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Development of Monograph to Estimate Actual Rotor Speed for a Given Nut Exit Velocity in a Centrifugal Nut Cracker

Assian Ubong Edet¹, Olosunde William Adebisi^{1*}, Antia Okon Orua¹

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ABSTRACT

In an attempt to shorten the computational procedure to estimate actual rotor speed for any given nut exit impinging velocity in a centrifugal nutcracker; a Monograph was developed using experimental data, analytical, and systematic approaches. The result showed that direct reading of actual rotor disc speed in rpm corresponding to any chosen nut exit velocity from any given rotor disc radius was achieved based on theoretical rotor speed. T-test comparing actual rotor disc speeds in rpm from the Monograph and model Equation 12 showed no statistically significant difference at 5% level of probability. Therefore, the developed Monograph is reasonably good for predicting the actual rotor disc speed in rpm required during nut cracking operation in a centrifugal nutcracker.

INTRODUCTION

Palm nut cracking is one of the essential unit operations involved in palm nut processing system. Traditionally, stone and pestle are used but this is inefficient. Modern processing uses machines/ systems (Oke, 2007). The efficiency of palm nut cracker / processing system may depend on the design of the components, nut varieties and physical properties, etc. (Antia and Obahiagbon, 2017). Imperfect machine component design may also affect its functionality. Several other aspects such as power requirement for cracking and running the shaft, cracking chamber size, rotor configuration, shaft diameter, separating unit designs, etc. cannot be relegated. Nevertheless, a lot of studies have been done towards providing models, data, etc. for the development of palm nut processing system (PNPS) by many scholars (Antia and Assian, 2018a and 2018b; Antia et al., 2019a and 2019b; Umani, 2014; Umani et al., 2020). The parameters such as average mass of the nut (\bar{m}) in kg and its exit velocity from the rotor disc has been used in computing palm nut translational kinetic energy. Also, the nut exit velocity necessary to crack the nut without objectionable damage to the kernel(s) ranged from 25.71 to 31m.s⁻¹. The energy released per unit nut was derived from the difference in nut translational kinetic energy and energy generated due to friction, sound, heat, etc. per unit nut mass. Besides, the theoretical rotor speed was found to be a function of aforementioned parameters as well as rotor disc radius and axial dimensions of the nut (Antia and Aluyor, 2018). In order to save computational time; avoid long tedious and rigorous computational algorithm that has a lot of independent variables, a monograph is preferred for easy reading off the required parameters and their corresponding values needed for machine design, experimental design and / or process design. Hence, the present study, was aimed at developing a monograph for direct reading of actual rotor disc speed (rpm) based on

any selected nut exit velocity from a certain rotor disc radius. The outcome of this work could easily assist in the design of palm nut processing system.

METHODS

Materials used in this work included: Software Package such as Microsoft Excel and experimental data.

Development of Monograph

Data were generated for theoretical speed of the rotor (N_r) in rpm, based on rotor disc radius (r), nut velocity (V_r) as (Antia et al., 2013).

$$N_r = \left[\frac{(1800)^{1/2} \bar{m} [v_r^2 - E_f]}{\pi^2 \bar{m} [3r^2 - 2r(d_1 + d_2 + d_3) + (d_1^2 + d_2^2 + d_3^2)]^{1/2}} \right] \quad (1 \text{ a})$$

Where, \bar{m} = nut mass (kg); E_f = energy generated due to friction, sound and heat; d_1, d_2 and d_3 are nut axial dimensions (m).

The plot of rotor disc radius against reciprocal of theoretical speed of rotor disc were carried out and presented in Figure 1 based on the following:

$$(i) V_r = (2\pi r N_r) / 60 \quad (\text{Khurmi and Gupta, 2012}) \quad (1)$$

Where, V_r = theoretical speed of nut exit from the rotor (m.s⁻¹), N_r = theoretical rotor speed (rpm) and r = rotor disc radius (m).

(ii) When rotor is on operation (working), the theoretical speed (N_{t}) and the actual rotor speed (N_a) may differ due to various factors.

(iii) However,

$$N_t \propto N_a \quad (2)$$

$$N_t = K_a N_a \quad (3)$$

Where, K_a is proportionality constant and takes care of various factors that may influence rotor during operation.

