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Full Paper

Design and development of semi-automatic cutting machine for young coconuts

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Abstract: The purpose of this research is to design, fabricate, test, and evaluate the prototype of a semi-automatic young coconut fruit cutting machine. The design concept is that fruit cutting is accomplished by pneumatic press on a young coconut sitting on a sharp knife in a vertical plane. The machine consists of 5 main parts: 1) machine frame, 2) cutting base, 3) knife set, 4) pneumatic system, and 5) tanks receiving coconut juice and cut fruits. The machine parts contacting edible parts of the fruit are made of food-grade stainless steel. In operation, a young coconut is placed on the cutting base and the pneumatic control is switched on. The coconut is automatically moved to the pressing unit and cut in half by a knife set. The coconut juice flows down to the tank while the cut fruits are separated and moved into the other tank. The machine is found to operate safely without damage to the fruits. The machine capacity is 480 fruits/hr with the total operating cost of about 2.63 USD/1000 fruits.

Keywords: young coconut, coconut cutting machine

Introduction

In Thailand, the Nam-Hom coconut, which is commonly known as the young coconut, is popular for its nice scent, sweet juice and high nutritional value. The young coconut can be consumed fresh or processed into canned products such as coconut juice and coconut jelly. The total export volume of

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young coconuts in 2006 was 33,334 tons and valued at 11.2 million USD [1]. The young fruit sold to the fresh market is usually trimmed to its outer husk so that the coconut looks attractive and can easily be opened. To ready the fruit for consumption, the husk and shell of the fruit must be cut open. Traditionally, a big knife is used to manually chop the husk and shell and create a hole of approximately 60 mm diameter at the top of the fruit. However, this method is hazardous and requires a skilled operator [2].

In an earlier attempt to open the coconut, Sapsomboon [3] invented a coconut opener for retail sale. This device was made of a circular zinc strip with the bottom side made like a saw while the other side was covered with a plastic dome. When the opener was covered on the top of the trimmed young coconut, it was manually pressed and the plastic dome was turned around by hand, then the husk and shell were cut by the saw strip of the opener. This opener was good for coconut retailing. The average time for opening was 41.4 sec/fruit [4].

Jarimopas and Kuson [2] later designed and constructed a young coconut fruit opening machine. The operating system was like a lathe machine which consisted of a fruit holder, a height control mechanism, a knife and its feed controller, and a power transmission system. During operation, the small stainless steel knife slowly penetrated through the husk and shell of the turning fruit in a direction perpendicular to its surface, thus resulting in a circular opening at the top of the fruit. The speed of opening each fruit was 30 seconds on the average.

However, in the industrial process of coconut juice canning for export in Pratumtanee province, fresh coconuts are required to be cut in half without outer husk trimming. Figure 1 shows a manual cutting machine for young coconuts consisting of a table with cutting base and a sharp knife which is mounted to a cantilever bar and a spring. When the operator places a young coconut on the cutting base and presses the cantilever bar, the coconut is cut in half by the sharp knife and the coconut juice pours down into the bowl which is beneath the cutting base. This method is considered very awkward, takes longer time and requires a strong operator for pressing the cantilever bar. Besides, the capacity of production is 2000-3000 fruits per day. The objective of this research, therefore, is to design and develop a semi-automatic cutting machine for the canned coconut juice industry. The specific objectives include: (1) the design and development of the semi-automatic cutting machine for young coconuts at a rate of 300 fruits/hour without outer husk trimming, and (2) testing and evaluation of the efficiency of the cutting machine.

Figure 1. The manual cutting machine for young coconuts

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Materials and Methods

Design and operation

Design parameters for a cutting machine consist of the size of young fresh coconut and the maximum compressive force used for cutting the coconut in half by a sharp knife. For the first parameter, 20 uniform and intact samples of mature coconut were randomly selected, weighed and measured by a size-measuring apparatus (Figure 2). The results of a 3-dimensional size of the fruit was 19.22±0.88 mm, 15.91±0.58 mm and 15.2±0.47 mm, with an average weight of 2.04 ±0.15 kg. For the second parameter, a sharp knife was mounted on a steel frame and placed at the bench of the universal testing machine (Testometric model M500-10kN) for measurement of the cutting force. The samples were divided into 4 groups, each group containing 5 fruits for testing at 4 different cutting speeds (10, 15, 20 and 25 cm/min). The fruit was placed between the knife edge and the cross head of the universal testing machine which was attached to a 10 kN load cell (Figure 3). The highest cutting force at each loading speed was recorded. Results showed that the higher the speed of cutting, the lower was the compressive force. However, the maximum force of 2535 N at 25 cm/min of loading speed was selected for the design of the machine. Variation of the cutting force happened due to the shell strength, which depended further on the fruit maturity.

The design concept of the machine was that the fruit cutting has to be accomplished by pneumatic pressing on a young coconut sitting on a sharp knife in a vertical plane. So it was necessary to calculate the diameter of the vertical pneumatic cylinder. The values used in calculation consisted of the pressure for pneumatic system (7 bars), the compressive force (2535 N) and the safety factor (3 times). The net cutting force was therefore, 2535 x 3=7605 N.

