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COMPUTER SIMULATION OF OPTIMIZATION MODELS FOR THE OPERATIONAL PERFORMANCE OF LAWNMOWER DURING CUTTING ACTION

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ABSTRACT

A computer simulation employed in an attempt to enhance the mathematical optimization models being developed to improved Lawnmower blade geometry for the attainment of high cutting efficiency during cutting action, the optimal blade thickness and blade width. The computational analysis of the algorithmic development confirmed blade angle of wrap of 3 to 4^0 should be the best design consideration. This angular range resulted in the best optimal values in the design for optimal blade width and thickness. The results obtained for theoretical power, optimal power, and electrical power to drive the cutting blades were also challenging and tempting. The best cutting efficiency is achievable when the number of blades are two, and the blade angle of wrap around the rotor shaft is 4^0. The improvement in cutting efficiency decreases as the number of blades increase. Geometrically, the cutting forces resulted in blade angle of cut of 45^0. The process avoids shock loading of the blades during cutting action. Hence the cutting forces are gradually taken up with less severe bending and twisting motion.

KEYWORDS: computer simulation, Blade angle of a wrap, Cutting force, blade optimization, Bending and twisting action, improved efficiency.

INTRODUCTION

The mathematical model was developed to provide an insight into the behavior of the cutting blade geometrical configuration concerning the performance specifications.[1] The computer simulation uses the same mathematical concept but requires the model that would be created through computer programming. The essence of the computer simulation is to forecast the future behaviors of the blade geometry cutting characteristic of the lawn mower.

The use of computer simulation becomes necessary because of the availability of computing power and improvements in programming languages. Also, there are inherent difficulties or impossibilities to accurately describe the blade angle, cutting force, optimal blade width, optimal blade thickness, and the wing. From the above reasons, computer simulation can represent these complexities precisely is required.[3]

A Lawn Mower is a piece of equipment to keep a lawn or grassy terrain very tidy and clean. The history, even the invention of lawn mower dated back to 1830.[4] Over the years different design concepts of lawn mower had evolved: belt driven lawn mower, gear driven lawn mower, lawn mower with air cushioning effect, robotic lawnmower, etc.[5,6] Frequently the mower can use natural gas, gasoline or diesel as a source of power. There are other variations of lawn mower, driven electrically.

Primarily they are designed to make grass cutting operation in a garden, sports arena or residential quarter much effortless to achieve. Figure 1 shows the archetypal pattern of a lawnmower blade configuration. The lawnmower during operation, the blade strikes the uncut grass with its side which is the leading edge. The tip of the blade on the leading edge is the cutting surface focus; the high-speed impact with the grass cuts the grass down.[2] Experimentally observation shows that approximately 70.4 meters per second are the blade tip speeds. The wing, which is the up-turned portion of the trailing edge of the blade, and it, is generally considered as the most critical design parameter that can be modified to obtain the yearning performance.

Several scholars have worked on improving the efficiency and the performance of the lawn mower. Tauro in his work, try to reduce the noise emanating from the use of commercial lawn mower blades.[2] He further reviewed many works of literature on the effect of a single blade on lawn mower to ascertain the efficiency of lawn mower, and reveal that the lawn mower and other types of rotating blades such as aircraft, propellers and fan blade; all have similar noise generation mechanisms. In trying to reduce the noise level, the application of the following theories; rotational speed reduction, length reduction, and the reduction of the width of the lawn mower blade; which are not a realistic solution for the performance of the lawnmower.[2] The modification of the lawn mower blades only give a limited noise reduction, but the interaction between the deck and the blade plays a vital role in the generation of noise while it is operational.

SIGNIFICANCE OF RESEARCH

The computational analysis of the mathematical models for optimization of Lawnmower blade geometry for effective cutting action is a unique design concept in the determination of the optimal number of blades, optimal blade width, and thickness. It is worthy to note that the approach lends itself to computational analysis that applied itself to the comparative analysis of the theoretical, optimal and electric power for more improved cutting effectiveness. The blade area ratio gives an insight into the fact that if the cutting base is merely a disc, there would not have been any cutting action order than rubbing action. Inadvertently, this effect would lead to an increased power requirement from the cutting operations. Hence, it is worthy to note that the computational analysis design considerations dictate two or four blades for improved cutting efficiency. The Lawn Mower is a bladed rotor; the geometric representation of the blade and forces acting on it is as shown in Figure 2 below.

