Design and Performances of a Coconut Dehusking Machine
Design and performance of a coconut dehusking machine

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Design and performance of a coconut dehusking machine
(Reka bentuk dan prestasi mesin pengupas kelapa)

Abstract
Manual husking is time consuming since it is hand operated using a sharp blade. Besides, it is dangerous and may cause severe back pain to the workers. In addition, the labour shortage in the agriculture sector is critical. Therefore, the development of a mechanical dehusking machine is essential to resolve these problems. This paper highlights the design and development of a mechanical coconut dehusking machine. It consisted of a petrol powered engine, hydraulic system, gears, chains, rollers with sharp spikes, mesh guard, speed controller and frame. The dehusking rate was estimated at 250 – 300 nuts an hour or 7 – 10 seconds per nut. Estimated cost of the dehusker machine is RM10,000 per unit.

Introduction
Coconut is one of the most important industrial crops in the tropics. In Malaysia, the total acreage of coconut is 115,000 hectares (Abdul Rahman 2009) and produces 400 million nuts annually (Arancon Jr. 2009). The domestic demand was reported to be 543 million nuts (Abdul Rahman 2009). Each part of the tree has its own commercial value that can be formed into various products and usages, including to cater for traditional and modern need. The coconut water is used by the food industry in making ‘nata de coco’, a jelly-like food which is a Malaysian favourite. To take out the flesh, the coconut nut has to be husked from the coconut skin. Currently, this is performed manually.

The traditional method of husking is by using traditional tools such as ‘parang’, hoe, blade or spear. The manual husking process requires an operator to use his or her strength and skill to bring the coconut sharply down into the blade, twist the coconut to one side, loosen the husk and detach the fibre from the shell. This action is repeated several times until the entire fibre is detached from the shell. This process is not only difficult and dangerous, but requires necessary skill, strong wrists and arms. Presently, no commercial mechanical husking has been developed, even though the manual method is hampered by poor productivity. In estates, workers are paid RM35 – RM50 for manually husking 800 – 1,000 nuts per day. On average, 100 husked nuts can be produced in 1 h. A machine that can mechanise the husking of coconuts should be developed to replace the inefficient method, time consumed and laborious problem of manual husking. Furthermore, this machine should produce more hourly and daily outputs as well as minimising the risk of coconut husking.

Titmus and Hickish (1929) published their first attempt on developing a mechanical coconut dehusker. Their idea and design were followed and improved by other researchers. MARDI developed a manually operated portable husking device, MD-1 by Abdullah and Zulkifli (1982). The device
was claimed to reduce human physical effort while husking but only suitable for Malayan Tall and Mawar coconut varieties. However, this device is still exposed to high risk as the operator is required to bend near to the husking blades.

Toh and Tan (1984) developed an electrical powered coconut dehusking machine. This machine requires the operator to feed the coconut into a series of turning husk removal in an assembly line. Sukra (1995) developed a mobile semi-mechanised pneumatic dehusking machine. His machine break husks and the broken husks are removed from the shell by an operator. The machine consists of a coconut platform, hopper, pneumatic system, husker blades, operator seat and two-wheel trailer. It is capable of husking Malayan Tall and Mawar coconut varieties at a rate of 150 – 250 coconuts per hour.

Further improvements of the above machines are necessary to improve their working rate, efficiency, safety, functionality and to reduce time consumption. Hence, a new version of a fully mechanical dehusking machine has been developed. This paper highlights the design, development and fabrication of the machine for various varieties of Malaysian coconuts.

Design and development
Conceptual design
The developed mechanical coconut dehusker consisted of a feeder guard, spiked rollers, guiding plates, sprocket gear and chain, hydraulic pump and hoses, power transmission unit (engine) and the main frame to support these components. Each roller spike is rotated in the opposite direction and can be controlled to move clockwise or anti-clockwise. Ripe coconuts are fed into the hopper and a handle was used to press the coconut towards the pair of spiked rollers. The spiked rollers will grip the husks and tear the husks from nut. After the separation, the nut will roll down while the husks will move into the spiked rollers and exit at the rear of the machine. The front and side elevation are shown in Figure 1.

