Optimization Of Motor Power Selection for Moveable Palm Fruit Bunch Stripper Using Customized M236 Machine Design Spreadsheet and Goal Seek Tool

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Abstract
In an attempt to select appropriate electric motor power required for moveable palm fruit bunch stripper, a Customized M236 Machine Design Spreadsheet powered by Microsoft Excel was employed in analytical design, simulation and optimization. Several model equations were generated based on the machine configuration related to the selection of the electric motor power rating. The model equations were keyed into the Customized M236 Machine Design Spreadsheet, based on the syntaxes understood by the programme, and simulated over a range of independent variables. Again, the response(s) of the simulation were optimized using Goal Seek Tool embedded in Microsoft Excel®. Based on using existing 5.0 and 6.0 hp electric motors, the results showed that a maximum of 2.0 and 3.0 oil palm fruit bunches could be stripped at a time using 5 and 6 hp electric motor rating respectively. Any increase in number of oil palm fruit bunches introduced into the stripper chamber will require an upgrade in electric motor rating.

Keywords: *Optimization, Motor power, Customized M236 Machine Design Spreadsheet, Palm fruit bunch, Stripper*

1.0 INTRODUCTION

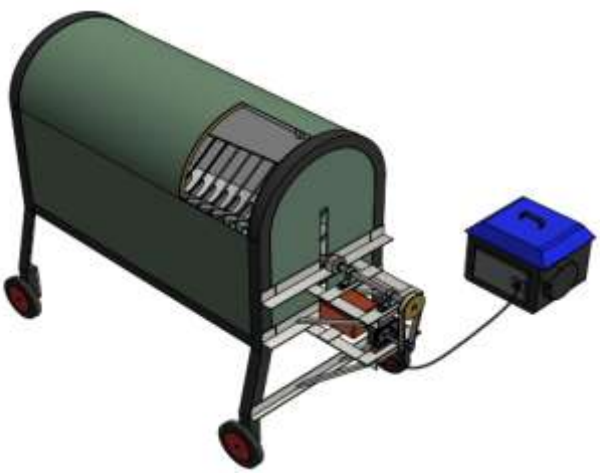
The oil palm (*Elaeis guineensis*) is indigenous to Africa (Hartley 1988; FAO, 2005). It grows well in tropical atmospheres. The three (3) principal assortments of oil palm are the Dura, Pisifera and Tenera. Tenera cultivar contains around 55 to 96 % mesocarp. Its shell thickness ranges from 0.5 to 4.0 mm with portion around 3 to 15% of the organic product by weight (Muthurajah, 2002). Tenera is largely received by almost all farmers since it has high oil content for any usage (Pantzaris and Mohd, 2001). Dura cultivar contains around 35 to 55 % mesocarp and its shell thickness ranges from 2 and 8 mm. The Pisifera is a shell-less and is made out of the whole carnal oil bearing mesocarp material (Muthurajah 2002; FAO, 2005). The palm fruits are obtained from oil palm bunch. The fruit bunch is garnered and subjected to several processing stages, e.g., bunch reception, stripping, sterilization, digestion, palm oil extraction/ clarification, nut-fibre separation, nut drying and cracking, kernel separation, kernel crushing and pressing. Nevertheless, two approaches are used. The principles used are the identical but unique facilities are utilized (FAO, 2011, Assian *et al.*, 2022). Nonetheless, the traditional technique of stripping of fruit bunch (FB) is time consuming and yield low quantity, and quality palm oil (Oshiobugie *et al.,* 2017). In a modern mechanical process, a rotating or fixed drum is fitted with rotary beaters. These beaters help in stripping the fruits from the bunch, leaving the spikelets on the main stem (Assian *et al.,* 2022). Today, sophisticated software applications are used in machine parts design analysis such as Solid-Work application, Customized M236 Machine Design Spreadsheet, Beam Version 2.69, etc (Olosunde *et al.,* 2023; Undiandeye *et al.,* 2024). Optimization and simulation techniques were by Olosunde *et al.* (2023) in their case study on the analytical design and simulation of palm nut cracker using customized M236 Machine Design Spreadsheet. Simulation is an influential approach to modelling manufacturing systems. It can predict system performances that are difficult to evaluate without a model (Rufus and Emmanuel, 2021). Machine parts may be analytically, numerically or structurally simulated and the response assessed to establish the optimum parameters necessary for development of a machine (Assian, 2019; Ubong *et al.,* 2021; Antia *et al.,* 2019; Antia *et al.,* 2021; Assian and Alonge, 2021). Therefore, in this study, optimum electric motor power rating for moveable oil palm fruit bunch stripper was obtained based on the varying quantity of oil palm fruit bunches using Customized M236 Machine Design Spreadsheet and Goal Seek Tool embedded in Microsoft Excel®. However, this study would provide suitable quantity of oil palm fruit bunches expected to be stripped off by specified electric motor power rating.