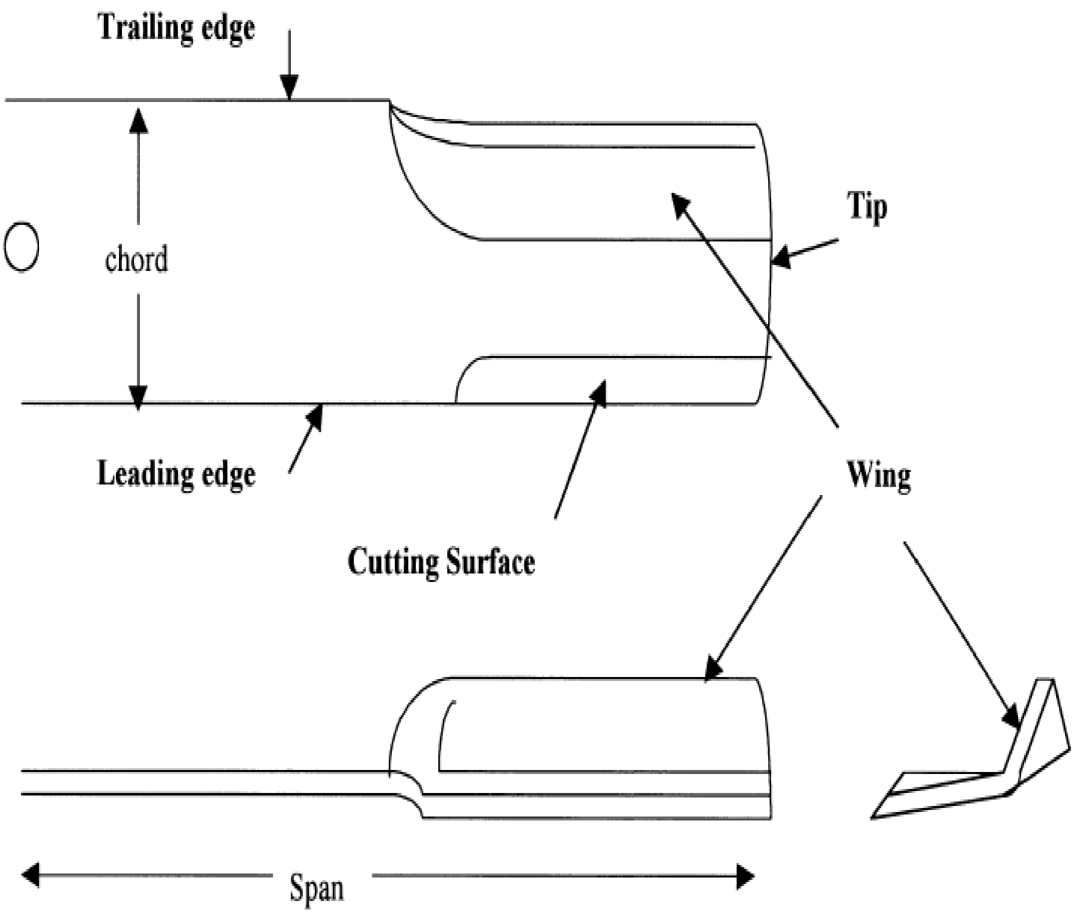

Figure 1: Archetypal pattern of a lawnmower blade (Source: Moore (1997)).