From Equations 1b and 3, we have

$$V_r = (2\pi K_a N_a) / 60 \quad (4)$$

$$r = ((60 V_r) / (2\pi K_a)) / N_a \quad (5)$$

(iv) If $K_a = 1$, then, from Equation 3

$$N_t = N_a \quad (6)$$

¹ Department of Agricultural and Food Engineering, Faculty of Engineering, University of Uyo, Uyo, P. M. B. 1017, Akwa Ibom State, Nigeria

* Corresponding author's e-mail: williamolosunde@uniuyo.edu.ng

Hence, to find the actual value of K_a and then N_a for a given system, plots of r and N_t at various V_t are required followed by evaluation of K_a values from the slope of the curves. Thus, Equation 5 could be rewritten as:

$$r = ((60 V_t) / (2\pi K_a)) 1 / N_t \tag{7}$$

Where, slope = $(60 V_t) / (2\pi K_a)$ and

$$K_a = (60 V_t) / (2\pi \text{slope}) \tag{8}$$

Mean K_a over the range of v_t was calculated based on Equation 8. From the obtained mean K_a , the actual rotor speed (N_a) could now be computed based on Equation 3 and the fact that rotor efficiency (η) is given as:

$$\eta = \text{output/input} = N_a / N_t \tag{9}$$

Therefore, from Equation 3, we have

$$N_a / N_t = 1 / K_a \tag{10}$$

From Equations 9 and 10, we have

$$N_a / N_t = 1 / K_a = \eta = K_f \tag{11}$$

Where, K_f = rotor operating factor (efficiency)

From Equation 11

$$N_a = 1 / K_a N_t = \eta N_t = K_f N_t = K_f 1 / (N_t^{-1}) \tag{12}$$

Based on Equation 12, the values of N_a were plotted

on the secondary y-axis against N_t^{-1} (x-axis) on the same graph and presented as Figure 2 referred to the developed monograph.

Illustration on the Use of Developed Monograph

- (a) Choose rotor disc radius, r (m) to be used.
- (b) Draw a straight line horizontally from rotor disc radius axis [primary y-axis] to meet the desired exit nut velocity, v_t (m.s^{-1}) curve.
- (c) Draw a straight line vertically downward from step b to meet the curve of reciprocal of theoretical rotor disc speed, (N_t^{-1})-axis.
- (d) Draw a horizontal line from N_t^{-1} curve in step c to meet N_a axis (secondary y-axis).
- (e) Read the value of the required N_a at the meeting point on N_a axis based on step d.
- (f) For practical illustration, use a typical data collected from a study on the models' simulation and test performance of a palm nut processing system given in Table 1.

Table 1: Rotor disc radius / nut exit velocity data.

Parameter	Symbol	Value					Unit
Selected rotor disc radius	r	0.082	0.084	0.087	0.092	0.100	m
Theoretical nut exit velocity	v_t	31	30	28	27	25	m.s^{-1}
Proportionality constant	K_a	1.31	1.31	1.31	1.31	1.31	
Rotor operating factor	K_f	0.763	0.763	0.763	0.763	0.763	

Now, steps (a) to (e) are summarily shown in Figure 3 using, for example, rotor disc radius, $r = 0.082$ m and the desired exit nut velocity, v_t (31.0 m.s^{-1}) in Table 1

computed using the developed Monograph and Equation 13 based on Equation 1b as:

$$V_a = (2\pi r N_a) / 60 \tag{13}$$

Validation of the Developed Monograph

The solutions using the developed Monograph (Figure 2) and model Equation 12, were presented and compared with each other using studentized-t-Test at 5% level of probability.

The actual rotor speed in meter per second (V_a) was

RESULTS

The plot of rotor disc radius against reciprocal of theoretical speed of rotor is shown in Figure 1 and a plot that incorporated rotor disc radius, reciprocal of theoretical speed of the rotor and actual speed of the rotor in rpm is presented in Figure 2 as Monograph.