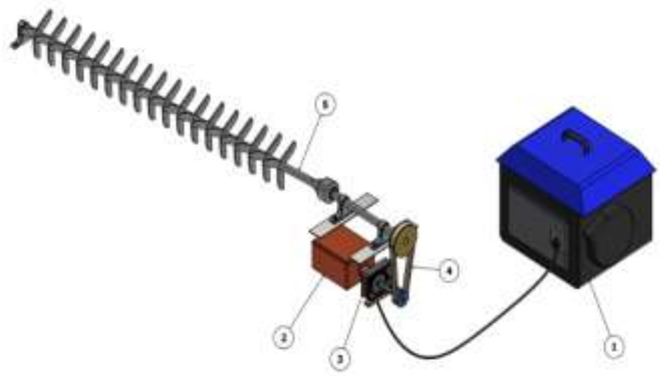
2.0 MATERIALS AND METHODS

In this research, the Customized M236 Machine Design Spreadsheet powered by Microsoft Excel was employed in analytical design, simulation and optimization of oil palm fruit bunch stripper parts / variable quantities

2.1 Analytical Design

Initially, the most important parts of oil palm fruit bunch stripper expected to impact on the total power required for stripping process (P_{sp}) are beaters, n-number of oil palm fruit bunches and shaft as shown in Figure 1.





Note: 1-Power generator, 2- Electric motor, 3-Gear box, 4- V-belt and 5-Shaft with beaters.

(a) **(b)**

Figure 1: (a) Three-D model of palm fruit bunch stripper, and (b) Parts of transmission system

(a) Weight of n-Number of Palm Fruit Bunch and Volume of a Beater Blade (V_{bb})

Weight of n-number of palm fruit bunch in the hopper (W_{nf}), and volume of a beater blade are given in Equations 1 and 2:

$$W_{nf} = n_f \, . \, m_{fb} . \, g \quad (1)$$

$$V_{bb} = h. \, b. \, l \quad (2)$$

where, n_f = number of palm fruits in the hopper, m_{fb} = mass of palm fruit bunch (kg) (Oshiobugie *et al.*, 2017; Assian *et al.*, 2022), g = acceleration due to gravity (9.81 $m.s^{-2}$), h = height of beater blade (m), b = base of beater blade (m) and *l* = length of beater blade (m).

(b) Total Number of Beater blades on the Shaft ($t_{-blades}$) and Weight of Total Number of

Beater Blades ($W_{t-blades}$)

Total number of beater blades on the shaft ($t_{-blades}$) and weight of total number of beater blades ($W_{t-blades}$) are derived from Equations 3 and 4:

$$t_{-blades} = n_{-spot} \, .q \quad (3)$$

$$W_{t-blades} = V_{bb} \times \rho \times g \times t_{-blades} \quad (4)$$

where, n_{-spot}= number of spot where beaters are located, q = number of beater blades per spot and ρ = density of beater blade (mild steel).

(c) Max Load Key on the Shaft ($W_{max.s}$) and Selection of Electric Motor / Generator

Assuming that the stripping force of palm fruits (F_{sp}) is 300 N by (Undiandeye *et al.* 2024), then, the maximum load key ($W_{max.s}$) and power required for stripping (P_{sp}) palm fruit bunch (PFB) considering the factor of safety are given in Equations 5 and 6 respectively (Khurmi and Gupta, 2012):

$$W_{max.s} = W_{nf} + W_{t-blades} + F_{sp} \quad (5)$$

$$P_{sp} = \frac{W_{max.s} \, N_s}{60} (f_s) \quad (6)$$

where, N_s = rotational speed of stripping unit shaft (rpm) and f_s = factor of safety.

