The Effect of Design Parameters on Force and Energy Requirements for Cutting Oil Palm Frond

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ABSTRAK

Satu kajian telah dijalankan bertujuan untuk mengkaji kesan rekabentuk pisau pemotong, sudut potongan dan tahap kematangan pelepah ke atas daya memotong (FOCSA) dan juga tenaga memotong (ENCSA) yang diperlukan untuk memotong pelepah sawit. Dua rekabentuk pisau telah diuji, (i) pemotong berbentuk sabit, dan (ii) pemotong berbentuk gunting. Sudut potongan dikaji pada kedudukan 45°, 60° dan 90°, manakala tiga tahap kematangan pelepah telah digunakan sebagai sampel ujian.

Ujikaji yang dijalankan menunjukkan bahawa rekabentuk pisau pemotong, sudut potongan, tahap kematangan pelepah dan juga gabungan di antara rekabentuk pisau pemotong dan sudut potongan memberikan kesan yang nyata ke atas FOCSA dan ENCSA. Didapati FOCSA maksimum untuk pemotong berbentuk sabit adalah 12.2kg/cm^2, manakala bagi pemotong berbentuk gunting pula adalah 22.9kg/cm^2. ENCSA maksimum adalah 65.4kg-cm/cm^2 dan 115.5kg-cm/cm^2 bagi pemotong berbentuk sabit dan berbentuk gunting, masing-masing. Ini menunjukkan bahawa pemotong berbentuk sabit memerlukan hanya 46% FOCSA dan 43% ENCSA berbanding kuantiti yang diperlukan oleh pemotong berbentuk gunting. Peningkatan sudut potongan dan kematangan pelepah akan meningkatkan FOCSA dan ENCSA dalam operasi pemotongan.

INTRODUCTION

Malaysia is currently the world's largest producer of palm oil. Statistics reveals that the total cultivated area of oil palm in 1960 was 55 000 hectares which produced about 92 700 tonnes of crude palm oil per annum. In 1997, however, the total area planted with oil palm was increased to about 2.819 million hectares producing about 9.1 million tonnes of crude palm oil which was about 50% of the total world's palm oil production (PORLA, 1997).

The Malaysian palm oil industry is now facing competition not only from other oils and fats producers but also from other palm oil producing countries. Rising competition in the world market, and shortage of labour are some of the factors that influence the well being and the future of the oil palm industry. Besides seeking new markets to expand our exports, other ways of minimizing the production cost should also be identified. Labour has been one of the major factors which could influence the well being of the oil palm industry. Importing foreign labours may be the short term measures, but do not offer the long term solution. Mechanization will offer the best solution to minimize the labour problem and this has been demonstrated in a number of developed countries.

At present, most of the field operations, *viz.* manuring, spraying and transporting of fresh fruit bunches (FFB) are already being mechanized; the cutting of FFB is still done manually. Therefore, more effort is needed to mechanize this operation. A study carried out by Malek (1993) was directed at determining the extent of mechanization in oil palm estates (*Table 1*).

Currently, cutting of fronds for harvesting of FFB for short palms is normally done using a chisel fixed to a short steel pole, while for taller palms (>2.5m height), a sickle attached to a bamboo or an aluminum pole is used. There are several disadvantages in using these manual tools. Obviously, the energy for cutting comes from the harvester itself. The burden in cutting can only be

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TABLE 1. EXTENT OF MECHANIZATION IN OIL PALM ESTATE

Operation	Extent of mechanization (%)
FFB cutting	0
Infield transportation	35
Mainline loading	59
Weeding	36
Fertilizer application	39

Note: The above study was based on a survey of 485 estates in Peninsular Malaysia.

reduced by the harvester's skill and the cutting tool's sharpness. Therefore, the harvester who handles such tools should be strong enough to perform the cutting and to maintain his energy throughout the day. It is observed that generally harvesters would not be able to maintain their endurance for the whole day and they normally stop in the afternoon (Razak, 1998). Over the past 10 years, many researchers (Hadi, 1994; Razak *et al.*, 1995; Rahim *et al.*, 1988 and Ahmad, 1990) have been trying to develop machines and tools to improve the efficiency of these harvesting operations.