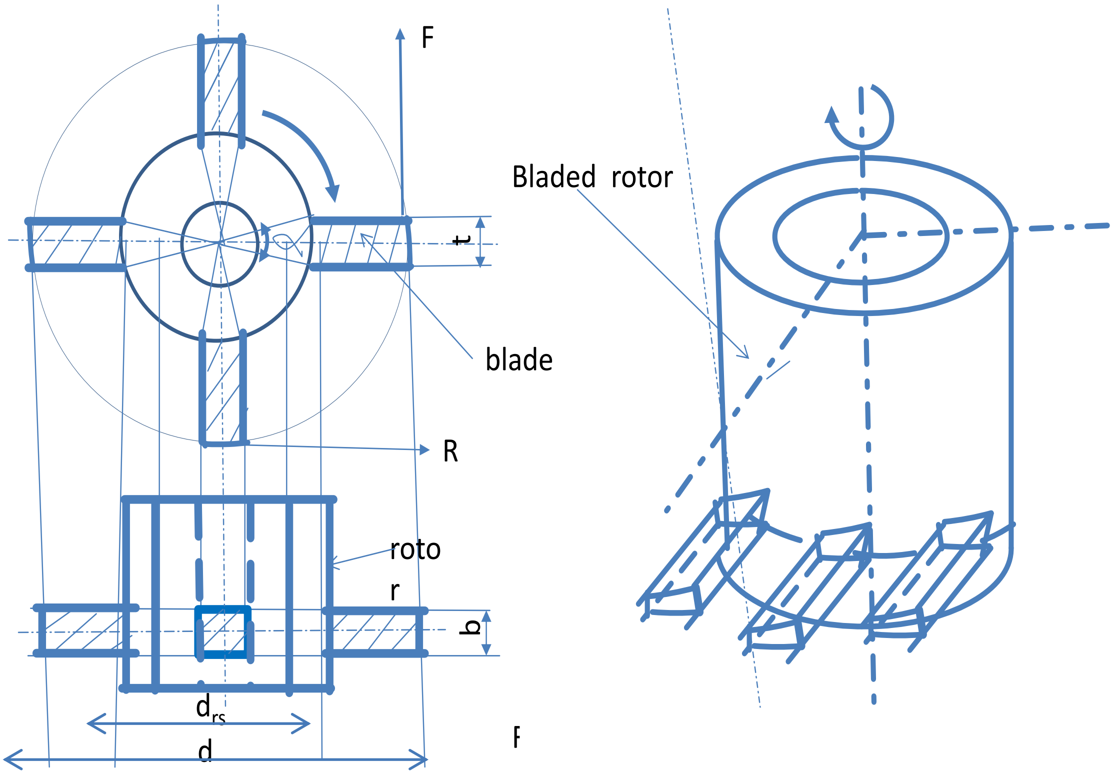

Fig 2a: Views of the bladed rotor (Source: Uzoma and Briggs (2019)).

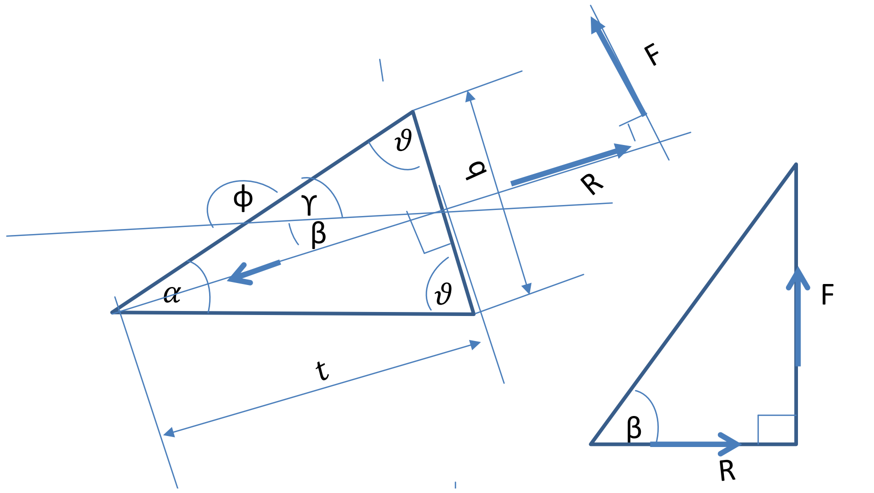

Fig. 2a: Geometric representation of the blade cutting angle and thickness (Source: Uzoma and Briggs (2019)).

Recalling the mathematical model (from equation 1 to 16) of lawn mower blade geometry used to attain improvement in the cutting efficiency of the lawn mower blade published previously by Uzoma and Briggs (2019).[1] “The cutting resistance of the grass is τ_g and the tangential force on the blade as F and while the base area is A. The base diameter being d, therefore:

$$\tau_g = \frac{F}{A}$$

$$F = \tau_g A = \tau_g \frac{\pi d^2}{4} \qquad (1)$$

The cutting torque, T acting on the blade, represented as :

$$T = Fr = \frac{Fd}{2} = \tau_g \frac{\pi d^2}{4} \quad \tau_g A = \tau_g \frac{\pi d^2}{4} \times \frac{d}{2}$$

$$T = \tau_g \frac{\pi d^3}{8} \qquad (2)$$

If ω is the angular rate of rotation of the blade per minute and N_b is the blade revolution per second the,

$$\omega = \frac{2\pi N_b}{60} \qquad (3)$$

Power required to drive the blade expressed as :

$$P = T\omega = \tau_g \frac{\pi d^3}{8} \times \frac{2\pi N_b}{60} = \tau_g \frac{\pi^2 d^3 N_b}{240} \qquad (4)$$

Equation 4, gives the equivalent power or horsepower to drive the electric motor.