The electric motor rated power, in hp, supplied for stripping process (P_{em}) considering its efficiency (ɳ) is given in Equation 7 (Antia *et al.*, 2021).

$$P_{em} = \frac{P_{sp}}{ɳ} \quad (7)$$

where, ɳ = motor power efficiency (%)

2.2 Numerical Simulation

Assuming that we have 5 or 6 hp electric motor / generator on ground. The task is to state or simulate the quantity of oil palm fruit bunches expected to be introduced into the hopper. First, the dependent, independent parameters and constants were recognized from Equations 1 to 7. Second, with the assistance of the *Customized M236 Machine Design Spreadsheet*, columns were created for parameter, symbol and unit. Third, the model equations were keyed into the *Customized M236 Machine Design Spreadsheet* based on the syntaxes understood by the programme. Fourth, some independent variables were varied over a certain range of values by simulation. Lastly, the results of activity were carefully evaluated, and if the results were unsatisfactory, the simulation was repeated over new sets of data and documented.

2.3 Optimization

Alternatively, if the results were unsatisfactory, the response(s) of the simulation could be optimized using *Goal Seek Tool* embedded in Microsoft Excel®. When the results were satisfactory, the parameters with their values were displayed and documented for use in the development of a palm fruit bunch stripper. In this particular case, the electric motor power rating required for stripping process (P_{em}) could be optimized by either reducing or increasing the quantity of oil palm fruit bunches into the hopper (n_f). Note that, other parameters such as dimensions of the beater blades (*h*, *b* and *l*), number of spot where beaters are fixed (n_{-spot}) and number of beater blades per spot (q) could also be varied. Thus, combining Equations 1 to 7, we have Equation 8, and we can say: Optimize,

$$P_{em} = \frac{(g\ [(n_f\ .\ m_{fb}) + (h.\ b.\ l\ .n_{-spot}\ .q\ )] + F_{sp})\ N_s .\ f_s}{60\ .\ \eta} \quad (8)$$

Subjected to constraints:

$$1 \leq\ n_f\ \leq 7 \quad (9)$$

where, Equation 8 is known as objective function; constraints are decision variables, and all other parameters are assumed to be constants (Assian *et al.*, 2021).

3.0 RESULTS AND DISCUSSION

3.1 Electric Motor Power Selection for Stripping More than Two Palm Fruit Bunches

Electric motor power selection for stripping more than two palm fruit bunches is given in Table 1.

Table 1: Electric motor power required for stripping process based on varying number of oil palm fruit bunch

Parameter	Symbol	Case I	Case II	Case III	Unit
Acceleration due to gravity	g	9.81	9.81	9.81	m/s^2
Mass of oil palm fruit bunch	m_{fb}	40	40	40	kg
Number of palm fruit bunches in the stripping chamber	n_f	2	4	6	
Weight of n-number of oil palm fruit bunch	W_{nf}	784.8	1569.6	2354.4	N
Height of beater blade	h	0.0887	0.0887	0.0887	m
Base of beater blade	b	0.0300	0.0300	0.0300	m
Length of beater blade	l	0.0500	0.0500	0.0500	m
Volume of a beater blade	V_{bb}	0.00007	0.00007	0.00007	m^3
Density of beater blade (mild steel)	ρ	7860	7860	7860	kg/m^3
Number of spots	n_{-spot}	12.00	12.00	12.00	
Each spot has q-number of beater blades	q	4.00	4.00	4.00	
Total number of beater blades	$t_{-blades}$	48.00	48.00	48.00	
Weight of total number of beater blades	$W_{t-blades}$	246.22	246.22	246.22	N
Stripping force after 24 hours of storage (Olotu *et al.* 2020)	F_{sp}	300.0	300.0	300.0	N
Maximum load key on the shaft	$W_{max.s}$	1331.02	2115.82	2900.62	N
Maximum speed of the shaft	N_s	100	100	100	rpm
Factor of safety	f_s	1.2	1.2	1.2	
Power expected for stripping process	P_{sp}	2662.03	4231.63	5801.23	W

	P_{sp}	2.662	4.232	5.801	kW
Note 1 hp = 0.745 kW		3.57	5.68	7.79	hp
Motor efficiency	ɳ	0.75	0.75	0.75	
Electric motor power supply (to be chosen)	P_{em}	4.76	7.57	10.38	hp