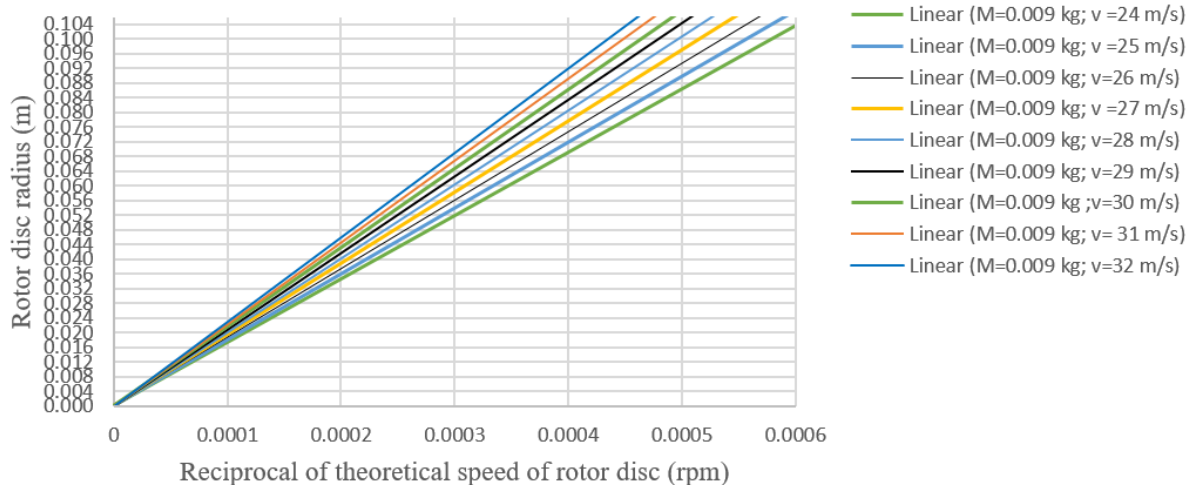


Figure 1: Rotor disc radius against reciprocal of theoretical speed of rotor.

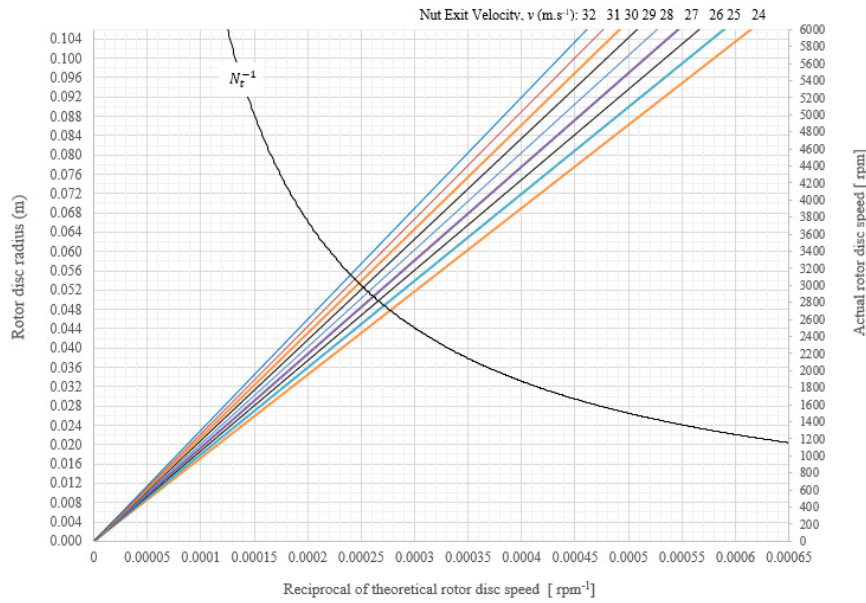


Figure 2: A monograph for reading actual rotor disc speed (rpm).

Figure 1 showed a linear relationship between rotor disc radius (r) and reciprocal of theoretical rotor speed in rpm (N_t^{-1}). The r increased with increase in N_t^{-1} while increase in nut velocity (v) decreased N_t^{-1} . In Figure 2, N_t^{-1} decreased

exponentially with increase in actual rotor disc speed in rpm (N_a). This implies that N_a is directly affected by the design theoretical rotor speed. Figure 3 illustrate the use of Monograph to obtain actual rotor speed (N_a) using step.

