UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF AN OIL PALM FRESH FRUIT BUNCH CUTTING DEVICE

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By

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LIST OF ABBREVIATIONS

Symbols

α	edge angle of the knife (degree)
β	oblique angle (degree)
q	wedge angle (degree)
j	reaction angle (degree)
g	tilting angle (degree)
A	cut area (cm^2)
a	acceleration of body (m/s^2)
ANOVA	analysis of variance
cofg	distance of center of gravity from the frond base (m)
D	coil diameter (cm)
d	depth of cut (cm)
ENCSA	specific cutting energy per unit cut area (kg-cm/cm^2)
F	frond maturity
f	force sensed by the load cell (kg)
Fc	cutting force (kg)
Fc_{max}	maximum cutting force (kg)
F_d	designed force (kg)
FOCSA	specific cutting force per unit cut area (kg/cm^2)
G	modulus of rigidity (N/cm^2)
H	hours left (hr)
k	perpendicular distance from the pivot to the line of Fc (cm)
k_s	spring stiffness (N/cm)
l	length of frond (m)
LRE	edge radius (cm)

Symbols

LSD	least square difference
LTB	blade thickness (cm)
LTE	edge thickness (cm)
LWB	blade width (cm)
m	mass of body (kg)
n	number of coil
r	correlation coefficient
r^2	coefficient of determination
RCBD	randomized complete block design
ROCSA	specific reaction force per unit cut area (kg/cm^2)
RENCSA	specific reaction energy per unit cut area ($kg\text{-}cm/cm^2$)
RPM	revolution per minute
R_s	spring radius (cm)
S	cutting angle (degree)
s	spring displacement (cm)
T	design factor
u	initial velocity of the body (m/s^2)
U_s	strain energy $N.cm^2/s^2$)
v	final velocity of the body (m/s)
W	weight of frond (kg)
w	width of cut (cm)
x	horizontal distance from the pivot to the linkage (cm)
x_0	length of pull (cm)
y	vertical distance from the pivot to the linkage (cm)

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April 1997

Chairman : **Assoc. Prof. Dr Desa Ahmad**

Faculty : **Engineering**

A study was conducted with the objective to investigate the effect of cutter design, cutting angle and frond maturity on specific cutting force and energy requirement per unit cut area for cutting oil palm fronds. Two designs were tested, that is sickle cutter and claw cutter. Cutting angles were studied at 90°, 60° and 45°, while three levels of frond maturities were used as test samples.

The experiment conducted showed significant effect of cutter design, cutting angle, frond maturity and the interaction of cutter design and cutting angle on specific cutting force (FOCSA) and energy (ENCSA) requirement for cutting oil palm fronds. The maximum FOCSA for sickle and claw cutter were 12.18 kg/cm^2 and 22.9 kg/cm^2 respectively, while the maximum ENCSA for sickle and claw cutter were 65.41 kg-cm/cm^2 and 115.5 kg-cm/cm^2 respectively. This indicated that sickle cutter required 88% less FOCSA and 76.5% less ENCSA to that of claw cutter. It was found that increasing the cutting angle would result in higher FOCSA and ENCSA requirements. The trend was found similar to frond maturity in that the mature the frond, the higher the FOCSA and ENCSA required to accomplish the cutting.

Another experiment using a spring activated sickle cutter (without countershear) to investigate the effect of cutting angle and frond maturity on specific reaction force and energy requirement for cutting oil palm fronds was carried out. This experiment was conducted to determine the reaction force that would be transferred to the harvester in the cutting operation. The experiment carried out showed significant effect of cutting angle on specific reaction force (ROCSA) and energy (RENCSA) but not on the frond maturity. Increasing the cutting angle from 45° to 90° would increase the ROCSA to about 72%. The maximum and minimum value of ROCSA were 2.5 kg/cm^2 and 1.1 kg/cm^2 respectively.

Cutting angle and frond maturity were found to significantly affect the R/Fc_{max} (the ratio of reaction force to maximum cutting force). The maximum and minimum ratio were 35% and 14% at cutting angle of 70° and 45° for cutting F3 and F1 respectively.