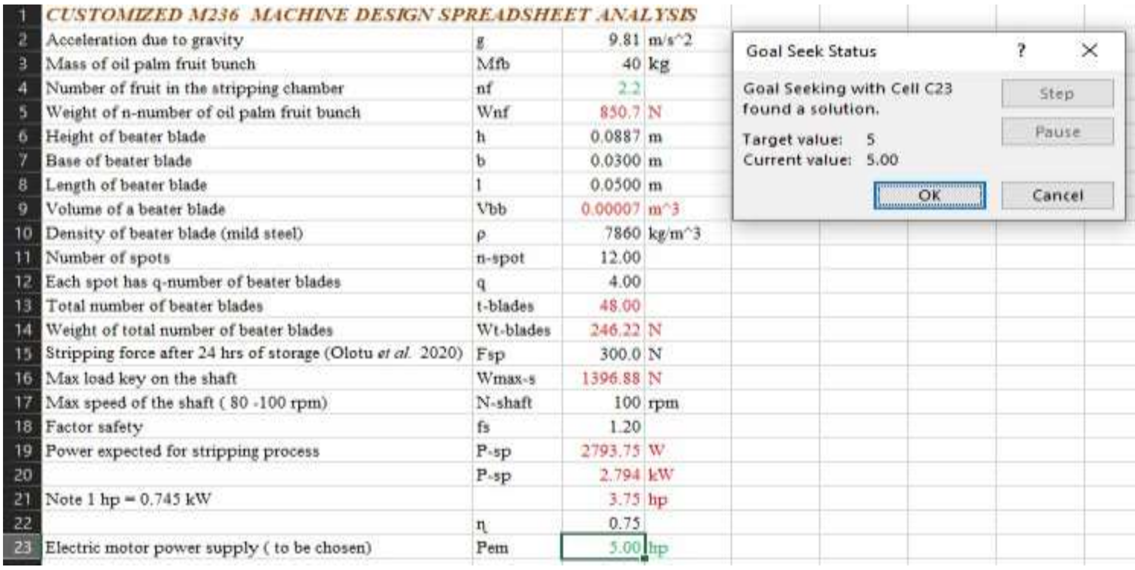
As could be seen in Table 1, increase in the number of oil palm fruit bunches in the stripping chamber (n_f) from 2 to 6, gave corresponding increase in weight of n-number of oil palm fruit bunch (W_{nf}) from 784.8 to 2354.4 N based on the mass of oil palm fruit bunch that was noted as 40 kg (Oshiobugie *et al*., 2017; Assian *et al*., 2022). The volume of a beater blade (0.00007 m^3) was generated as the product of height, base and length of the beater blade. Hence, the density of the beater blade (7860 kg/ m^3) and the number of spots (12) based on the fact that each spot has 4 number of beater blades, were utilized to compute total number of beater blades as 48. As a results, the weight of total number of beater blades was simulated as 246.22 N. Consequently, the maximum load keys on the shaft ($W_{max.s}$) of 1331.02, 2115.82 and 2900.62 N, respectively for 2, 4 and 6 palm fruit bunches, were simulated as the sum of the total weight of n-number of oil palm fruit bunch, weight of total number of beater blades and force required for stripping the fermented oil palm fruit bunches for 24 hours (300 N). With the maximum shaft speed of 100 rpm and factor of safety (1.2), power expected for stripping process (P_{sp}) were obtained as 2.662 kW (3.57 hp), 4.322 kW (5.68 hp) and 5.801 kW (7.78 hp) respectively for 2, 4 and 6 oil palm fruit bunches; also, with the recognition of electric motor efficiency (ɳ = 75%), the electric motor power rating expected to be selected (P_{em}) were accordingly 4.76, 7.57 and 10.38 hp. It could be observed that the system could take up to 2 or 3 oil palm fruit bunches at a time if 5 or 6 hp electric motor /generator were to be selected for stripping process.

(b) Optimization of Electric Motor Rated Power Required for Stripping Process

Before and after optimization process of 5.00 and 6.00 hp electric motor required for stripping operation are shown in Figures 2 to 5.