With manual tools, it was found that cutting of fronds and FFBs required more energy than lifting the pole (Razak *et al.*, 1998). Thus, if a mechanical cutter is developed, a harvester would be able to work longer hours and consequently, increase his daily productivity.

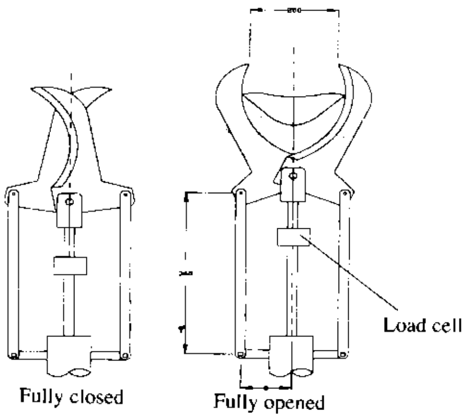
This study was carried out to formulate and develop a technology to cut fronds and fruit bunches efficiently. The design criterias for the device were set to reduce the cutting force, fast cutting action and ease of handling. In carrying out the study, a test rig was designed and developed to find out the effect of the studied parameters on the cutting force (FOCSA) and energy (ENCSA) requirements.

MATERIALS AND METHODS

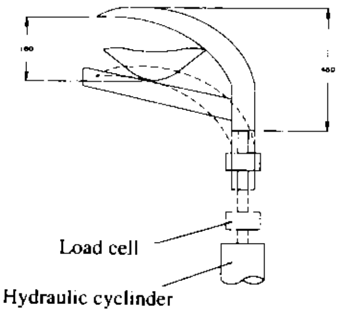
In this study, two types of cutters were investigated. The first was the claw and the second was sickle cutter. Blades of predetermined dimensions and materials were fabricated. Experiments were formulated for each of these cutters to determine the parameters required for this study. For the claw cutter, two blades (the left and right) were fabricated of equal dimensions. While for sickle cutter, a commonly used sickle was studied. The sickle was modified at the fixing end to accommodate the fixture for the experiment.

Claw Cutter

The configurations and dimensions of the blade and its set-up are shown in *Figure 1a*. The blade weighing about 0.6kg was made of high carbon steel with 3mm thickness. Its total length and width were 32cm and 16cm, respectively. The cutting edge was designed to have a curvature of 20cm radius so that it could grasp and cut the frond effectively. The edge angle (α) was designed to be at 10°, and its oblique angle (β) was



a. Claw cutter



b. sickle cutter

All dimension in mm

Figure 1. Cutting test rig for (a) claw cutter (b) sickle cutter.

kept constant at 24° in all positions. Both blades were joined by a pivot. A hydraulic cylinder was used to activate the blades in the cutting operation. A load cell was located in the middle of the rod to measure the pulling force required during cutting. During the experiment, the frond was located at a distance of about 20cm from the pivot. This distance was selected because it was the point of contact of the frond edge in actual cutting in the field. The distance was kept constant for all tested samples of fronds.

Generally, for the claw cutter, cutting forces provided by the two edges of the blades must be taken into consideration in completing a cutting. Therefore, the pulling force sensed by the load cell was the resultant force required by the two blades. The cutting force requirement is equal to the resistance force given by the material. Assuming the friction force at the blades pivot is much smaller as compared to the pulling force (f), the following equation represents the maximum cutting force requirement at the cutting point (by taking moment about the point 0, *Figure 2a*):