A prototype spring activated sickle cutter was then developed based on information obtained from the experiments. The prototype was field tested in which a time and motion study to cut fronds as well as fruit bunches was carried out. Test conducted revealed that the cutter could cut a frond and a fruit bunch in 20.08 s and 7.2 s respectively. On average the cutter needed three strokes to accomplish a cutting due to insufficient length of spring. Therefore, in future, some improvements and modifications should be made on its spring design so as to increase its efficiency.

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REKABENTUK DAN PEMBINAAN ALAT PEMOTONG TANDAN KELAPA SAWIT

oleh

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Satu kajian telah dijalankan bagi mengkaji kesan faktor rekabentuk, sudut potongan dan kematangan pelepah ke atas keperluan daya potongan dan tenaga specifik bagi memotong pelepah kelapa sawit. Dua rekabentuk pemotong diuji, iaitu pemotong sabit dan pemotong gunting. Sudut potongan diubah dari 90°, 60° dan 45°, manakala tiga tahap kematangan pelepah digunakan sebagai sampel ujikaji.

Ujikaji yang dijalankan menunjukkan faktor rekabentuk, sudut potongan, tahap kematangan pelapah dan juga interaksi yang dihasilkan oleh faktor rekabentuk dan sudut potongan telah memberikan kesan nyata terhadap daya memotong spesifik (FOCSA) dan tenaga spesifik (ENCSA). Nilai maksimum FOCSA bagi pemotong sabit dan gunting adalah 12.18 kg/cm^2 dan 22.9 kg/cm^2 masing-masing, manakala nilai maksimum ENCSA bagi pemotong sabit dan gunting adalah 65.41 kg-cm/cm^2 dan 115.5 kg-cm/cm^2 masing-masing. Ini menunjukkan pemotong sabit memerlukan daya memotong spesifik 88% dan tenaga spesifik 76.5% kurang jika dibandingkan dengan pemotong gunting. Telah juga didapati dengan meningkatkan sudut potongan akan meningkatkan daya dan tenaga spesifik. Keputusan yang sama diperolehi bagi tahap kematangan pelepah dimana lebih matang pelepah maka lebih tinggi daya dan tenaga

diperlukan untuk memotong.

Satu lagi eksperimen menggunakan pemotong sabit berspring (tanpa pengampu) bagi mengkaji kesan sudut potongan dan tahap kematangan pelepah terhadap daya dan tenaga tindakbalas bagi memotong pelepah sawit telah dijalankan. Eksperimen ini dijalankan bagi menentukan berapakah daya yang mungkin dipindahkan kepada penuai semasa menjalankan operasi pemotongan. Eksperimen dijalankan menunjukkan kesan nyata oleh sudut potongan ke atas daya tindakbalas (ROCSA) dan tenaga tindakbalas (RENCSA). Tahap kematangan pelepah didapati tidak memberikan kesan ke atas ROCSA dan RENCSA. Meningkatkan sudut potongan dari 45° sehingga 90° didapati akan meningkatkan ROCSA kepada 72%. Nilai maksimum dan minimum ROCSA adalah 2.5 kg/cm^2 dan 1.1 kg/cm^2 masing-masing.

Sudut potongan dan tahap kematangan pelepah didapati memberi kesan yang nyata terhadap R/fc_{max} (nisbah daya tindakbalas kepada daya potongan maksimum). Nilai maksimum dan minimum nisbah ini adalah 35% dan 14% pada sudut potongan 70° dan 45° bagi memotong F3 dan F1 masing-masing.

Sebuah prototaip alat pemotong berspring telah dibangunkan berdasarkan maklumat kejuruteraan yang diperolehi melalui eksperimen yang dijalankan. Prototaip ini telah diuji diladang dengan menjalankan 'time and motion study' bagi memotong pelepah dan buah tandan segar (BTS). Ujikaji yang dijalankan mendedahkan bahawa prototaip ini mampu untuk memotong pelepah dan BTS dalam masa 20.08s dan 7.2s masing-masing. Secara puratanya, prototaip ini memerlukan tiga kali untuk memotong satu pelepah. Ini disebabkan spring yang digunakan adalah kurang panjang. Oleh yang demikian, pada masa hadapan, sedikit pengubahsuaian dan pembaikan perlu dilakukan terutamanya pada rekabentuk spring bagi meningkatkan lagi kecekapan alat ini.