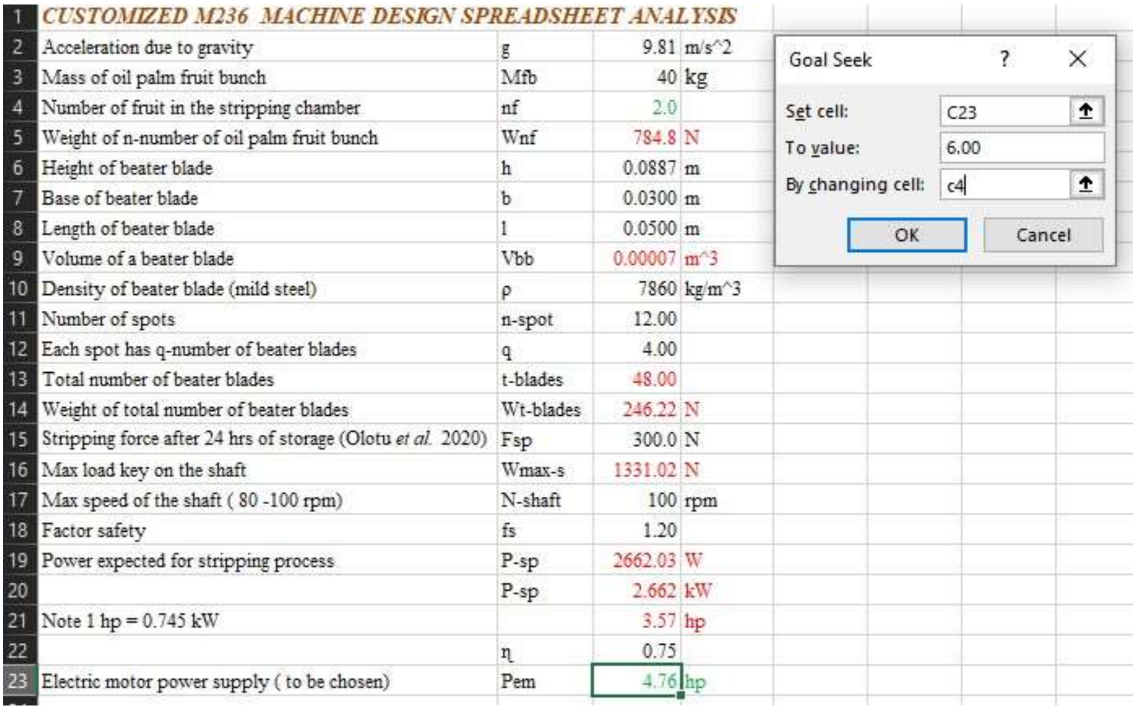
1	CUSTOMIZED M236 MACHINE DESIGN SPREADSHEET ANALYSIS			
2	Acceleration due to gravity	g	9.81	m/s^2
3	Mass of oil palm fruit bunch	Mfb	40	kg
4	Number of fruit in the stripping chamber	nf	2.0	
5	Weight of n-number of oil palm fruit bunch	Wnf	784.8	N
6	Height of beater blade	h	0.0887	m
7	Base of beater blade	b	0.0300	m
8	Length of beater blade	l	0.0500	m
9	Volume of a beater blade	Vbb	0.00007	m^3
10	Density of beater blade (mild steel)	ρ	7860	kg/m^3
11	Number of spots	n-spot	12.00	
12	Each spot has q-number of beater blades	q	4.00	
13	Total number of beater blades	t-blades	48.00	
14	Weight of total number of beater blades	Wt-blades	246.22	N
15	Stripping force after 24 hrs of storage (Olotu *et al.* 2020)	Fsp	300.0	N
16	Max load key on the shaft	Wmax-s	1331.02	N
17	Max speed of the shaft (80 -100 rpm)	N-shaft	100	rpm
18	Factor safety	fs	1.20	
19	Power expected for stripping process	P-sp	2662.03	W
20		P-sp	2.662	kW
21	Note 1 hp = 0.745 kW		3.57	hp
22		ɳ	0.75	
23	Electric motor power supply (to be chosen)	Pem	4.76	hp