$$Fc_{max} = 2f(x)/k \qquad [1]$$

where

Fc_{max} = maximum cutting force by two edges,kg

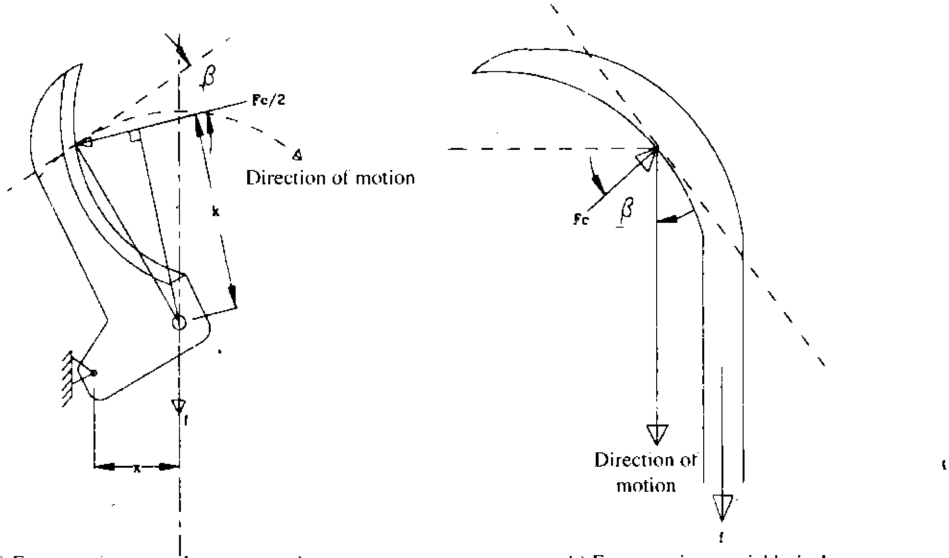
Fc = cutting force,kg

f = force sensed by the load cell, kg

k = perpendicular distance from pivot to the line of Fc, cm

x = horizontal distance from the pivot to the linkages, cm

The maximum cutting force arose when the direction of Fc was on the horizontal line, that is when the value of x was 10cm (*Figure 2a*). Substituting the values of k and x, and also the force sensed by the load cell (f) into Equation 1, the maximum value of the cutting force for cutting



a) Forces acting on a claw cutters edge (1 off)

b) Forces acting on sickles' edge

Note
Fc = cutting force
f = pulling force by hydraulic cyclinder
β = oblique angle

Figure 2. Forces acting on the blade edges (a) claw cutter (b) sickle cutter.

frond could be obtained.

Sickle Cutter

An ordinary sickle (popularly used by the oil palm harvesters) was used for this study. The edge angle was 10° and the thickness 3mm. The sickle was made of hardened steel through heat treatment. A countershear to react the cutting force was put at 15cm from the end tip of the sickle and it was installed at 15° with respect to the horizontal line. The end of the sickle was connected to the hydraulic pusher rod to enable the sickle to move downwards while performing the cutting. A load cell was placed in the middle of the rod to sense the pulling force required during cutting. *Figure 1b* shows the configuration and dimensions of the blade and also the experimental set-up. During the test, the edge of the frond was located at the beginning of the sickle curve to get the effect of slice cutting and this point was kept constant for all tested fronds.

By solving the involved forces vertically (*Figure 2b*), the maximum cutting force is given by the following equation:

$$f = (Fc)\cos\beta \quad [2]$$

$$Fc = f/\cos\beta$$

$$Fc_{max} = f \text{ when } \beta \Rightarrow O$$

where

Fc_{max} = maximum cutting force, kg

Fc = cutting force, kg

f = force sensed by the load, kg

β = cutting oblique angle, deg

Test Rig

Two experimental test rigs for measuring force and energy requirement in cutting oil palm frond were designed and developed. *Figures 3* and *4* show the experimental rigs setting for sickle with countershear and claw cutter, respectively. Test rigs were built with mild steel frames. The cutters were actuated by a 4-tonne hydraulic cylinder run by a single phase Enerpac Hydraulic Pumpset. The force applied through hydraulic cylinder was sensed by the load cell (Kyowa LT-500 KF) and the signal was amplified by an amplifier (Kyowa WGA-710A).

