The Sixteenth International Symposium on Artificial Life and Robotics 2011 (AROB 16th '11),
B-Con Plaza, Beppu,Oita, Japan, January 27-29, 2011

Towards the automation of cashew shelling operation

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Abstract: Vietnam is one of the world's largest countries in terms of exporting cashew nuts in kernel form. Gross export value in this field was $750 million in 2009. Domestic production of raw cashews is about 400,000 tons and they are also imported from abroad about 100,000 tons. Hence, a large number of labors work for cashew processing industry. Although most cashew processing operations have been automated, the shelling operation is still conducted manually. Hence, not only shelling rate is very low compared to other operations, but also labor conditions are strenuous and unsafe. Currently, more than 200,000 labors engage in cashew shelling operations in Vietnam. This paper presents a robotic system design for cashew shelling operation to improve working conditions and production efficiency. The proposed design includes the milling operation of cashew shell and splitting process of the milled shell by wedge. In addition, the conveyer system to transport cashews is also designed for increasing the production efficiency. For designing the system, we consider the following three criteria to evaluate the efficiency [1]: (1) shelling rate (kg/h): weight of cashew kernels obtained per unit time, (2) shelling efficiency (%): ratio of shelled cashews over total cashews handled, and (3) whole-kernel recovery (%): ratio of whole kernels obtained over whole and broken kernels. The proposed system achieves 300kg/h, 95% and 80 %, respectively.

Keywords: cashew shelling; milling operation; splitting process; wedge; plate disk

I. INTRODUCTION

Vietnam is one of the world's largest countries in terms of exporting cashew nuts in kernel form. Although most cashew processing operations have been automated, the shelling operation is still manually conducted. Hence, not only shelling rate is very low compared to other operations, but also labor conditions are strenuous and unsafe. Currently, more than 200,000 labors engage in cashew shelling operations in Vietnam.

There are mainly two methods for shelling cashews as follows:

• Cut the shell using form-milling cutter

• Break the shell using hammer-like tool or split it by wedge-type tool

The first method is applied in countries such as Vietnam, Indonesia, Thailand, India and some African countries. Cutters with two thin blades whose profile is based on the cashew shape are used for shelling the cashew (Fig. 1 and 2). Cashews have to be previously classified by size in this approach. Cashew nuts are manually placed between two blades. These blades are connected with two foot pedals by links. Workers pedal them to operate the blades. They use one pedal to cut the cashew and the other pedal to rotate one blade by 90 degree to remove the shell from the cashew kernel.

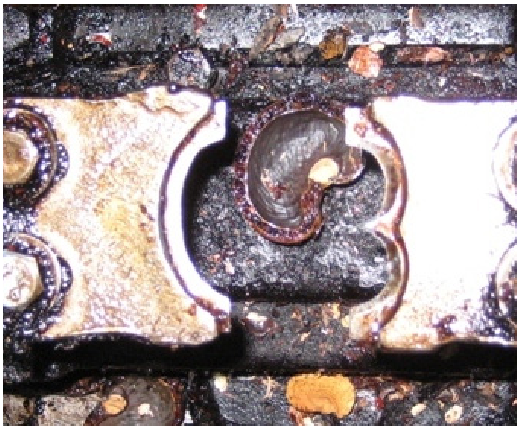

Fig. 1 Cashew shell cutter

Fig.2 Manual cashew shelling

After this operation, workers also use a small knife to take the kernel out of the shell. This method has advantages and disadvantages as follows:

Advantages:

- Simple and inexpensive equipment
- Easy operation

Disadvantages:

- Low shelling rate (approximately 40-60 kg / shift)
- Hard and unsafe working conditions
- The whole-kernel recovery depends on worker's skill

Some countries employ hammer-like tools for breaking the cashew shell. Workers break the cashew shell and take the kernel out of the shell manually. Although this method is simpler than the previous method, the whole-kernel recovery is very low and it largely depends on the worker's ability.

