Current Achievement and Future Plan for Improvement for E Cutter Development

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E Cutter is a harvesting tool dedicated for oil palm fresh fruit bunch (FFB). It employed rapid chopping method and bunch harvest as it harvesting method. The E Cutter development was inspired by the usage of *Cantas*™ which currently efficient tool for oil palm FFB harvesting. However, due to height limitation that influences the operation of *Cantas*™, the development of E Cutter was seen as a breakthrough to at least maintaining the performance of *Cantas*™ in harvesting higher palm tree. Both of E Cutter and *Cantas*™ comprise three major parts. There are energy provider part at the bottom, actuator part at the top and energy transmitter in the middle. Compared to *Cantas*™ that totally applies mechanical system, the E Cutter is applies the electrical system especially in the actuator and energy transmitter part. However, in this paper, the progress of the E Cutter actuator development was focused. The previous achievement of the actuator and future planning for improvement will be explained. In the end part of this paper, the design target and type of future actuator will be developed for E Cutter also has been stated.

Keywords： *Cantas*™, E Cutter, linear actuator, oil palm harvesting tool.

1. Introduction

Currently, palm oil is world's most consume vegetable oil. With fraction of 35% of total world's vegetable oil consumption, the palm oil has left the soya bean oil in second place with fraction of 27% [1-3]. This phenomenon was influenced by the awareness of the Trans Fat effect to the human health [1]. In order to support the world demand of palm oil, its production is projected to be increase 3.47% per year [2]. Therefore, the production of palm oil needs to be increase significantly. However, in this paper, the increment of palm oil production through the harvesting technique is focused. The transformation from the manual style by using sickle and aluminum pole to the mechanization style is seen as an option to the increase the oil palm harvesting production. The mechanize technique through a mechanical system has been established. Yet, due to the limitation of height, a new system needs to be introduced. Thus, this paper will discuss the status of the new harvesting system development and future planning for improvement.

2. Mechanization of Oil Palm Fresh Fruit Bunches

In Malaysia, the mechanization of the oil palm fresh fruit bunches (FFB) harvesting has been started by the Malaysia Palm Oil Board (MPOB). The MPOB has developed an efficient tool for FFB harvesting called *Cantas*™. The construction of this tool is as shown in Fig. 1 [4 - 6].

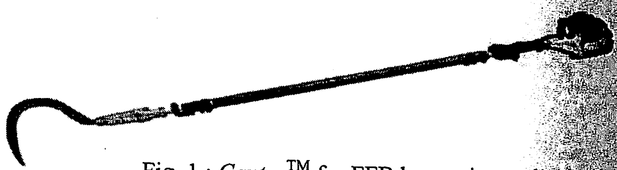

Fig. 1 : *Cantas*™ for FFB harvesting tools

This tool is consists of 2 stroke engine located at the bottom side and special design sickle at the top side. The engine will provide mechanical energy in term of rotational motion to the system. The sickle will vibrate along the harvesting activity in order to cut the fronds and bunches. The rotational motion develop by the engine is convert to linear motion to vibrate the sickle by using the bevel gear. The mechanical energy produce by the engine in transmit to the bevel gear via a shaft inside the aluminum pole [4-6]. The *Cantas*™ was proven as an efficient tool base on the several field trials. As in [6], this tool was recorded to increase worker ratio to area of land (ha) about 1:38 compared to 1:18 by using manual harvesting style. Furthermore, the *Cantas*™ also has increased the FFB productivity from 4.19 tonnes/day to 11.60 tonnes/day.

Even though this tool has significant improvement to the productivity of the FFB harvesting, however, this tool become inefficient for the height of tree higher than 8m. At height of over than 8m, the pole will start bend due to weight of bevel gear and sickle. This occurrence will made the shaft inside the pole bends and thus the mechanical energy could not be transfer to the bevel gears [4,5]. Therefore, another type of tool needs to be developed. The new tool is not only aimed to having at least similar performance as *Cantas*™, but it operation should not influence by the bending pole problem.

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3. E Cutter Development

To encounter the drawback of *Cantas*™, E Cutter was proposed [7]. The E Cutter structure is as shown in Fig. 2. The 2 stroke engine used in *Cantas*™ will still be used in E Cutter. However, the engine will be attached to the mobile electrical generator in order to convert the mechanical energy to electrical energy. The bevel gear will be replaced by the linear actuator in order to provide direct linear vibration motion to the sickle in order to accomplish the harvesting activity. A copper wire will be used to replace the shaft inside the aluminum pole in order to transmit the electrical energy provide by the electric generator to the linear actuator [7]. Therefore, this tools will keep operate efficiently even though the pole is bend due to the height increments due to the copper is more flexible compare to the shaft in *Cantas*™.