Meanwhile, the compressive force F of the pneumatic cylinder was calculated by the following formula [5]:

$$F = 10\,(A \times P) \qquad (1)$$

and

$$D = \sqrt{\frac{4A}{\pi}} \qquad (2)$$

where A = cylinder area, cm^2
P = air pressure, bar
D = diameter of pneumatic cylinder, cm

The calculated diameter was 11.8 cm and the size available in the market was 12.5 cm. Therefore, the diameter of vertical pneumatic cylinder was 12.5 cm and the length of cylinder was 25.0 cm. Another set of two horizontal pneumatic cylinders which were used for the lateral movement of the cutting base had a diameter of 1.6 cm and length of 28 cm. These cylinders were placed side by side of the cutting base.

The prototype was designed and fabricated (Figure 4) to comprise : 1) machine frame, 2) cutting base, 3) knife set, 4) pneumatic system, and 5) tanks for coconut juice and cut fruits. The machine parts which were in contact with the edible parts of the fruit were made of food-grade stainless steel. The operation procedure was as follows: first, the young fruit was placed on the cutting base, then the operator switched on the control to automatically move the base to be under the pressing unit. The base automatically stopped as sensed by a limit switch and the centre of the fruit was aligned with that of the

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cutting knife. The other limit switch simultaneously triggered the downward movement of the pressing unit to press the young coconut fruit to be cut in half by the cutting knife. The coconut juice was allowed to flow down to the middle tank while the cut fruits were separated into another tank beside.

Figure 2. A size measuring apparatus

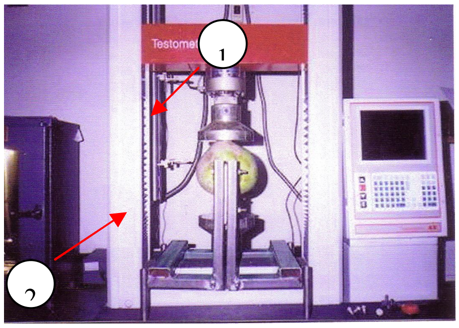

Figure 3. Measurement of cutting force by universal testing machine: 1) cross head of the universal testing machine; 2) sharp knife

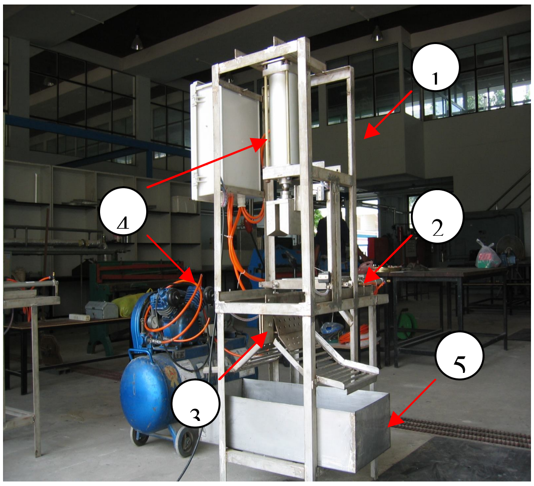

Figure 4. Prototype of the semi-automatic young coconut fruit cutting machine: 1) machine frame; 2) cutting base; 3) knife set; 4) pneumatic system; 5) tank

Performance test

The investigation on the effect of pressing unit speed and orientation of young coconut to be cut on the quality of cutting was conducted. The direction of placing the coconut was either parallel or perpendicular to the knife edge with speed of the pressing unit at 10, 15 and 20 cm/sec. Each test was performed with 5 replications and the analysis of variance technique was applied.

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Engineering economics

The estimated cost of the cutting machine was about 3,175 USD, which included material, pneumatic system, construction cost, 2-hp compressors, and profit of the machine for producer (about 30%, 30%, 15%, 15%, and 10% respectively). The cost of cutting per fruit could be evaluated [6] from the fixed cost (depreciation and interest) and variable cost (electricity, labour and maintenance). Sink fund method was used to calculate the fixed cost. Details of assumption for calculating the variable cost are given in Table 1.

Table 1. Details of calculating variable cost

Machine life	10	years
Salvage value	10	%
Electricity	0.095	USD / unit
1 – labor cost	6.0	USD / day
Working hour	8	hours / day
Working day	210	days / year
Machine capacity	480	fruits / hour
Interest	6	% / year

Results and Discussion

The cutting direction of the coconut was shown to play an important role on the quality of cutting. It is clear (Figure 5) that if the direction of placing the coconut fibre was parallel to a knife edge, it did not successfully cut the coconut in half at any speed of the pressing unit because the knife could not completely cut the fibre of the coconut fruit. However, if the direction of placing the coconut fibre was perpendicular to the knife edge, the fruit was absolutely cut without any damage at any speed of the pressing unit. The pressing unit speed insignificantly affected the cutting quality at $p<0.05$. The appropriate speed was 20 cm/sec because of the least working time. Therefore, the cutting efficiency of the machine was 100%. The time used was only 6-8 seconds from the start until finishing of the process, so the estimated time for cutting was 7 sec/fruit or the capacity of the cutting machine was 480 fruits/hour. The operating cost per 1,000 fruit was about 2.63USD.

a)

b)

Figure 5. Appearance of young coconut fruit after cutting: a) direction of placing coconut fibre was parallel to the knife edge; b) direction of placing coconut fibre was perpendicular to the knife edge.

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Conclusions

Using the pneumatic system for cutting, a semi-automatic cutting machine for young coconuts was designed and tested for coconut juice processing export industry. Fruit fibre orientation must be perpendicular to the knife edge. The machine operation was easy and safe with 100% cutting efficiency and the exporter was happy to use the machine. The machine capacity was 480 fruits/hr while the total operating cost was about 2.63 USD/1000 fruits.

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