Figure 2: Before optimization process for 5.00 hp



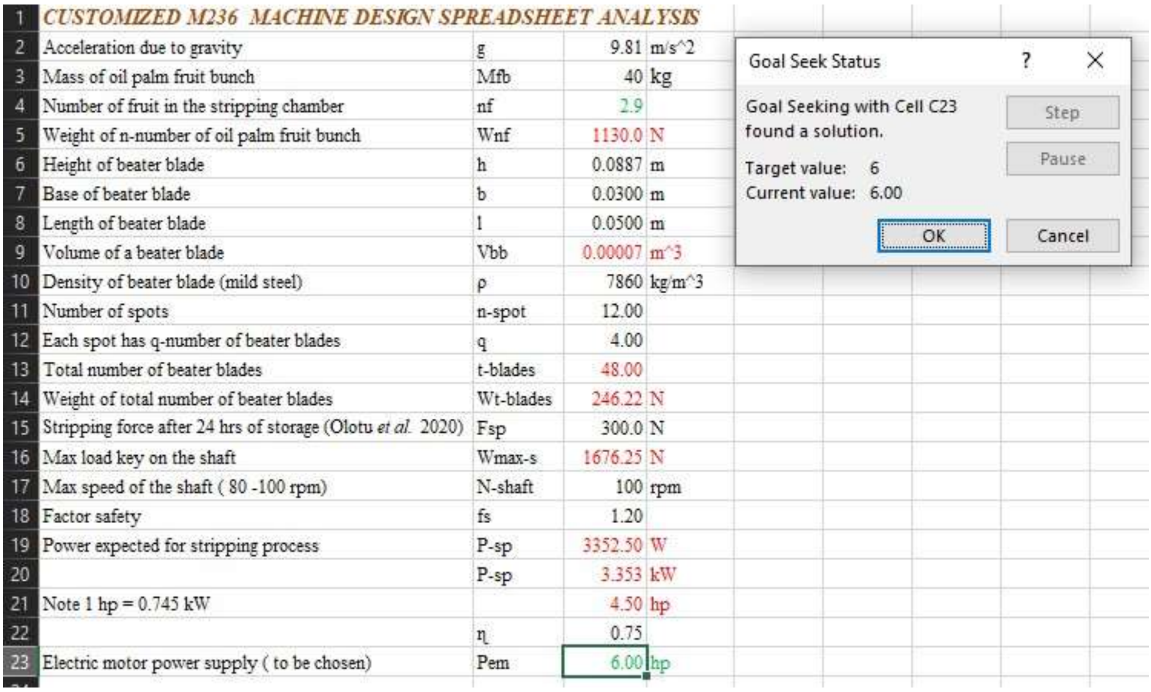
1	CUSTOMIZED M236 MACHINE DESIGN SPREADSHEET ANALYSIS			
2	Acceleration due to gravity	g	9.81	m/s^2
3	Mass of oil palm fruit bunch	Mfb	40	kg
4	Number of fruit in the stripping chamber	nf	2.2	
5	Weight of n-number of oil palm fruit bunch	Wnf	850.7	N
6	Height of beater blade	h	0.0887	m
7	Base of beater blade	b	0.0300	m
8	Length of beater blade	l	0.0500	m
9	Volume of a beater blade	Vbb	0.00007	m^3
10	Density of beater blade (mild steel)	ρ	7860	kg/m^3
11	Number of spots	n-spot	12.00	
12	Each spot has q-number of beater blades	q	4.00	
13	Total number of beater blades	t-blades	48.00	
14	Weight of total number of beater blades	Wt-blades	246.22	N
15	Stripping force after 24 hrs of storage (Olotu *et al.* 2020)	Fsp	300.0	N
16	Max load key on the shaft	Wmax-s	1396.88	N
17	Max speed of the shaft (80 -100 rpm)	N-shaft	100	rpm
18	Factor safety	fs	1.20	
19	Power expected for stripping process	P-sp	2793.75	W
20		P-sp	2.794	kW
21	Note 1 hp = 0.745 kW		3.75	hp
22		η	0.75	
23	Electric motor power supply (to be chosen)	Pem	5.00	hp