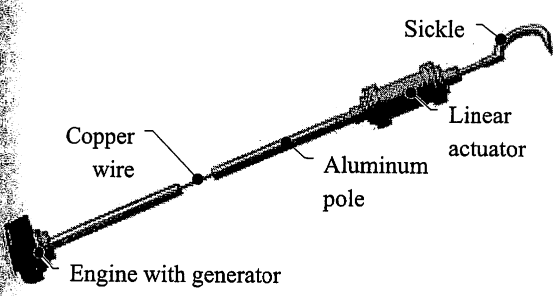


Fig. 2 : E Cutter for FFB harvesting tools

3.1 *Current Achievement of E Cutter*

There are two major parts playing important role in E Cutter development. First is to design and develop the mobile electrical generator and second is to design and develop the linear actuator. However, in this paper, the progress of design and development of the linear actuator will be discussed. There are two types of linear actuator have been developed for E Cutter which are:-

a) Slot less type linear oscillatory actuator (SLTLOA) [8,10,12]
b) Slotted type linear oscillatory actuator (STLOA) [7,8,9,11]

There are two versions of each type of linear actuator has been developed in order to improve the performance of the linear actuator. For the SLTLOA, the improvement is involved of increment on the number of permanent magnet and coil. Meanwhile, for the STLOA, the improvement is involved the increment of it outer size and optimization of the permanent magnet and coil size. The structures of those linear actuators are shows in Fig. 3.

Each advance version of each type of linear actuator has improving the previous version of each it. However, the focus was only given to improve the static performance in term of static thrust. Fig. 4 shows the comparison of static thrust of each linear actuator at input power of 50W.

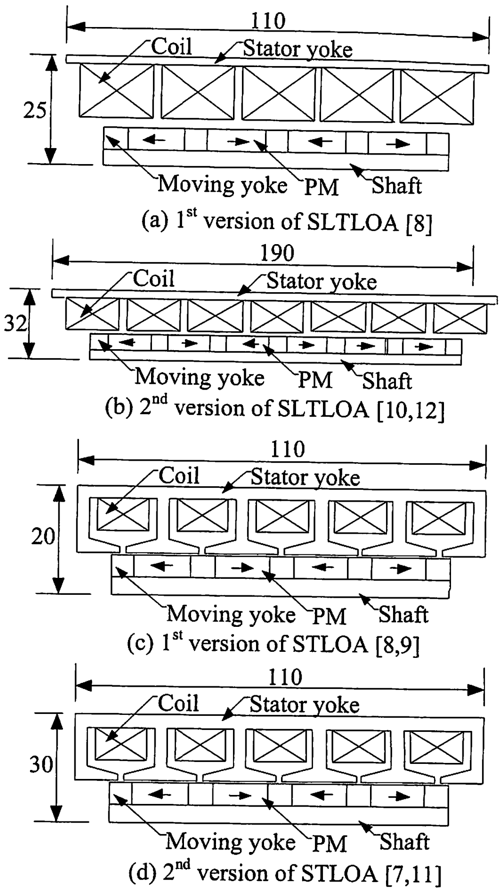


Fig. 3 : Structure of developed linear actuator for E Cutter

All the linear actuators developed has been test in laboratory before it could be confirm to be implement in E Cutter system. As the latest type of linear actuator which is 2nd version of STLOA (STLOA V.2) it is confirm that, the thrust required by application has been fulfill. Fig. 5 show the STLOA V.2 is undergoing the test in the laboratory. However, it cutting time is high comparing to the *Cantas*™. The *Cantas*™ is only need about 2 seconds to finish the cutting but the STLOA V.2 needs about 6 seconds. This is due to low of total displacement and frequency of oscillation by the STLOA V.2 compare to *Cantas*™. The STLOA V.2 operates at 68 Hz of oscillation frequency and 10 mm of total displacement [7] while *Cantas*™ operates at 50 Hz to 80 Hz of oscillation frequency and 16 mm of total displacement [4-6]. Therefore, a new linear actuator needs to be design in order to increase the reliability and performance of the E Cutter.

3.2 *Design Specification of New Linear Actuator*

The specification of STLOA V.2 will be referred to create the design specification of new linear actuator for E Cutter. Since the thrust of STLOA V.2 is adequate to perform the harvesting activity, hence, the new linear actuator should have a minimum thrust as STLOA V.2. The new linear actuator also should maintain the low size and weight in order to increase the usage and reliability of the E Cutter system. Therefore, the same volume and weight is target as STLOA V.2 for the new linear actuator. Table 1 is shows the comparison of specification between STLOA V.2 and the new linear actuator.