CHAPTER I

INTRODUCTION

Malaysia is currently the world's biggest producer of palm oil. However, the Malaysian palm oil is now facing competition not only from other oil and fat industries but also from other palm oil producing countries. Rising competition in the world market, declining in price, and shortage of labour are some of the factors influencing the well being and future of oil palm industry.

Palm Oil Industry in Malaysia

In 1960, Malaysia was only a small producer of oil palm with a total cultivated area of 55,000 hectares and producing about 92,700 tonnes per annum. In 1995, however, the total area planted with oil palm increased to about 2.358 million hectares producing about 7.6 million tonnes of crude palm oil, which was about 64% of the total world's production. It is estimated that by the year 2005, Malaysia may produce 10 million tonnes of crude palm oil and 2.5 million tonnes of palm kernel (Dato' Khalid, 1996).

Although the industry is facing competitions from other edible oils produced by other countries, and the campaigns by soybeans society not to buy palm oil, it is expected that the prospect of this industry will be boosted further in the 90's, through the opening of several new markets especially Myanmar and Vietnam in Asia, Tunisia, Morocco and a few countries in Africa and South America. Demand will also grow in many developing countries such as India, China and other European Union countries due to the tight supply condition of other fats and oils in the world market. In Malaysia, however, the high production cost of palm oil is mainly due to the high labour cost. Presently, labour cost in the plantation is about 30 to 35% of the total production cost (Turner and Gillbank, 1982).

Oil Palm Mechanization

Shortage of labour recently has forced all parties involved in the industry to find ways and means to at least maintain the profit through balancing the productivity and the production cost. There are many ways to increase productivity such as by having good agronomy and management practices. Acute labour shortage problem can be reduced through mechanization. In relation to this, there are three-pronged strategies introduced by the Malaysian government. First, the introduction of foreign labour as a temporary stop-gap measure against labour shortage. Secondly, oil palm plantations have been expanded into East Malaysia and Indonesia, where land as well as labour are still available. Thirdly, research and development (R&D) has been intensified to introduce labour-saving technology (Dato' Khalid, 1996).

The objectives of mechanization are mainly to reduce production cost, reduce labour requirement, increase productivity and improve efficiency of field operations. The country has been facing labour shortage since 1980's and now the problem is becoming more critical. It was reported that the land to labour ratio has been decreased from 6:1 in 1960 to 10:1 in 1996 and the figure is expected to increase further (Malek, 1996). However, it was proven that the use of mechanised system has increased the ratio to about 12 to 13 hectares per worker (Teo Leng, 1996).

At present, most of field operations are already being mechanized. This includes land clearing, manuring, spraying and FFB transporting. Harvesting of FFB, however, is still done manually and this operation requires a big number of labour. Therefore, more effort is needed to mechanise this operation. It was reported that on average a harvester could harvest 3 t/day and this productivity has remained unchanged as there is no new technology being introduced for harvesting (Turner and Gillbanks, 1982).

For comparison, Table 1 shows the extent of mechanisation in oil palm estates based on a survey carried out by Malek (1993).

Table 1
Extent of Mechanisation in Oil Palm Estate
(Based on survey of 485 estates in Peninsular Malaysia)

Operation mechanised	Extent of mechanisation (%)
FFB cutting	0
Infield transportation	35
Mainline loading	59
Weeding	36
Fertiliser application	39

Source: Malek (1993)

The table shows that mechanization has been introduced in most of the operations. However, cutting operation is still done manually. Mechanisation in mainline loading has achieved nearly 60% and is considerably being practised by many estates throughout the country. Infield transportation can be further improved. Its smaller percentage was mainly due to unsuitability of existing machines to fit various terrain conditions which restricts their accessibility and problematic soils such as peaty and swampy areas. PORIM is progressively doing research and development, putting effort to develop machines that can work in various terrains and able to perform in all weathers. These multi-terrain and all-weather machines are expected to increase the percentage of the usage of machine in the infield transportation operation besides increasing the productivity.