Let the shearing resistance of the rotor shaft material be τ_{rs} and its area of cross section A_{rs}, then;

$$\tau_g = \frac{F}{A_{rs}}$$

$$F = \tau_{rs} A_{rs} = \tau_{rs} \frac{\pi d_{rs}^2}{4} \qquad (5)$$

Torque T_{rs} on the rotor shaft expressed as:

$$T_{rs} = \tau_{rs} \frac{\pi d_{rs}^3}{8} \qquad (6)$$

Equation 4 and 6 give the expression for the rotor shaft diameter, d_{rs}.

$$\tau_{rz}\frac{\pi d_{rz}^3}{8}=\tau_g\frac{\pi^2 d^3 N_b}{240}$$

$$d_{rz}=\sqrt[3]{\frac{\tau_g}{\tau_{rz}}d^3} \qquad (7)$$

If the speed reduction of the electric motor is N(rev/min) and the speed reduction from the motor to the driven blade is ½, then:

$$\frac{N_b}{N}=\frac{1}{2}$$

$$N_b=\frac{1}{2}N$$

Power to drive the cutting blade is expressed as:

$$P_{ele}=\tau_g\frac{\pi^2 d^3 N_b}{240}=\tau_g\frac{\pi^2 d^3\frac{N}{2}}{240}$$

$$=\tau_g\frac{\pi^2 d^3 N}{480} \qquad (8)$$

The power required to drive the cutting blade should be dependent on the number of the blade, n, and the area of the cutting blade occupied by the base. Hence, the concept of the blade area ratio, A_r is:

$$A_r=\frac{Effective area\ of\ the\ cutting\ blade}{Area\ of\ the\ cutting\ base}$$

Where,

$$0\le A_r\le 100\%$$

$$A_r=\frac{A-A_b}{A} \qquad (9)$$

$$A=\frac{\pi d^2}{4}-\frac{\pi d_{rz}^2}{4}, \qquad A_b=nt\left(\frac{d-d_{rz}}{2}\right)$$

$$A_r=\frac{\left(\frac{\pi d^2}{4}-\frac{\pi d_{rz}^2}{4}\right)-\left(nt\left(\frac{d-d_{rz}}{2}\right)\right)}{\left(\frac{\pi d^2}{4}-\frac{\pi d_{rz}^2}{4}\right)}-1-\frac{2nt}{\pi(d+d_{rz})}$$

With referenceto Fig.1, $d_{rz}=\frac{2t}{\alpha}$.

$$A=1-\frac{2nt}{\pi\left(d+\frac{2t}{\alpha}\right)} \qquad (10)$$

The power to drive the cutting blade expressed in terms of the blade area ratio Ar,

$$P_{Ar} = \tau_{\varepsilon} \frac{\pi^2 d^3 N}{480} \times A_r$$

$$= \left(\tau_{\varepsilon} \frac{\pi^2 d^3 N}{480} \right) \left(1 - \frac{2nt}{\pi \left(d + \frac{2t}{\alpha} \right)} \right) \qquad (11)$$

At optimal blade width, t_{opt}, for effective cutting action, $dP_{Ar}/dt=0$.

$$\frac{dP_{Ar}}{dt} = \pi \left(d + \frac{2t}{\alpha} \right) 2n - \frac{4\pi nt}{\alpha} = 0$$

$$t_{opt} = \frac{\pi d \alpha}{2(n-1)} \qquad (12)$$

Optimal power to drive the system expressed as,

$$P_{optr} = \left(\tau_{\varepsilon} \frac{\pi^2 d^3 N}{480} \right) \left(1 - \frac{2nt_{opt}}{\pi \left(d + \frac{2t_{opt}}{\alpha} \right)} \right) \qquad (13)$$

The blade angle of twist, β, is expressed as:

$$\tan \beta = \frac{F}{R}$$

$$\beta = \tan^{-1} \frac{F}{R}$$

Optimal blade thickness, bopt, is given as:

The cutting efficiency, ***η***, is the ratio of blade area ratio power requirement to the electric power requirement.

$$\frac{t_{opt}/2}{\sin(\alpha/2)} = \frac{b_{opt}}{\sin\left(90 - \frac{\alpha}{2}\right)}$$

$$b_{opt} = \frac{t_{opt} \tan\left(\frac{\alpha}{2}\right)}{4} \qquad (14)$$

$$\eta = \frac{P_{Ar}}{P_{elec}} \qquad (15)$$

The improved cutting efficiency,$_{imp}$, is the ratio of the difference in the real power in terms of the blade area ratio to optimal power over the electrical power requirement".