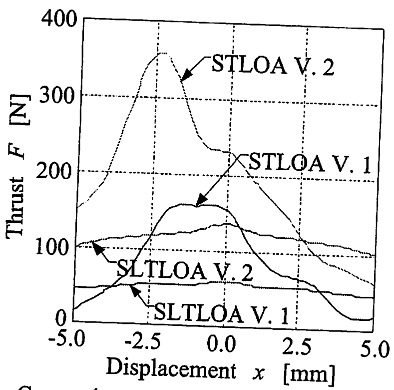


Fig. 4 : Comparison of thrust for developed linear actuator

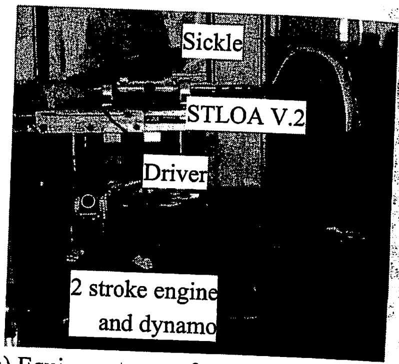
The main improvement target in the new linear actuator is in term of it dynamic performance. The oscillation frequency, f and the total displacement, x are the main concern of improvement. Since the *Cantas*™ is having maximum frequency and total displacement of oscillation are 80 Hz and 16 mm respectively, therefore, the same values is target for the new linear actuator.

The total displacement, x is closely related with the thrust developed by the actuator. Higher value of thrust produce higher value of total displacement,. The higher thrust will be produce if the appropriate instantaneous current is injected to the actuator. However, due to effect of frequency, the current response of an actuator is depends on the ratio between coil inductance and resistance which is electrical time constant, τ_e. The equation of current, thrust and electrical time constant, τ_e is as below.

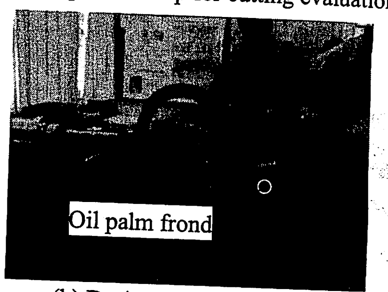
Table 1 : Comparison of STLOA V.2 and new linear actuator specification

STLOA V.2 [7]		New linear actuator	
Starter Force, $F_{x=0}$	222 N	Minimum force, F_{min}	222 N
Thrust constant, $k_{f(x=0)}$	58.15 N/A	Thrust constant, k_f	> 58.15 N/A
Total weight, W	2.0 kg	Total weight, W	2.0 kg
Volume, V	3.25×10^{-4} m^3	Volume, V	$< 3.25 \times 10^{-4}$ m^3
Displacement, x	10mm	Displacement, x	16mm
Frequency, f	68 Hz	Frequency, f	80 Hz
Input power, P_{in}	100 W	Input power, P_{in}	< 100 W

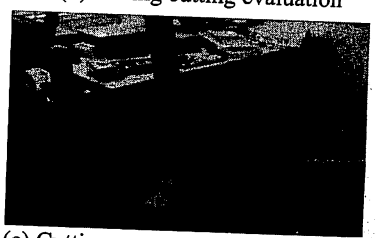
Base on equation (1), it shows that, lower value of electrical time constant, τ_e will made the current and thrust response will more faster. Therefore, higher total displacement could be obtained at higher frequency due to the force and current will reach its maximum value faster. By considering the value of frequency of oscillation is 80 Hz, the electrical time constant, τ_e is targeted to having value lower than the half of one oscillation complete cycle which is 6.25 ms.



(a) Equipment setup for cutting evaluation



(b) During cutting evaluation



(c) Cutting process successfully done

Fig. 5 : Cutting evaluation of STLOA V.2

$$i(t)=\frac{V}{R}\left(1-e^{t/\tau_e}\right) \quad (1)$$

$$F(t)=k_f i(t) \quad (2)$$

$$\tau_e=\frac{L}{R} \quad (3)$$

Where $i(t)$ is the instantaneous current in [A], V is the voltage supply in [V], R is the coil resistance in [Ω], τ_e is the electrical time constant in [s], $F(t)$ is the instantaneous thrust in [N], k_f is the thrust constant in [N/A] and L is the coil inductance in [mH].