Although wedge-like tools are also used for automatic split of the cashew shell, shelling efficiency and whole-kernel recovery are not sufficient.

This paper presents a robotic system design for cashew shelling operation to improve working conditions and production efficiency. The proposed design includes the milling operation of cashew shell and splitting process of the milled shell by wedge. In addition, the conveyer system to transport cashews is also designed for increasing the production efficiency.

II. SHELLING MACHINE DESIGN

1. Specifications and machine structure

The following specifications are required for automatic shelling machine:

- shelling rate (kg/h): 2000 kg / shift for each system.
- shelling efficiency (%): > 70%
- whole-kernel recovery (%) > 90%

Figure 3 shows a schematic of the designed cashew shelling machine. This machine consists of the following five parts: (1) vibratory cashew feeder, (2) conveyer belt for transporting the cashew, (3) rollers to clamp the cashew tightly, (4) cashew milling cutter, and (5) cashew shell splitter.

The vibratory cashew feeder provides cashews between the pair of conveyor belts continuously. The conveyer belts transport cashews into a position between a pair of disk cutters. After cutting, cashews are put into a splitter that removes shells from kernels.

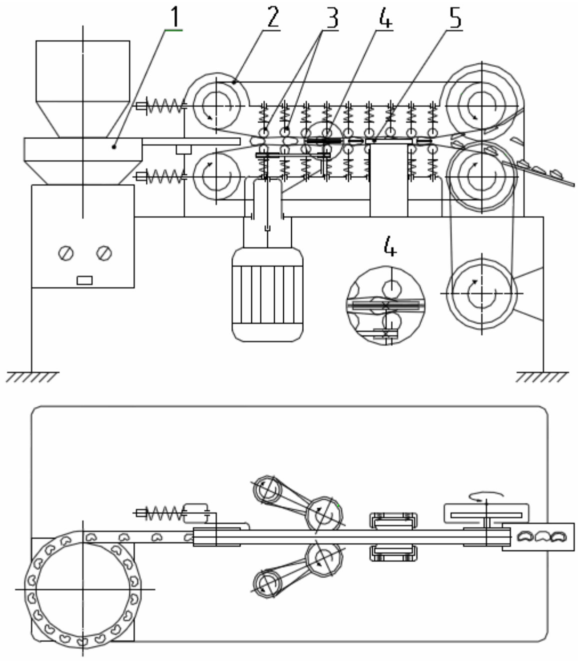

Fig.3 Cashew shelling machine structure

2. Shell cutting system

Figure 4 shows a schematic of the cashew shell cutting system, which includes disc milling cutters rotating with an appropriate speed.

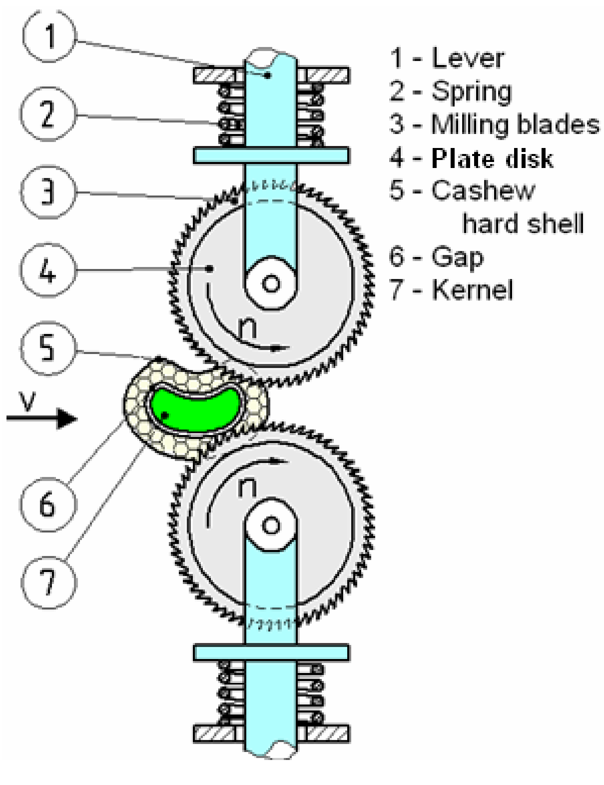

Fig.4 Cashew shell cutting system

The cutters are supported by springs. Cashews are transferred into a position between two milling cutter blades by conveyers.