Harvesting of Oil Palm Fresh Fruit Bunches (FFB)

At present, harvesting of short palms is normally done by using a chisel fixed to a short steel pole. Cutting is a result of throwing the chisel at a high speed to frond or fruit stalk. In order to execute the cutting operation, the harvester requires enough space around him so that he will produce enough momentum to throw the tool and cut through the material. The degree of success depends greatly on the efficiency of the tool used as well as his experience and skills.

For tall palms (greater than 2.5 metres height), a sickle attached to a long pole is used. The pole may either be made of bamboo or aluminium. The sharpness, shape and profile of the sickle will greatly contribute to the effectiveness in the cutting operation. Cutting is done by the method of slicing through pulling the sickle downwards. The pulling force given by the harvester, with the added advantage of the flexibility of the pole, allow the sharp edge to cut through the material.

There are several disadvantages in using these manual tools. Obviously, energy for cutting comes mainly from the harvester, and it can only be reduced by the tool sharpness and self skill. Thus, the harvester who is handling such tools should be strong enough to maintain his energy throughout the day. It is observed that generally the harvesters would not be able to maintain their endurance for the whole day and they normally stop in the afternoon. This, off course would result in low productivity. It was also observed that at the most, they can only harvest until 2.00 in the afternoon. They do not have enough energy to continue harvesting beyond this time as their energy decrease as the working hour increases. Harvesting of tall palms normally is a great problem to the harvester. They must have enough energy and skill in lifting and handling the long pole, and cutting the fronds as well as fruit bunches.

Over the past ten years, PORIM has been developing machines and tools to improve the field operation's efficiency. There are many inventions which have been commercialised and introduced to the industry. In the harvesting operation , two main issues are being given attention, that is the pole and the cutting device. The harvesting pole has now been changed from bamboo to aluminium alloy which is lighter. A number of brands are available in the market with the price ranging from RM150 to RM 600 (15 metres length). The weight ranges from 6.5 to 8.5 kg. Efforts are being made to increase the comfortability of handling by reducing its total weight and deflection. A newly designed knife which is much lighter and long lasting is also being developed. Lighter tools will be much easier to handle and as a result, fruit bunches which could not be harvested then could now be reached, thus improving productivity.

Scope of the Problem

Harvesting of oil palm constitutes of four interrelated activities, viz. cutting of fronds and fruit bunches, stacking of fronds, collecting of loose fruit, and carrying the fruit bunches and loose fruits to the collection point. With the exception of cutting, other activities are already being mechanised. Over the years a lot of efforts had been undertaken by the industry to develop an effective cutting device. Though some efforts showed some convincing results, economically they still could not compete with the existing tools (chisel attached to a short steel pole for short palm or sickle attached to an aluminium pole for tall palm). Chisel and sickle were found to be more cost-effective.

It has been recognised that because of the urgent requirement, most tools were developed without considering necessary technical information in cutting frond as well as fruit bunches. Aspects such as materials' physical properties, materials' reaction against cutting edge design, method of cutting, cutting angle and speed of cutting were not really considered. So far, researchers had designed and developed prototypes with their own pace without having enough engineering inputs.

Hadi (1993) has taken an initial step in investigating the effect of design parameters on the specific cutting force and energy for cutting oil palm stalks and spikelets. However, he worked at a very low speed. According to Prince et al. (1958) and Chancellor (1965), the usefulness of those results in designing proper tools were very limited as it is very far away from the actual practices. Actual practice of cutting of oil palm by using either chisel or sickle, is at very high speed in order to get the momentum that is the product of weight of tool and the speed of cutting.

Chisel and sickle are widely used cutting tools in the country. They are considerably effective and cheap and no new designed tools can beat them so far. However, with the tools, the harvesters are really forced to expel or discharge a lot of energy in the cutting operation.

Harvesting of short palm may be easy to do. A chisel which is attached to a short steel pole is normally used. The process of cutting requires the harvester to throw the tool with a very high speed to the target. But, again, angle of cutting plays an important role in the efficiency of cutting.