Thus,

$$\eta_{imp} = \frac{P_{Ar} - P_{opt}}{P_{elec}} \qquad (16)$$

Computational Algorithmic Coding

The algorithms coding for the computational analysis are as outlined:

```
% COMPUTER SIMULATION OF THE OPTIMIZATION MODELS FOR THE OPERATIONAL
% PERFORMANCE OF LAWN MOOWER DURING CUTTING ACTION
% INITIALIZATION (INPUT PARATERS)
% SPEED OF ELECTRIC MOTOR, n (Ren/min)
N=3000;
% ROTOR SHEARING RESISTANCE, RS(N/m2)
RS=75*10^6;
% cutting resistance of the grass,GS (N/m2)
%  GS=15*10^6;
GS=150000;
% DIAMETER OF THE BASE AREA OF THE CUTTING BLADE, D (m)
disp('DIAMETER  d   OF THE CUTTING BLADE  BASE')
d=0.65;
fprintf('%10.4f/',d)
% RADIUS OF THE BASE AREA OF THE CUTTING BLADE, r (m)
r=d/2;
pi=22/7;
% SPEED OF THE BLADE, Nb (rev/min)
Nb=N/2;
% ANGULAR RATE OF ROTATION OF THE BLADE, W (rad/s)
w=(2*pi*Nb)/60;
% TANGENTIAL VELOCITY AT THE TIP OF THE CUTTING BLADE, V (m/s)
V=r*w;
disp(' The value of  n1 =? ')
n1=6;
```

```
fprintf('%10.4f/',n1)
for theta=1:1:5
disp('THETA')
fprintf('%10.4f/',theta)
Alp=(pi*theta)/180;
% ROTOR SHAFT DIAMETER, drs (m)
drs=((GS*d^2)/RS)^(1/3);
disp('drs')
fprintf('%10.4f/',drs)
% BLADE THICKNESS, T (m)
t=(drs*Alp)/2;
% OPTIMAL BLADE THICKNESS, topt(m)
topt=(pi^d*Alp)/(2*n1-1);
% OPTIMAL BLADE WIDTH (m)
bopt=topt*tan(Alp/2);
% BLADE AREA RATIO, ar (dimensionless)
disp('AREA   RATIO')
% Ar=1-(2*n1*drs*Alp)/(pi*(d*t+((2*t)/theta)));
Ar=(1-(2*n1*drs*Alp)/(pi*(d+drs)));
fprintf('%10.4f/n',Ar)
%  OPTIMAL AREA RATIO Aropt (dimensionless)%
% Aropt=(2*n1*topt)/(pi*(d*topt+((2*topt)/theta)));
Aropt=(1-(2*n1*topt)/(pi*(d+drs)));
% POWER REQUIRED TO DRIVE THE CUTTING BLADE IN TERMS OF THE BLADE
AREA RATIO, AR
P=((pi^2*drs^3*GS*Nb)/480)*Ar;
% CUTTING FORCE IMPARTED ON THE CUTTING BLADE
F=P/V;
R=F;
% THE BLADE CUTTING ANGLE,   Beta
%  Beta=tan^(-1)(R/F);
%  disp('TUTTING  ANGLE Beta=')
%  fprintf('%10.4f/n',Beta)
disp('THE CUTTING  FORCE  F=')
```

```
fprintf('%10.4f/n',F)
% OPTIMA POWER REQUIRED TO DRIVE THE CUTTING BLADE IN TERMS OF THE BLADE AREA RATIO, AR
Popt=((pi^2*drs^3*GS*Nb)/480)*Aropt;
% POWER REQUIRED TO DRIVE THE ELECTRIC MOTOR
Pelec=((pi^2*drs^3*GS*Nb)/480);
disp('ALP')
fprintf('%10.4f/n',Alp)
disp('ttopt    bopt')
fprintf('%10.6f/n',t,topt,bopt)
disp('P Popt  Pelec')
fprintf('%10.4f/n',P,Popt,Pelec)
end
```

Analysis of Computational Results

Table 1: Computational Results.