4. Evaluation of Linear Actuator Type.

Before the new linear actuator could be design, the type of linear actuator should be defined first. The type is select based on the type of linear actuator that has been commercialized. There are 5 types of linear actuator that has been compared which are :-

i. Coreless type LA (CL)
ii. Single Magnet Core Type LA (1M)
iii. Double Magnet Core Type LA (2M)
iv. Linear AC Servo LM (SM)
v. Shaft Motor (ShM)

There are 9 manufacturers with 315 number of various linear actuators has been choose to be compared. Table 2 shows the list of manufactures with the respective type of linear actuator manufactured with the number of each in bracket.

Each type of linear actuator's characteristic for each manufacturer has been compared with the design target. To ease the process of elimination in order to choose appropriate type of linear actuator for the E Cutter, the comparison is made by using radar plot. Fig. 6 (a) – 6 (e) shows the best 5 of linear actuator for each type compare with the design target. If the point of each linear actuator characteristics are outer than the design target, it recognize as fulfill the design target. The linear actuator for each type which is having fulfill most of the design target is choose as the best model of each type and compare with design target as shown in Fig 6 (f).

The summary of the comparison of the best model of each type of linear actuator with the design target is as listed in Table 3. The (√) marking is represent this characteristic is fulfill the design target. Meanwhile (×) represent the characteristic that not fulfill the design target. The percentage of in bracket is show how far the characteristic of that particular linear actuator away from the design target.

Table 2 : Manufacturer and their type of linear actuator

	Shaft motor	Single Magnet Core	Double Magnet Core	Core less	Linear AC servo
GMC Hillstone	X (46)				
Rockwell Automation				X (24)	
Festo					X (6)
Sanyo Denki		X (15)	X (10)		
Justek, Inc.				X (17)	
Hiwin	X (9)		X (16)	X (23)	
Baldor Motion			X (18)		X (23)
Yaskawa	X (12)	X(15)	X (8)	X (15)	
LinMot					X (58)

Table 3 : Summary of best model of each linear actuator type with the design target

Type LA	F	k_f	τ_e	P_{in}	V	W
Coreless	√	× (31%)	√	√	× (115%)	× (450%)
Single Magnet Core	× (25%)	√	√	√	× (54%)	× (50%)
Double Magnet Core	√	× (14%)	√	× (5%)	√	× (300%)
Linear AC Servo	× (10%)	√	√	√	× (208%)	× (350%)
Shaft Motor	× (10%)	√	√	√	√	× (150%)

As shown in Table 3, all the linear actuator type had been fulfilled the electrical time constant, τ_e required. All of it, having the value of electrical time constant, τ_e is below than 6.25 ms. However, all the linear actuators were not fulfilled the weight, W requirement. The weight of single magnet core type linear actuator had less far from the design target which is 50 % and the coreless linear actuator had more far in term of weight characteristics with 450 % away from the design target, even though, this type of actuator was fulfilled the thrust, F requirement. Only double magnet core type linear actuator was not fulfilled the input power, P_{in} requirement with percentage of 5 %. This type of linear actuator also was not fulfilled the thrust constant, k_f requirement as well as to the coreless type of linear actuator while other type of linear actuators were fulfilled this characteristics requirement. Double magnet core type of linear actuator had been fulfilled the design target of thrust, F similar to the coreless type of linear actuator meanwhile others were not fulfilled this design target. For the volume, V requirement, only for the double magnet core type of linear actuator and shaft motor were fulfilled the design target.

Therefore, by referring to the Table 3, the shaft motor having a potential to be implement as the actuator for the E Cutter. Apart of being fulfill the design requirement except the thrust, F and weight, W, the shaft motor is having lowest value of electrical time constant, τ_e which having main priority to improve the dynamic response of the E Cutter actuator. However, the structure of the shaft motor need to be optimize in order to improve it characteristic to make sure it could fulfill the design target. The strategies that could be taken is by optimize the size of permanent magnet and coil to reduce the total weight, W and increase the turn of the coil turn to increase the magnetomotive force, mmf hence increase the thrust, F of shaft motor.