Harvesting of tall palms, on the other hand, requires a different way and technique. A sickle which is attached to an aluminium pole is normally used. Two activities have to be done. First is lifting the pole up right and secondly cutting the fronds and fruit bunches. These two activities (lifting and cutting) require high skill and energy. Skill is in handling of tool and energy for lifting and cutting. Most harvesters cannot perform longer in a days work as they get tired as they work along. At the most they can work for four hours and they would call-off in the afternoon. The harvesting productivity of workers for various heights of palm is shown in Table 2.

The table shows that height of palms has significant influence on the productivity. The taller the palm, the more difficult the fruit could be harvested, thus lowering the productivity. Harvesting of shorter palm (< 3 m height) seems to be very easy to do. A gang (2 workers) could evacuate about 400 to 1000 bunches a day (Turner and Gillbanks, 1982). Two factors contribute to this encouraging productivity. First, the height of the palms and second, fruit bunches are still small (not heavy). However, when the palms grew older and taller, their productivity will be reduced and a gang could only evacuate about 50 to 90 bunches a day especially in harvesting of palms more than 12 metres height (Razak et al. 1995).

Table 2
Workers' Productivity (joint labour - 2 workers)

Palms' height (m)	Productivity (bunches/day)
< 3	400 - 1000
3 - 6	150 - 250
6 - 12	100 -150
> 12	50 - 90

Source: Turner and Gillbanks, 1982
Razak et al., 1995

Table 3 shows the percentage of harvesters' time working in the field. On the average, collecting of loose fruits and bunches and cutting and stacking fronds consume the longest time. Productivity can be increased if these activities, i.e. cutting and collecting activity can be mechanised. Besides increasing productivity, introduction of mechanization could also reduce the number of workers in these particular activities.

harvesters realized that cutting job required more energy than lifting of pole. Thus, if a mechanical tool that require 'less energy' is available for the cutting operation, the harvesters would be able to work longer hour and consequently increase their daily productivity. Less energy means that the harvesters need not use their energy in the cutting operation. They only have to put the tool right on the frond or bunch stalk and push a trigger. The frond and the fruit will then be cut. A reasonable price of tool that is able to give better productivity would balance the bottom line, that is the cost-effectiveness. It would be still a bonus if a mechanical tool with 'less energy' for cutting can be produced even though the cost-effectiveness still remains the same.

Objectives of the Study

Based on the above information, clearly there is an immediate need to formulate and develop a technology that can cut fronds and fruit bunches easily and efficiently. Therefore, the overall goal of this study is to get an effective cutting device with the following design requirements:

- lower cutting force
- fast in cutting action
- easy to handle

A test rig will be designed and developed to determine the cutting force and energy for cutting oil palm frond. This will determine the best cutting method which can fulfill the above design requirements. The device that requires lower cutting force and energy will be chosen as this could reduce the power requirements. Lower power requirement would reduce the size of power pack, and consequently could reduce the total weight. A lighter tool would have more advantages as it can be easily handled.

If the tool is light and easy to handle, the cutting operation could be done faster, thus increasing the harvesting productivity. Information on force and energy requirement for cutting oil palm frond would be investigated for the design purposes.

Thus, the specific objectives of the study were as follows:

1. To design and develop two test cutters, viz (a). sickle with countershear cutter and (b). claw cutter. These two cutters would be installed on a test rig to study the effect of the parameters under study on specific cutting force and energy.

2. To design and develop a test rig to carry out work as stated in the first objective. The experimental results are very important in providing basic technical data for the development of the mechanical cutting device.

3. To design and develop a prototype sickle cutter. This cutter would be of spring activated type.

4. To investigate the effect of cutting angle and frond maturity on the specific reaction force and energy per unit cut area on the spring activated cutter.

5. To carry out field test in assessing cutters' workability. This would be done by carrying out Time and Motion Study (TMS) to get time taken to cut frond as well fruit bunch.

This thesis is organized into seven chapters. Chapter I discusses the problem related to the existing practises of harvesting of oil palm fresh fruit bunches.