Experimental Procedures

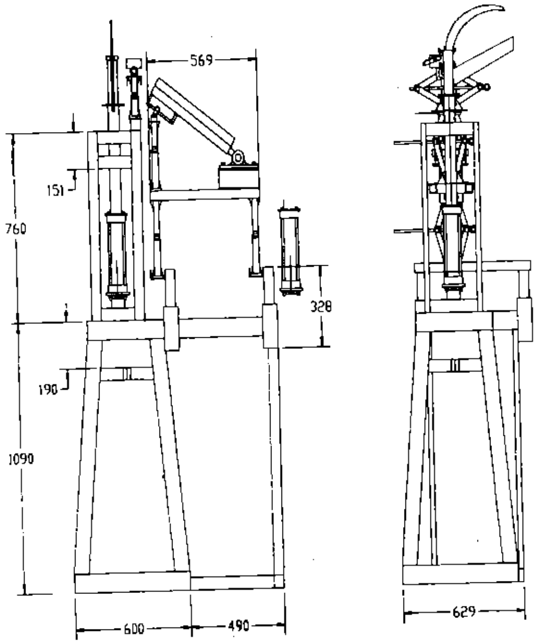
Cutting force, cutting energy and the effect of cutting on the material are influenced by the knife movement with respect to the material and the countershear. It is also influenced by the knife orientation to its direction of motion. Cutting force is the resultant of the stresses applied on the material (Persson, 1987; Wieneke, 1972; O'Dogherty, 1981). The cutting energy is the energy required to accomplish the cut which is the product of cutting force and the depth of cut or the cut area. Tests were done to evaluate the effect of design (claw and sickle cutters), cutting angle (45°, 60° and 90°) and frond maturity (Fl, F2 and F3) on the cutting force and energy requirement. The results were useful for the designer to design cutting tools.

Parameters investigated were as follow:

1. Cutter design (T) - method of cutting
   (i) claw (T1) and (ii) sickle cutter (T2).
2. Cutting angle (S) - angle of the knife travel with respect to fronds longitudinal
   (i) S1 = 90°, (ii) S2 = 60° and (iii) S3 = 45°.
3. Frond maturity
   (i) Fl = the second frond below the ripe fruit which is considered as the most matured frond compared with others,
   (ii) F2 = frond above the ripe fruit, and
   (iii) F3 = frond above the F2.

All fronds were taken from commercial palms of similar age.

In this study, one end of the frond sample was fixed and allowed to move vertically with regard to the pivot as to vary the cutting angle. The cutter was then forced downwards by using the hydraulic cylinder to cut the material into two halves. The force required for cutting was measured by the load cell which was placed in between the cutting device and the hydraulic

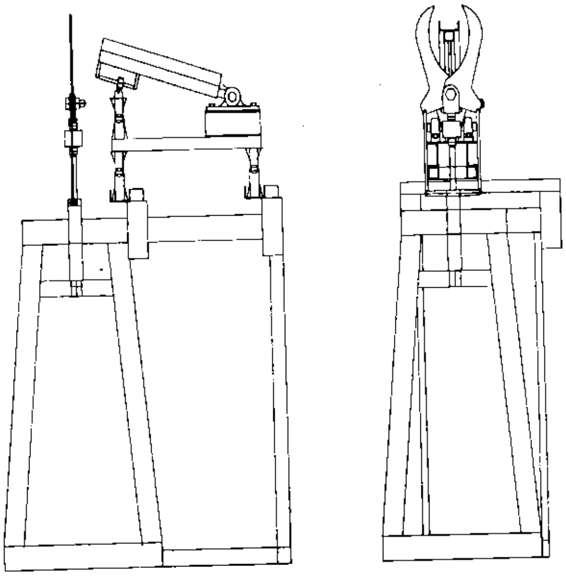


Side view

Front view

all dimension in mm

Figure 3. Experimental set-up for sickle cutter.



Side view

Front view

all dimension in mm

Figure 4. Experimental set-up for claw cutter.

	Claw cutter	**Sickle cutter**
Max. cutting force, F_{cmax} (kg)	2f(x)/k	F
Max. sp. cutting force FOCSA (kg/cm^2)	2f(x)/k.A	F/A
Max. sp. cutting energy ENCSA (kg-cm/cm^2)	FOCSA.d	FOCSA.d

where A = cutting area, cm^2

d = depth of cut, cm

pusher rod. The reading of the load cell was amplified by an amplifier which was only recording the maximum value of the cutting force. The actual value of the cutting force is the difference between the force sensed by the load cell under load and without load. The maximum cutting force was then determined using equations (1) and (2) for claw cutter and sickle, respectively.

The effects of cut such as depth (d), width of cut (w) and cut area (A) were measured manually using graph paper after each test was completed. These data would then be used for calculating specific cutting force (FOCSA) and specific cutting energy (ENCSA). Maximum cutting force and energy were calculated from the above equations.