Feeder guard
The feeder guard was designed for safety purposes to protect the operator away from the rotary spiked rollers. This is why the feeder guard is located very close to where the dehusking process is done. The feeder guard is made of iron rods and creates an opening of 60 cm in diameter and 60 cm long. The feeder guard was designed in such a way to accommodate all varieties of coconut. The outlet was designed to be smaller than the inlet because the dehusked coconuts are relatively smaller.

Spiked rollers
Two spiked rollers are considered as the main mechanism of the machine. These components, which move in opposite direction, are the ones that grip and tear the coconut husks in the dehusking process. The spiked rollers are made of hollow iron shaft of 90 mm outside diameter, 10 mm thick and 600 mm long. The hollow shafts are inserted into a solid iron shaft of 35 mm diameter and 920 mm long and fixed at the centre. Each hollow pipe was welded with 33 units of iron spikes arranged in helical arrangement along the surface. The spikes were designed in a conical shape of 10 mm diameter and 10 mm high. The spacing between spikes was 20 mm and the helical angle was 15° between spikes. The solid shafts were attached to the main frame using pillow block ball bearing of 35 mm diameter. A sprocket with 22 teeth was fixed at one end of one shaft while the other shaft was fixed with an 18 teeth sprocket. Both roller spikes with sprockets are shown in Figure 2.

Guiding plates
A pair of guiding plates is located near the spiked rollers. The main purpose of these plates was to ensure that only the exposed spikes are the ones that will do the gripping and tearing process. The other spikes will be covered by the guiding plates. These plates were cut with a zig-zag shape at one
The size of both guiding plates was 130 mm x 610 mm, the groove size was 30 mm x 30 mm and 50 mm between grooves.

**Main frame**
The main frame was designed to support and place all components of the machine. The main frame was fabricated using angle iron mild steel 36 mm x 6 mm. The dimension of the main frame is 875 mm x 1,245 mm x 590 mm. The main frame is divided into three partitions. The first partition of 590 mm x 720 mm is used to place the spiked rollers and hydraulic motor. The second partition
measured at 220 mm x 590 mm is used to place the hydraulic pump and lever, which would control the roller moving clockwise and anti-clockwise. The third partition of 590 mm x 305 mm is used to place the hydraulic tank and engine. The height of the main frame is 880 mm.

**Power transmission system**

The machine is powered by a 4.1 kW (5.5 hp) petrol engine. This engine will drive the hydraulic system that controls the speed and movement of the spiked rollers via a hydraulic motor. A 34 teeth sprocket is attached to the hydraulic motor. This sprocket will drive the 22 teeth and 18 teeth sprockets attached to the spiked rollers using a roller chain system. The speed of the hydraulic motor sprocket and the teeth numbers of the spiked rollers sprocket could be calculated from the following formula:

\[ N_1 T_1 = N_2 T_2 = N_3 T_3 \]  \[ \text{(1)} \]

\[ N_2 = \frac{(N_1 T_1)}{T_2} = \frac{(N_3 T_3)}{T_2} \]

Where,

N1 = speed of the hydraulic motor, rpm
N2 = speed of the driven shaft, rpm
N3 = speed of the hydraulic pump motor, rpm
T1 = diameter of the sprocket
T2 = diameter of the driven sprocket mounted at driven roller spikes shaft
T3 = driven sprocket teeth numbers motor hydraulic

Therefore, the speed of driven shaft (N2) = \((1,200 \times 22)/34 = 776 \text{ rpm}\)
(N3) = \((1,200 \times 18)/34 = 635 \text{ rpm (different direction)}\)

The shaft was made of mild steel and was subjected to combined bending and twisting moments. The diameter of the shaft was calculated using the following formula:

Torque transmitted by the first roller shaft,

\[ T = \frac{(p \times 60)}{2\pi N} \]  \[ \text{(2)} \]

\[ T = \frac{(4,125 \times 60)}{2\pi \times 776} \]
\[ = 50.75 \text{ Nm} \]