Lawnmower base diameter d (m)	Blade number n	Wrap angle (Ө˘)	Rotor shaft diameter d_{rs} (m)	Blade width (m) t (m)	Optimal blade width t_{opt} (m)	Optimal blade thickness b_{opt} (m)	Theoretical power P (Watts)	Optimal power P_{opt} (Watts)	Electrical power P_{elec} (Watts)	Improved cutting efficiency (%)	Blade area ratio Ar (dimensionless)
		1	0.0945	0.0008	0.0123	0.0001	3901	3830	3912		0.99972
		2	0.0945	0.0017	0.0245	0.0004	3890	3749	3912		0.9944
0.65	2	3	0.0945	0.0025	0.0362	0.001	3879	3667	3912	5.42 7.26	0.9915
		4	0.0945	0.0033	0.0449	0.0017	3868	3584	3912		0.9887
		5	0.0945	0.0041	0.0613	0.0027	3857	3502	3912		0.9859
		1	0.0945	0.0008	0.0053	0.000046	3890	3842	3912		0.9944
		2	0.0945	0.001651	0.0106	0.000083	3868	3772	3912		0.9887
0.65	4	3	0.0945	0.002476	0.01575	0.000413	3846	3701	3912	3.71 4.91	0.9831
		4	0.0945	0.0033	0.021	0.000734	3824	3632	3912		0.9774
		5	0.0945	0.00413	0.0263	0.00115	3802	3561	3912		0.9719
		1	0.0945	0.00825	0.003341	0.000029	3879	3845	3912		0.9915
		2	0.0945	0.001651	0.006683	0.000117	3846	3778	3912		0.9831
0.65	6	3	0.0945	0.002476	0.010024	0.000263	3813	3711	3912	2.45 3.48	0.9746
		4	0.0945	0.003301	0.01337	0.000467	3780	3644	3912		0.9651
		5	0.0945	0.004127	0.01671	0.00073	3747	3577	3912		0.9577

The computational results of some paramount parameters affecting the operational performance of the Lawnmower during cutting action are in Table 1. The blade area ratio is a pointer to the fact that if the cutting blade is to be merely a disc, the cutting action would have been rubbing action. Thus, this requires tremendous power to effect cutting action. As observed the ability to make cutting reduces as the number of blades increase but up to a limit. The computational results show an indication that the cutting power decreased when the number of cutting blades changed from 2 to 4. There is a need to increase cutting power when the number of blades changed from 4 to 6. Based on the wrap angle of the blade around the rotor shaft, the best optimal cutting efficiency obtained at a wrap angle of 3 to 4^0.

CONCLUSION

The essential focus of this paper is to develop computer simulations techniques evolved to satisfy the analysis tool to predict and manage the geometrical characteristics of the lawnmower blade. The application of the computational data faithfully would lead to lowering overhead cost, reducing labor requirement, and streamlining operations of the lawn mower. However, there is still more work to do to better understanding and quantity the procedures of improving the quality of performance cutting efficiency of the lawn mower.

RECOMMENDATION

The results of the computational, algorithmic coding should be applied in the production of new generational Lawnmower. More so, the blade angle of cut, β, was geometrically determined as 45^0, even being the optimal value and practically relevant to avoiding shock loading the blades during cutting action. The best possible range of this angle should be obtained experimenting on a physical model.

NOMENCLATURE

F, R—tangential force at the blade tip (N)

A—base area of the cutting blade (m2)

T_g—cutting resistance of the grass (N/m2)

r—base area radius (m2)

ω—angular rate of rotation of the blade (m2)

N—motor revolution (rev/s)

P—power required to drive the blade (Watts)

P_{Ar}—theoretical power required to drive the blade in terms of blade area ratio (Watts)

P_{opt}—optimal power required to drive the blade (Watts)

P_{ele}—electrical power required for cutting action (Watts)

T—cutting torque (Nm)

Nb—blade revolution (rev/s)

T_{rs}—rotor shaft shearing resistance (N/m2)

A_{rs}—rotor shaft area of cross section (m2)

Ar—area ratio (dimensionless)

n—number of blades

t—blade width (m)

b—blade thickness (m)

t_{opt}—optimal blade width (m)

b_{opt}—optimal blade thickness (m)

α—angle subtended by the cutting blade at the centre of the rotor shaft (degree)

β—cutting angle (degree)

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