production. In comparing studies with previous research on potato cutting machines, several interesting differences and similarities were found. Previous research conducted by Appeltans et al. in 2020 [15] focused on using optical sensors to detect the presence of potatoes under the cutting blade, while newer research emphasizes the use of different sensors, such as pressure sensors or motion sensors. The studies also indicate that the designed machine integrates an automatic safety system, whereas in previous research, the machine was not equipped with this feature. Additionally, another difference lies in the use of the electric motor. In previous research, researchers used a motor with lower power, while in this study, a 0.5 HP electric motor is used to enhance efficiency and machine strength. Nevertheless, both studies emphasize the use of type A V-belts in the machine drive system, demonstrating consistency in component selection. Despite these differences, there are also similarities in the goals of both studies, namely to introduce a potato cutting machine that can enhance production efficiency and reduce manual labor. Both aim to provide a more efficient solution in the process of cutting potatoes into consistent fries. Thus, this comparative study illustrates the evolution in the design and technology of potato cutting machines from previous research to this study, with an emphasis on the use of different sensors, integration of automatic safety systems, and improvements in motor power to enhance overall machine performance.

CONCLUSION

This research concludes that the design and development of a French fry cutting machine equipped with an automatic safety system have been successfully achieved with the aim of enhancing the productivity of the French fry industry. The integrated sensor system in this machine plays a crucial role in ensuring operational safety by detecting the presence of human hands and automatically stopping the pusher lever. Utilizing a motor with a power of 0.5 HP and a rotation of 1400 rpm, along with a crankshaft speed of 46 rpm, this machine can operate efficiently. The use of a 1:30 WPA gearbox with a 20 mm diameter shaft ensures effective power transmission, while a 40-inch type A V-belt and a 3-inch pulley strengthen its drive system. The test results show that this machine is capable of achieving a production capacity of 84 kg/hour, confirming the success of the design of an effective and efficient French fry cutting machine. This research makes a significant contribution to improving the industrial production process of French fries and emphasizes the importance of integrating automation technology in the development of modern production machines. Furthermore, this machine also facilitates further processing and opens up opportunities for small and medium-sized enterprises (SMEs) to utilize this machine in French fry production.

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