- **Figure 2. Roller spikes shaft and sprockets**
Torque transmitted by second roller shaft opposite rotation,
\[ T = \frac{p \times 60}{2\pi N} \]
\[ T = \frac{(4.125 \times 60)}{2\pi \times 635} \]
\[ = 62.02 \text{ Nm} \]
Where,
\[ P = \text{power transmitted by the shaft, W} \]
\[ N = \text{speed of the shaft, rpm} \]

Maximum bending moment for a shaft loaded on both the ends was given by,
\[ M = W \times L = 133 \times 0.92 = 122.36 \text{ Nm} \]
Where,
\[ W = \text{load acting on the shaft, (133 N)} \]
\[ L = \text{length of the shaft, mm (920 mm)} \]

The equivalent twisting moment,
\[ T_e = \sqrt{(K_m \times M)^2 + (K_t \times t)^2} \] ........................................(3)
\[ = (1.5 \times 122.36)^2 + (1.5 \times 50.75)^2 \]
\[ = 33,687 + 5,795 = 198.7 \text{ Nm} \]
Where,
\[ K_m = \text{combined shock and fatigue factor for bending, 1.5} \]
\[ K_t = \text{combined shock and fatigue factor for torsion, 1.5} \]

But equivalent twisting moment,
\[ T_e = \frac{\pi}{16} \times \tau \times d^3 \] ..........................(4)
\[ d = (\frac{te}{\pi} \times \frac{1}{16} \times \tau)^{1/3} \]
\[ = (31.79 \times 10^3 / \pi \times 220.63 \times 10^6)^{1/3} \]
\[ = 0.03579 \text{ m} \]
\[ = 35.79 \text{ mm choose standard shaft 45 mm for safety design for both shafts} \]
\[ S_f = 45/35.79 = 1.2 \]
For second shaft calculated:
\[ d = 0.0362 \text{ m or 36.2 mm choose standard shaft 45 mm, } S_f = 1.2 \]
Where,
\[ \tau = \text{maximum allowable shear stress, } 220.63 \times 10^6 \text{ Nmm} \]
\[ d = \text{diameter of the shaft, mm} \]
The diameter of the shaft could also be calculated by using equivalent bending moment. Using the above formulas, the diameter of the shaft was about 45 mm and the length of the shaft was 920 mm.

**Hydraulic system**
The hydraulic system is used to rotate both spiked rollers. The hydraulic system consists of a hydraulic tank, pump, hoses, pressure controller and flow control valve. To rotate both spiked rollers, a roller chain system was used. Sprockets, will transmit torque from the hydraulic motor to the spiked rollers. The hydraulic lever controller was used to control the spiked rollers rotation direction, either clockwise or anti-clockwise. A ‘stop’ operation was also provided for safety purpose. The flow control valve will act as the operation lever which will determine the movement direction of the spike rollers. To generate the hydraulic pump, the petrol powered engine is used. The pressure controller is used to control the speed of the spike rollers by adjusting the pressure of the hydraulic.
Layout, configuration and construction
The layout and configuration of the equipment is shown schematically in Figure 1. The constructed equipment is shown in Plates 1 – 2. The construction of the equipment mainly involved cut and weld task using commonly available mild steel materials. The hydraulic tank, hydraulic lever valve controller and hydraulic hoses for the roller rotation were outsourced from a local manufacturer.

Performance and evaluation of the coconut dehusker
The completed machine was tested in the field with four varieties of coconut, namely Malayan Tall (MT), West African Tall (WAT), Malayan Yellow Dwarf and Malayan Red Dwarf. A sample of 10 coconut fruits from each variety were prepared for testing the machine. The engine was started and the throttle was setting to run the machine in 1,200 rpm, speed detector was used to evaluate the roller rotational speed. Each sample was fed into the machine continuously and the time to complete the dehusking process for each sample was taken. The experiment was repeated until 10 samples for each treatment variety were completed. The other data such as physical properties of coconut varieties were also recorded.