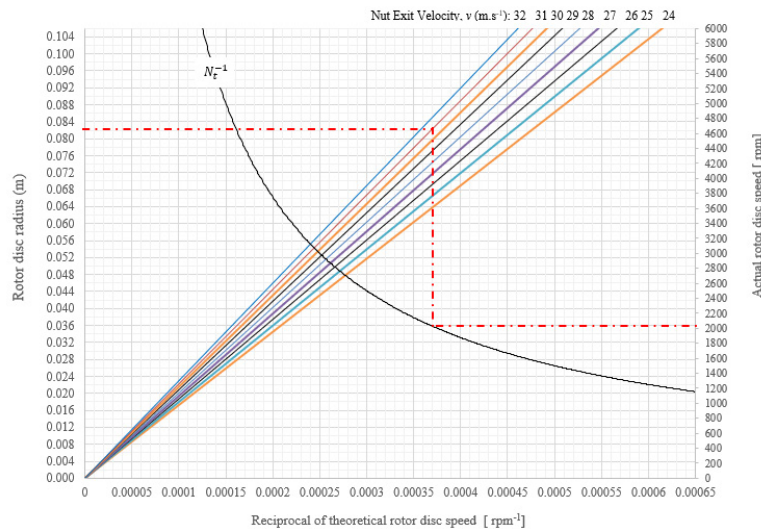


Figure 3: A monograph for reading actual rotor disc speed (rpm).

Table 2: Actual rotor disc speed using developed Monograph and model Equation 12

Parameter	Symbol	Value	Value	Value	Value	Value	Unit
Selected rotor disc radius	r	0.082	0.084	0.087	0.092	0.100	m
Theoretical nut exit velocity	v_t	31	30	28	27	25	$m.s^{-1}$
Proportionality constant	K_a	1.31	1.31	1.31	1.31	1.31	
Rotor operating factor	K_f	0.763	0.763	0.763	0.763	0.763	
Reciprocal of theoretical rotor disc speed	N_t^{-1}	0.000370	0.000392	0.000433	0.000472	0.000560	rpm^{-1}
Actual rotor disc speed (Monograph)	N_{a*}	2060.00	1950.00	1765.00	1600.00	1385.00	rpm
Actual rotor disc speed (Model Equation)	N_a	2063.13	1947.34	1762.95	1617.29	1363.14	rpm
Actual rotor disc speed (Equation 10)	V_{a*}	17.69	17.16	16.08	15.42	14.51	$m.s^{-1}$

The computation of actual rotor disc speed using the developed monograph and model Equation 12 is shown in Table 2. From Table 2, the rotor operating factor, K_f (efficiency) of 0.763 (76.3%) was obtained for each rotor radius (r) at various theoretical exit nut velocities (v_t)

based on Equation 12 and Monograph (Figure 3). Also, the actual rotor disc speed obtained from the Monograph and model Equation 12 were comparatively close. The statistical analysis on the comparison of actual rotor disc speed is presented in Table 3.

Table 3: Comparison of actual rotor disc speed using the Monograph and model Equation 12.

		Mean	SD	df	5% Level of Probability	
					t_{cal}	t_{Tab}
Actual rotor disc speed (Monograph)	N_{a*}	1752.00	270.19	8	-0.007	2.306
Actual rotor disc speed (Model Equation)	N_a	1750.77	275.87			

Note: SD= standard deviation, df=degree of freedom; For decision rule, if Table t-value (t_{Tab}) > calculated t-value (t_{cal}), there is no statistically significant difference.

From Table 3, t-test analysis showed that there was no statistically significant difference between the two arrays of rotor disc speed at 5% level of probability. This implies that the developed Monograph is valid and reasonably good for reading directly the value(s) of actual rotor disc speed (rpm) if rotor disc radius (m) and nut exit velocity ($m.s^{-1}$) from the same rotor are defined.

CONCLUSION

A Monograph was developed using experimental data, analytical and systematic approaches. Statistical analysis showed that the Monograph can be used to read off directly the value of actual rotor disc speed in rpm necessary to run the cracking unit if the rotor disc radius and theoretical nut exit velocity are known, instead of going through rigorous computation.

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