3. Clamping system

Cashew nut is positioned between two V-shaped conveyor belts (No. 2 in Fig. 5) and tightly clamped by springs (No. 4) and pins. Rollers (No. 3) are employed to reduce friction. Cashew nuts are transferred by the conveyor belt to the cutter (No. 1) position. Clamping force of the spring must be large enough so that pins penetrate the cashew shell and the belt settles the cashew position. Cashew nut is kept fixed against the cutting force.

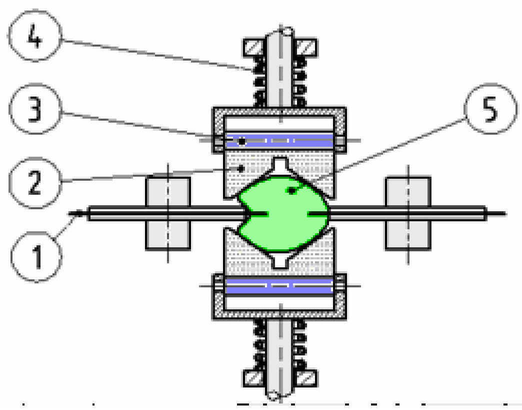

Fig. 5 Cashew clamping system

4. Design calculations

A. Force magnitudes

The cashew cutting force was measured by experiment. The force is less than 5N for a 100 mm diameter blade. The clamping force for cutting is calculated theoretically based on the cutting force, and is estimated approximately as 60 N. The separating force of the shell from the kernel is calculated theoretically, and is estimated approximately as 9 N. The clamping force for the separation is calculated theoretically based on cutting force, and is estimated approximately as 18N for each side.

B. Cutting tool parameters

A cashew shell is a type of wood composed of natural organic compounds, plastic outer shell, spongy middle layer, and hard and brittle inner layer. We have the following parameter values: Number of teeth of the disc cutter is z = 64, the cutter width is W = 2 mm (This cutter width has a larger value than that in [2] to create a larger groove for the separation of the shell from the kernel by wedges.) Because the shell has a wood-like material, we employ 9XC alloy steel for the cutter whose hardness is 39-40 HRC, and the cutting speed is $v = 10.5$ m / s.

C. Cutting conditions

Figure 6 shows forces in the cashew and cutters at the beginning of cutting process. The following notations are used.

R: thrust force

F_c: cutting force

F_{lx1}, F_{lx2}: spring force acting in the direction perpendicular to lines AO_1 and CO_2, respectively.

N_{11}, N_{21}: forces acting from the cashew to plate disks

N_{12}, N_{22}: forces acting from plate disks to the cashew

F_{ms1}, F_{ms2}: frictions between plate disks and the cashew (They have the same direction with F_C).

α_1 : Angle between N_{11} and the vertical line.

α_2 : Angle between N_{21} and the vertical line.

f': Friction coefficient between the cashew and plate disks.