Dehusking mechanism
The mechanism that is used to dehusk coconuts will be in the type of spiked rollers. It has two spiked rollers that are positioned within a distance from each other so that there is enough space for the husks to exit the machine. The waste or the husk of the coconuts will then move downwards to a collection bin. To have this kind of operation, the coconuts should be fed vertically into the machine. Therefore, it should be positioned at a certain angle, so that the husks and the nut can move in different directions.

Table 1 shows the physical characteristic of the coconut varieties used to determine the parameter of the design feeder for coconut dehusker. The design of the coconut dehusking machine created using AutoCAD. A 3D drawing was prepared so that it would be easier to convert to 2D drawing afterwards. Figure 1 showed the side and front view drawing of the coconut dehusker machine. Figure 2 showed the detail design of roller and spikes.

Plate 1. Side view of mechanical coconut dehusker
Plate 2. Coconut dehusker in operation
Table 1. Total mean physical properties (cm) of coconut varieties (n = 10)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Circumference</th>
<th>Length</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malayan Tall</td>
<td>59.49</td>
<td>23.43</td>
<td>3.40</td>
</tr>
<tr>
<td>West African Tall</td>
<td>47.58</td>
<td>20.50</td>
<td>2.73</td>
</tr>
<tr>
<td>Malayan Red Dwarf</td>
<td>44.90</td>
<td>20.59</td>
<td>2.56</td>
</tr>
<tr>
<td>Malayan Yellow Dwarf</td>
<td>47.54</td>
<td>19.30</td>
<td>2.38</td>
</tr>
</tbody>
</table>

**Machine description**

Generally, the function of the machine is to scrap the coconut skin and the coconut husk from the skin. It is a portable machine which can be operated indoors or outdoors. The 4.1 kW (5.5 hp) petrol engine transmits power to generate a hydraulic pump which operates a hydraulic motor. The hydraulic motor then rotates the gears and double spiked rollers that are connected to them. The speed of the spiked rollers, which is controlled by the hydraulic motor, is adjusted via a pressure gauge. The direction movement of the spiked rollers is controlled by a lever that controls the forward, reverse and stop direction.

The spiked rollers are covered with a mild steel mesh tunnel. This mesh tunnel acts as a safety guard to avoid operator’s hand from insertion towards the spiked rollers during operation. A lever located on the mesh tunnel is used to adjust the coconut position during dehusking operation. During operation, the rotating spiked rollers will squeeze the coconut husk, detach the husk from the nut and push it towards the rear end of the machine. The coconut nut that was separated from the husk is dropped towards the front end of the machine. This is why the spiked rollers are positioned in an inclined direction. The husks can be dropped at the rear while the nut is dropped at the front of the machine. This machine only requires one operator to operate this machine.

**Results and discussion**

A machine that specifically functions to dehusk coconuts was designed, developed and fabricated. After obtaining the required parameters such as design concepts, power generation, physical properties of coconuts and dehusking mechanism, a design of the machine was created using AutoCAD. The power used by the machine was petrol powered engine, which is lighter and smaller compared to diesel powered engine. The physical properties of coconuts (weight, vertical and horizontal circumference, radius and husk thickness) were obtained to justify the size of the handle. Table 1 shows the mean reference parameter to design the machine. The machine was fabricated in house at MARDI Headquarters, Serdang with reference to the 3D drawing of the machine.

**Overall performance**

Almost all design requirements set out for the proper type have been met. Nevertheless, there is scope for further improvement to its performance especially with respect to its effective machine capacity and application working rate. Table 2 shows the average dehusking time including handling time of different coconut varieties. This result is similar to those reported by Md Akhir et al. (2006) and Mohd Taufik and Md Akhir (2014).

**Cost appraisal for machine**

Table 3 shows the simple economic analysis. The annual costs of operating a machine can be divided into two categories namely fixed cost and variable cost or running cost. The fixed costs consist of depreciation, interest on capital, insurance and taxes where applicable. The variable costs comprise repairs and labour, together with fuel consumption. The cost of operation was calculated using procedure recommended by RNAM test code (United Nations 1995). Annual working hours were
estimated as 800 hours per annum (William et al. 2005). The breakeven point and pay back period were also calculated for the machine.