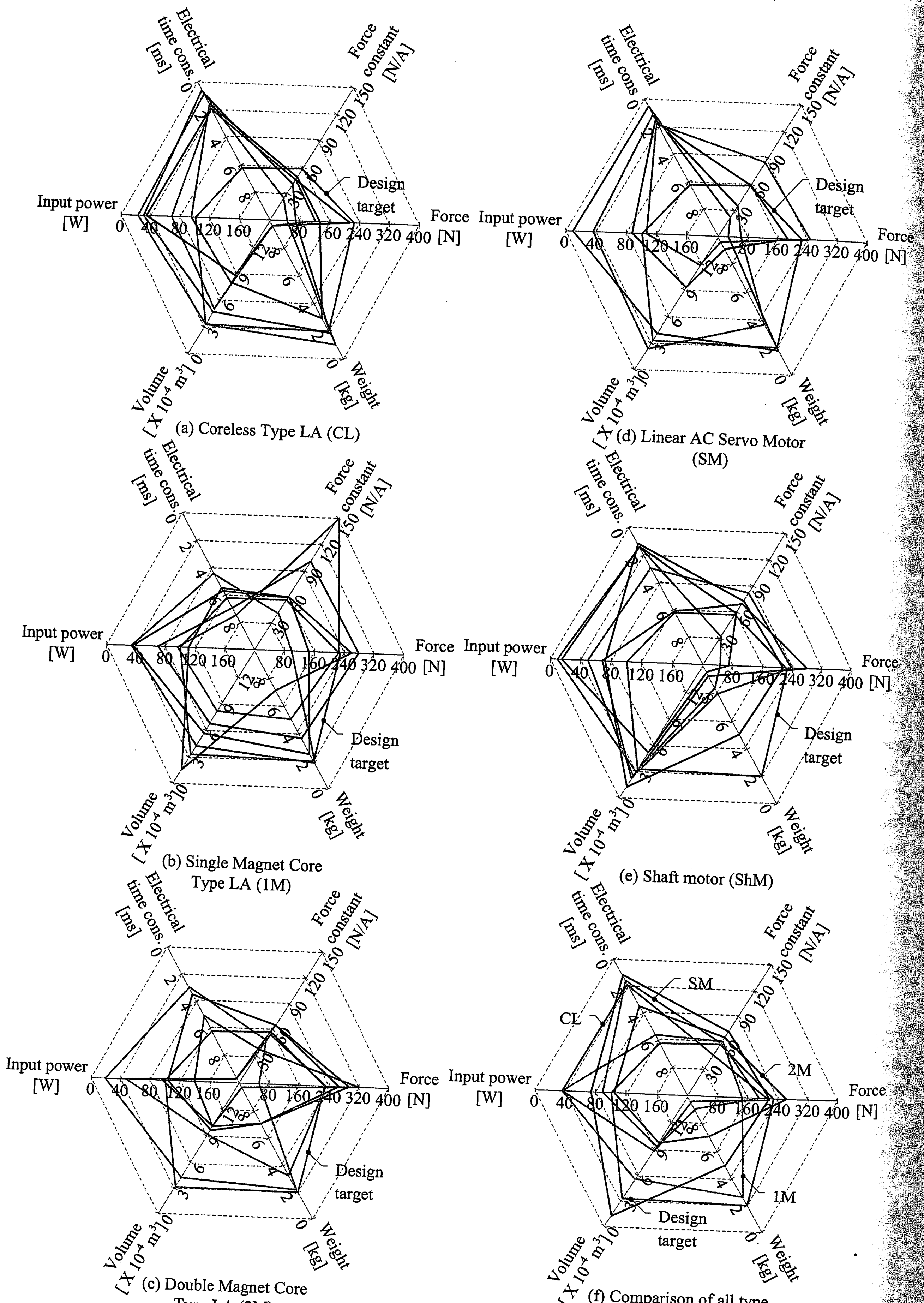


Fig. 6 : Comparison of LA characteristics with design target

5. Conclusion.

Nowadays, the *Cantas*™ has been as most efficient tool for oil palm FFB harvesting. However, the *Cantas*™ has is inefficient in harvesting activity for the height of palm higher than 8m. Therefore, the E Cutter is proposed in order to encounter the drawback of the *Cantas*™. The E Cutter is replaced the energy transmission system from the mechanical system to electrical system. The 2 stroke engine will attached with electrical generator and the electrical linear actuator will use at the top side of the tool. A cooper wire will be used to replace the shaft in order to transmit the energy from the bottom side to the top side. In this paper, the progress of development of actuator for E Cutter was focused. The previous achievement of the actuator such as type of actuator and its performance has been discussed. Furthermore, the improvement of the actuator also has been explained. The design target and the potential of type of linear actuator also had been stated. Several type of linear actuator that has been commercialized has been compared to become a benchmark for selecting the appropriate type of linear actuator for E Cutter implementation. As a result, shaft motor has been chose as a type of future linear actuator for E Cutter implementation. However, structure modification and optimization are essential to make sure the shaft motor fulfill the design target.

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