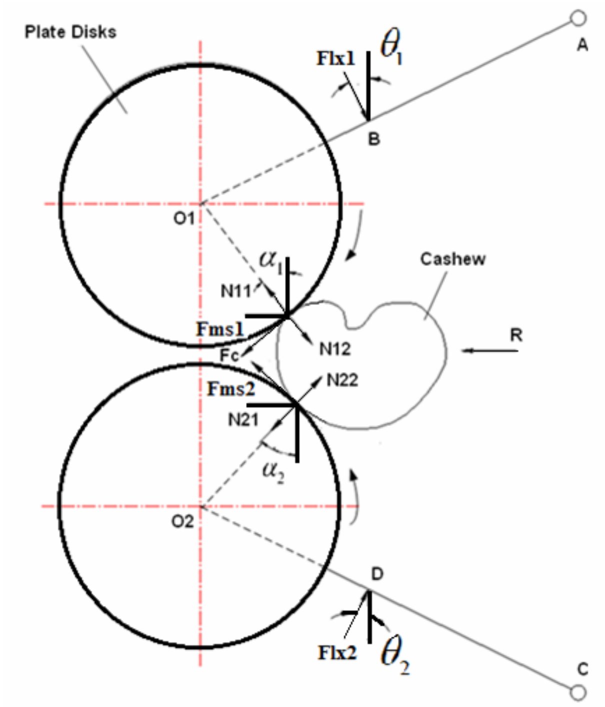

Fig. 6 Forces in cashew and cutter

We have the following conditions for cutting the cashew shell:

$$\begin{cases} N_{11}.\cos\alpha_1 - F_{ms1}.\sin\alpha_1 \geq F_{lx1}.\cos\theta_1 \\ N_{11}.\sin\alpha_1 \geq -F_{ms1}.\cos\alpha_1 + F_{lx1}.\sin\theta_1 \end{cases} \Leftrightarrow \begin{cases} N_{11}.\cos\alpha_1 - f^{/}.N_{11}.\sin\alpha_1 \geq F_{lx1}.\cos\theta_1 \\ N_{11}.\sin\alpha_1 \geq -f^{/}.N_{11}.\cos\alpha_1 + F_{lx1}.\sin\theta_1 \end{cases} \quad (1)$$

$$\begin{cases} N_{21}.\cos\alpha_2 - F_{ms2}.\sin\alpha_2 \geq F_{lx2}.\cos\theta_2 \\ N_{21}.\sin\alpha_2 \geq -F_{ms2}.\cos\alpha_2 + F_{lx2}.\sin\theta_2 \end{cases} \Leftrightarrow \begin{cases} N_{21}.\cos\alpha_2 - f^{/}.N_{21}.\sin\alpha_2 \geq F_{lx2}.\cos\theta_2 \\ N_{21}.\sin\alpha_2 \geq -f^{/}.N_{21}.\cos\alpha_2 + F_{lx2}.\sin\theta_2 \end{cases} \quad (2)$$

Consider the force balance in the horizontal direction, we have

$$\mathrm{R} + \mathrm{F_c}.(\cos\alpha_1 + \cos\alpha_2) + \mathrm{F}_{ms1}.\cos\alpha_1 + \mathrm{F}_{ms1}.\cos\alpha_2 = \mathrm{N}_{12}.\sin\alpha_2 + \mathrm{N}_{22}\sin\alpha_2$$
$$\Leftrightarrow \mathrm{R} + \mathrm{F_c}.(\cos\alpha_1 + \cos\alpha_2) = \mathrm{N}_{12}(\sin\alpha_1 - f^{'}.\cos\alpha_1) + \mathrm{N}_{22}(\sin\alpha_2 - f^{'}.\cos\alpha_2) \quad (3)$$

and for vertical direction,

$$\mathrm{F_c}.(\sin\alpha_1 - \sin\alpha_2) + \mathrm{F_{ms1}}.\sin\alpha_1 - \mathrm{F_{ms2}}.\sin\alpha_2 = -\mathrm{N}_{12}.\cos\alpha_1 + \mathrm{N}_{22}.\cos\alpha_2$$
$$\Leftrightarrow \mathrm{F_c}.(\sin\alpha_1 - \sin\alpha_2) = -\mathrm{N}_{12}.(\cos\alpha_1 + f^{'}.\sin\alpha_1) + \mathrm{N}_{22}(\cos\alpha_2 + f^{'}.\sin\alpha_2) \quad (4)$$