Table 2. Total mean time of coconut dehusking and handling in different variety (n = 10)

<table>
<thead>
<tr>
<th>Coconut variety</th>
<th>Husking time</th>
<th>Handling</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malayan Tall</td>
<td>7.15</td>
<td>3.52</td>
<td>10.66</td>
</tr>
<tr>
<td>West African Tall</td>
<td>6.98</td>
<td>3.27</td>
<td>10.26</td>
</tr>
<tr>
<td>Malayan Red Dwarf</td>
<td>7.64</td>
<td>3.34</td>
<td>10.98</td>
</tr>
<tr>
<td>Malayan Yellow Dwarf</td>
<td>12.84</td>
<td>3.32</td>
<td>16.20</td>
</tr>
</tbody>
</table>

Table 3. Cost estimates for machine

<table>
<thead>
<tr>
<th></th>
<th>Annual cost (RM)</th>
<th>Cost/hour (RM)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td>(10,000 – 2,000)/10 = 800</td>
<td>1.00</td>
</tr>
<tr>
<td>Interest @ 10% of average price</td>
<td>[(10,000 + 2,000)/2] x 0.10 = 600</td>
<td>0.75</td>
</tr>
<tr>
<td>Insurance (1% of purchase price)</td>
<td>[(10,000 + 10,000)/2] x 0.01 = 100</td>
<td>0.125</td>
</tr>
<tr>
<td>Taxes (1% of purchase price)</td>
<td>10,000 x 0.01 = 100</td>
<td>0.125</td>
</tr>
<tr>
<td></td>
<td>Total fixed cost (A)</td>
<td>2.00</td>
</tr>
<tr>
<td><strong>Variable cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repair and maintenance</td>
<td>10% of purchase price</td>
<td>1.25</td>
</tr>
<tr>
<td>Labour cost</td>
<td>6.25</td>
<td></td>
</tr>
<tr>
<td>Fuel @ RM1.80/litre (2 litres/h)</td>
<td>3.60</td>
<td></td>
</tr>
<tr>
<td>Lubrication, 10% of fuel cost</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>Raw materials (coconuts)</td>
<td>250 – 300 nuts/h</td>
<td>200.00</td>
</tr>
<tr>
<td>RM0.80/nut</td>
<td>Cost of operation (B)</td>
<td>211.46</td>
</tr>
<tr>
<td><strong>Selling cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nut after dehusk (RM2/nut)</td>
<td>250 nuts = 500</td>
<td>500.00</td>
</tr>
<tr>
<td></td>
<td>Total selling cost (C)</td>
<td>500.00</td>
</tr>
<tr>
<td><strong>Profit cost (D)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D = C – (A+B)</td>
<td></td>
<td>288.54</td>
</tr>
</tbody>
</table>

Calculated by assuming annual working hours as 800 hours (William et al. 2005)

A mechanical coconut dehusker to dehusk coconuts of different varieties has been designed, developed and evaluated. The prototype implement satisfied almost all of its design requirements especially in terms of general preferment, effectiveness in executing the design tasks, and owning and operation costs. Based on preliminary machine testing, the total fixed cost and variable cost of the machine is RM213.46/h operation. Nuts can be sold to dealer at farm price of RM2/nut and the total selling price was RM500. The total profit cost is RM288.54 in an hour. Pay back period to the machine is after 40 h operation.

Conclusion

A mechanical coconut dehusker to dehusk coconuts of different varieties has been designed, developed and evaluated. The prototype implement satisfied almost all of its design requirements especially in terms of general preferment, effectiveness in executing the design tasks, and owning and operation costs. Based on preliminary machine testing, the total fixed cost and variable cost of the machine is RM213.46/h operation. Nuts can be sold to dealer at farm price of RM2/nut after dehusk. The total selling price become RM500/h operation. Total profit cost in 1 h machine operation is RM288.54. The pay back period for the dehusker machine is after 40 h operation.
References

Abstrak