RESULTS AND DISCUSSIONS

An analysis of variance for the specific cutting force (FOCSA) and specific cutting energy (ENCSA) is shown in *Table 2*. It indicates significant effects of cutter design, cutting angle, frond maturity and the interaction of design and cutting angle. Other interactions were found not affecting the FOCSA and ENCSA. Maximum FOCSA was obtained through the interaction of T2SIF1 (22.9kg/cm^2), while the minimum FOCSA was from TIS3F3 interaction (7.7kg/cm^2). The maximum FOCSA for sickle and claw cutter were 12.2kg/cm^2 and 22.9kg/cm^2, respectively. For ENCSA, the maximum value was from the interaction of T2S IFI (115.5kg-cm/cm^2) and the minimum value was achieved through the interaction of TIS3F3 (29.3kg-cm/cm^2). The maximum ENCSA for sickle and claw cutters were 65.4kg/cm-cm^2 and 115.5kg-cm/cm^2, respectively.

Effect of Cutters

The effect of design on FOCSA and ENCSA are presented in *Table 3*. The average FOCSA and ENCSA were minimum for sickle cutter, *i.e.* 9.36kg/cm^2 and 42.98kg-cm/cm^2, respectively compared to 14.4kg/cm^2 and 67.27kg-cm/cm^2 respectively for claw cutter. Experiments carried out showed that sickle cutter (T1) offers lower FOCSA and ENCSA than the claw cutter (T2).

Effect of Cutting Angle

The relationships of the cutting angle on FOCSA and ENCSA are shown in *Figures 5* and *6*. For both cutters, higher cutting angle would result in higher cutting force and energy. The difference in slope shows that there was an interaction between the two designs of cutter and the cutting angle (T*S). The FOCSA and ENCSA did not differ so much at 45°, but as the cutting angle increased, there was a rapid increase for claw cutter (*Figure 5*). It was also noticed that increasing the cutting angle from 45° to 90° increased the FOCSA by 24% for sickle and 111% for claw cutter, respectively. Similarly, the ENCSA increased to 17% for sickle and 110% for claw cutter due to the increase of cutting angle.

TABLE 2. ANALYSIS OF VARIANCE FOR SP. FOCSA AND ENCSA PER UNIT CUT AREA

Source of variation	df	ANOVA SS	Mean squares	F value	Pr>F
FOCSA					
Design (T)	1	685.8	685.8	112*	0.0001
Cutting angle (S)	2	867.1	433.8	70.8*	0.0001
Frond(F)	2	418.7	209.4	34.2*	0.0001
T*S	2	192.6	96.3	15.7*	0.0001
T*F	2	8.74	4.37	0.71	0.4925
S*F	4	15.4	4.00	0.65	0.6264
T*S*F	4	11.13	2.78	0.45	0.7686
ENCSA					
Design (T)	1	15 925.2	15 925.2	53.5*	0.0001
Cutting angle (S)	2	16 103.7	8 051.9	27*	0.0001
Frond (F)	2	16 120.8	8 060.4	27.1*	0.0001
T*S	2	8 756.7	4 378.3	14.7*	0.0001
T*F	2	201.2	100.6	0.34	0.7140
S*F	4	868.6	217.1	0.73	0.5741
T*S*F	4	181.3	45.3	0.15	0.9615

TABLE 3. AVERAGE FOCSA AND ENCSA FOR THE TWO CUTTERS

	Sickle cutter (T1)			Claw cutter (T2)		
Cutting angle	90°	60°	45°	90°	60°	45°
FOCSA (kg/cm^2)						
F1	12.8	10.8	9.36	22.9	15.2	11.2
F2	10.6	8.42	8.27	20.6	11.6	10.7
F3	8.82	8.11	7.7	19.7	9.8	8.0
ENCSA (kg-cm/cm^2)						
F1	65.4	56	51.3	115.2	78	57.4
F2	44.8	36.4	41.5	94.4	54.5	52.6
F3	32.6	29.7	29.3	80.6	37.8	34.5

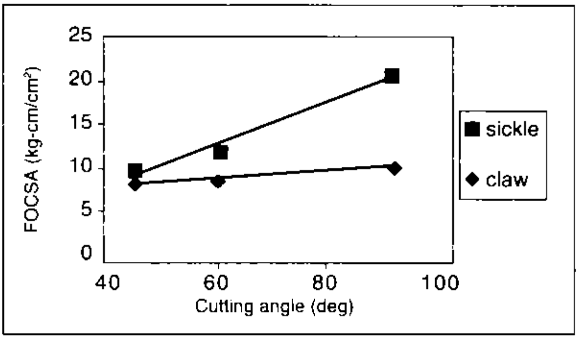


Figure 5. Effect of cutting angle on FOCSA.