Letting

$x = \sin\alpha_1 - f^{'}.\cos\alpha_1$

$y = \sin\alpha_2 - f^{'}.\cos\alpha_2$

$z = \cos\alpha_1 + f^{'}.\sin\alpha_1$

and $u = \cos\alpha_2 + f^{'}.\sin\alpha_2$,

and considering $N_{11} = N_{12}$ and $N_{21} = N_{22}$, we obtain

$$\mathrm{N}_{11} = [u.[\mathrm{R} + \mathrm{F_c}.(\cos\alpha_1 + \cos\alpha_2)] - y.\,\mathrm{F_c}.(\sin\alpha_1 - \sin\alpha_2)]/(y.z + x.u) \quad (5)$$

$$\mathrm{N}_{21} = [z.[\mathrm{R} + \mathrm{F_c}.(\cos\alpha_1 + \cos\alpha_2)] + x.\,\mathrm{F_c}.(\sin\alpha_1 - \sin\alpha_2)]/(y.z + x.u) \quad (6)$$

Substituting N_{11} and N_{21} in (5) and (6) into (1) and (2), we have

$$\begin{cases} \dfrac{[u.[R + F_c(\cos\alpha_1 + \cos\alpha_2)] - y.F_c.(\sin\alpha_1 - \sin\alpha_2)]}{(y.z + x.u)}(\cos\alpha_1 - f^{/}.\sin\alpha_1) \geq F_{lx1}.\cos\theta_1 \\ \dfrac{[u.[R + F_c(\cos\alpha_1 + \cos\alpha_2)] - y.F_c.(\sin\alpha_1 - \sin\alpha_2)]}{(y.z + x.u)}(\sin\alpha_1 + f^{/}.\cos\alpha_1) \geq F_{lx1}.\sin\theta_1 \end{cases} \quad (7)$$

$$\begin{cases} \dfrac{[z.[R + F_c(\cos\alpha_1 + \cos\alpha_2)] + x.F_c.(\sin\alpha_1 - \sin\alpha_2)]}{(y.z + x.u)}(\cos\alpha_2 - f^{/}.\sin\alpha_2) \geq F_{lx2}.\cos\theta_2 \\ \dfrac{[z.[R + F_c(\cos\alpha_1 + \cos\alpha_2)] + x.F_c.(\sin\alpha_1 - \sin\alpha_2)]}{(y.z + x.u)}(\sin\alpha_2 + f^{/}.\cos\alpha_2) \geq F_{lx2}.\sin\theta_2 \end{cases} \quad (8)$$

Applying experimental parameters $\alpha_1 = 21^\circ$, $\alpha_2 = 28^\circ$, $f^{'} = 0.25$ and $\theta_1 = \theta_2 = 26/28^\circ$, we confirm that conditions (7) and (8) are satisfied as follows:

For (7), we have

311 (N) > 23.7 (N) and 218.05 (N) >11.55 (N) (9)

For (8), we have

285.98 (N) > 23.7 (N) and 257.82 (N) > 11.55 (N) (10)

5. Summary of experiment

The first prototype achieves the following performance experimentally: (Test with 1 ton raw cashew and 5 trials, 200Kg for each trial.)

- Shelling rate (kg/h): 2200 kg / shift for each system.
- Shelling efficiency (%): larger than 72%
- Whole-kernel recovery (%): larger than 95%

III. CONCLUSION

Automatic cashew shelling equipments are required in many countries that produce cashews in kernel form, because shelling rate is not sufficient and labor conditions are strenuous and unsafe in manual shelling operations. This paper presents a shelling machine design based on the milling of cashew shell and the conveyer system. A prototype system was developed to verify the performance of the proposed machine design. This research has opened a new direction for the automation of Vietnam's cashew industry.

ACNOWLEDGEMENTS

This work has been supported by the SUPREM-HCMUT (Strengthening University Project for Research-Based Education Model in Ho Chi Minh University of Technology) with assistance provided by the Japan International Cooperation Agency (JICA).

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