Figure 3: After optimization process for 5.00 hp



1	CUSTOMIZED M236 MACHINE DESIGN SPREADSHEET ANALYSIS			
2	Acceleration due to gravity	g	9.81	m/s^2
3	Mass of oil palm fruit bunch	Mfb	40	kg
4	Number of fruit in the stripping chamber	nf	2.0	
5	Weight of n-number of oil palm fruit bunch	Wnf	784.8	N
6	Height of beater blade	h	0.0887	m
7	Base of beater blade	b	0.0300	m
8	Length of beater blade	l	0.0500	m
9	Volume of a beater blade	Vbb	0.00007	m^3
10	Density of beater blade (mild steel)	ρ	7860	kg/m^3
11	Number of spots	n-spot	12.00	
12	Each spot has q-number of beater blades	q	4.00	
13	Total number of beater blades	t-blades	48.00	
14	Weight of total number of beater blades	Wt-blades	246.22	N
15	Stripping force after 24 hrs of storage (Olotu *et al.* 2020)	Fsp	300.0	N
16	Max load key on the shaft	Wmax-s	1331.02	N
17	Max speed of the shaft (80 -100 rpm)	N-shaft	100	rpm
18	Factor safety	fs	1.20	
19	Power expected for stripping process	P-sp	2662.03	W
20		P-sp	2.662	kW
21	Note 1 hp = 0.745 kW		3.57	hp
22		η	0.75	
23	Electric motor power supply (to be chosen)	Pem	4.76	hp

Figure 4: Before optimization process for 6.00 hp



1	*CUSTOMIZED M236 MACHINE DESIGN SPREADSHEET ANALYSIS*			
2	Acceleration due to gravity	g	9.81	m/s^2
3	Mass of oil palm fruit bunch	Mfb	40	kg
4	Number of fruit in the stripping chamber	nf	2.9	
5	Weight of n-number of oil palm fruit bunch	Wnf	1130.0	N
6	Height of beater blade	h	0.0887	m
7	Base of beater blade	b	0.0300	m
8	Length of beater blade	l	0.0500	m
9	Volume of a beater blade	Vbb	0.00007	m^3
10	Density of beater blade (mild steel)	ρ	7860	kg/m^3
11	Number of spots	n-spot	12.00	
12	Each spot has q-number of beater blades	q	4.00	
13	Total number of beater blades	t-blades	48.00	
14	Weight of total number of beater blades	Wt-blades	246.22	N
15	Stripping force after 24 hrs of storage (Olotu *et al.* 2020)	Fsp	300.0	N
16	Max load key on the shaft	Wmax-s	1676.25	N
17	Max speed of the shaft (80 -100 rpm)	N-shaft	100	rpm
18	Factor safety	fs	1.20	
19	Power expected for stripping process	P-sp	3352.50	W
20		P-sp	3.353	kW
21	Note 1 hp = 0.745 kW		4.50	hp
22		η	0.75	
23	Electric motor power supply (to be chosen)	Pem	6.00	hp

Figure 5: After optimization process for 6.00 hp

Looking at Figure 2 critically, the before optimization process for 5.0 hp, 2 oil palm fruit bunches had already given 4.76 hp. When ***"Data Menu"*** was tapped, ***"What-If -Analysis"*** was selected. Still under it, "***drop-down-arrow***" was clicked, then ***"Goal Seek"*** option was also selected. Automatically, ***"Goal Seek Dialog Box"*** appeared. Under ***"Set cell"*** cell, C23, which indicated P_{em}, was inputted. 5.00 hp was keyed in at the cell, ***"To Value".*** Then, the desired cell (C4) to be changed was inputted in ***"By changing cell",*** and **"Ok"** was clicked. As a result in Figure 3, the optimization yielded P_{sp} of 2.74 kW (3.75 hp) from 2.662 kW (3.57 hp), $W_{max.s}$ of 1396.88 N from 1331.02 N, W_{nf} of 850.7 N from 784.8 N and n_f of 2.2 from 2.0. There was increase in all the measured parameters since a higher motor rating was used. Again, in Figure 4, 6.0 hp had the same initial value as in Figure 2, but after optimization process gave P_{sp} of 3.353 kW (4.5 hp), $W_{max.s}$ of 1676.25 N, W_{nf} of 1130.0 N and n_f of 2.9 (≈ 3.0). In a nutshell, maximum of 2.0 and 3.0 oil palm fruit bunches could be stripped at a time using 5 and 6 hp electric motor rating respectively. Any increase in number of palm fruit bunches introduced into the stripper chamber / hopper will require an upgrade in electric motor rating. Besides, the configuration such as capacity of the stripping chamber may also be affected.

4.0 CONCLUSION

In selecting suitable electric motor power rating required for moveable palm fruit bunch stripper, a Customized M236 Machine Design Spreadsheet powered by Microsoft Excel was used in analytical design, simulation and optimization. The results revealed that a maximum of 2.0 and 3.0 palm fruit bunches could be stripped per time using 5 and 6 hp electric motor rating respectively.

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