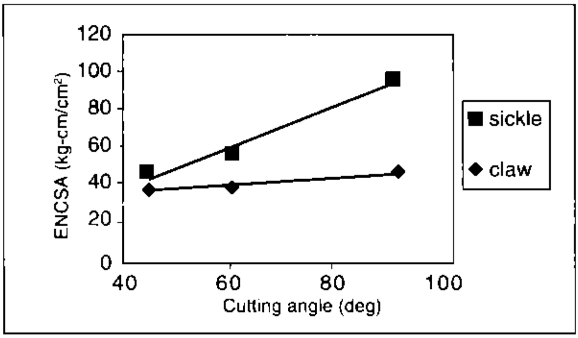


Figure 6. Effect of cutting angle on ENCSA.

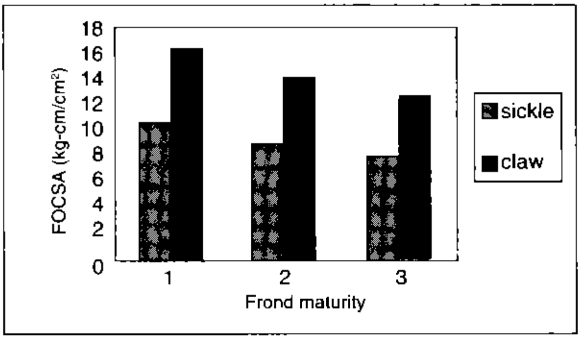


Figure 7. Effect of frond maturity on FOCSA.

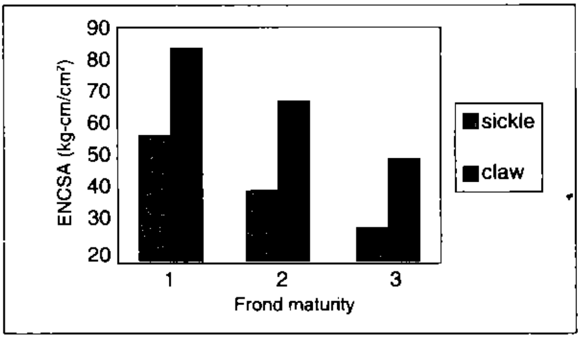


Figure 8. Effect of frond maturity on ENCSA.

Effect of Frond Maturity

Figures 7 and *8* illustrate the effect of frond maturity on the FOCSA and ENCSA. The FOCSA and ENCSA required to accomplish the cutting increased as the frond gets mature. This is due to the hardness of the fibers as the older the frond the harder is the fiber.

CONCLUSIONS

The results showed that all factors under study, *viz.* cutter design, cutting angle and frond maturity were found to affect the FOCSA and ENCSA (p-value=0.0001). On the average, sickle cutter at about 9.36kg/cm^2 of FOCSA is 35% less when compared to 14.4kg/cm^2 required by claw cutter. Similarly, the graph profile of the ENCSA had the same trend as shown by the FOCSA showing the increment of ENCSA when the value of the cutting angle and frond maturity were increased. Cutting angle was found to affect FOCSA and ENCSA in which the higher the cutting angle, the higher the FOCSA and ENCSA required. Frond maturity was found to have high influence on the FOCSA and ENCSA. The more mature the frond, the higher were the FOCSA and ENCSA required to accomplish the cutting. It was also concluded that there was a significant interaction between the cutting angle and the frond maturity on FOCSA and ENCSA produced. Further research in improving the cutting mechanism is being looked into.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to all colleagues who have given a lot of assistance and advice to make the study successful especially to Dr Ariffin Darus and Dr Mohd Basri Wahid for the help and support. Appreciation is also given to the Director-General of PORIM for permission to publish this paper.

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