

Development of a Tool to Determine the Energy Required to Cut and Top Sugarcane

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Abstract

Sugarcane harvesting is a labor intensive operation and its mechanization is a recent development in Nigeria. The difficulties in providing the needed spare parts for the imported harvesting machines and labor shortages during harvesting periods impede the country's drive towards self-sufficiency in sugar production. To develop an effective and efficient machine for harvesting of sugarcane, a preliminary data on the energy requirement for the cutting and topping of sugarcane must be available to the designer. A simple apparatus was developed to calculate the energy requirement for cutting and topping of sugarcane. The apparatus consists of: crank, sprocket, chain, freewheel, flange, front hub, spindle, frame and the base support. The result of evaluation test reveals that 15.71 Joules and 23.83 Joules were needed for cutting the top and base of the sugarcane, respectively.

Keywords: *Harvesting machines, energy requirement, self-sufficiency, evaluation test.*

1. Introduction

Mechanization of farm operations has been pursued vigorously by both private and government organizations to improve the production of various crops. The mechanization of sugarcane harvesting is not an exception in this regard. Blackburn (1991) rightly recognized that sugarcane harvesting was notoriously labour intensive, and the need to provide a labour to harvest cane, in a great measure, lead to the development of slave trade between West Africa and the Americas. Euroconsult (1989) assessed the labor requirement of sugarcane at 150 to 170 man-day/ha when all operations, except land preparation, were done manually. Agboola (1979) reported that the mechanization of sugarcane harvesting, like its cultivation as raw material for industrial plant, is a recent development in Nigeria. Sugarcane is harvested in Nigeria manually by hand which is proved to be an impediment to the expansion of its cultivation. Hence, there is

a need to gear efforts toward bridging the gap between demand and production of sugarcane by developing simple tools and appropriate technology machines that fit the general objective of mechanization for increased food production.

The knowledge of the energy required to cut and top sugarcane plant is the basis for the design of a machine for harvesting of sugarcane. Since the machine is envisaged to save energy, it is pertinent to find the energy required to cut sugarcane plant. Sugarcane cutting is achieved by impact, whether by hand or machine. Because of the scanty literature available, the authors have not seen previous works on energy requirements for sugarcane cutting. Hence, this is the reason to search for means of studying the energy requirement based on the design of a machine to harvest sugarcane plant. The objective of this study is to develop a tool to be used empirically to determine the energy requirement for cutting and topping sugarcane plant.

2. Material and Method

2.1 Description of the Machine

A simple apparatus (tool) was developed to empirically calculate the energy requirement to cut and top sugarcane plant. The apparatus (tool) consists of (Fig. 1): (1) crank, (2) sprocket (14 teeth), (3) chain, (4) freewheel and sprocket (18 teeth), (5) flange, (6) hub, (7) spindle, (8) spindle housing, (9) fork, (10) frame, (11) handle, and (12) cutting disc. Different discs with different masses were used to find the cutting energy. The device exploits the inertial forces of the disc when accelerated to cut the sugarcane. In order to vary the forces, the discs were cut from metal sheets of different thicknesses (Table 1). The discs were mounted on the flange. Chopper harvester blade was used on the disc and later on the machine for cutting sugarcane.

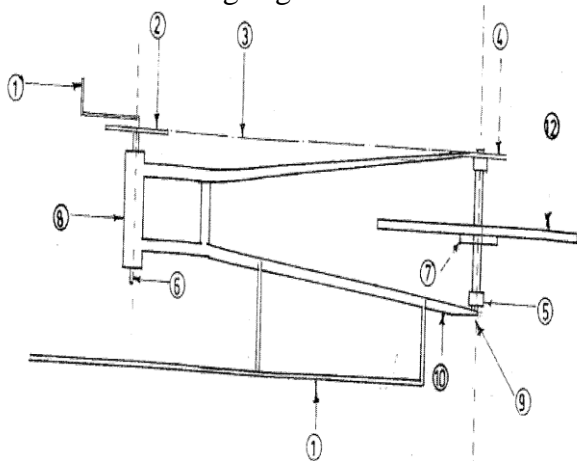


Fig. 1. Components of the cutting tool.

The flange, hub and freewheel was found to be 0.675 Kg. The protruding part of the blade was 50 mm. When these were fitted with the discs and blade, the masses changed as shown in Table 2.

Table 1. The thickness, radius and mass of the discs.

Disc	Thickness, mm	Radius, mm	Mass, kg
I	2	115	0.3
II	5	130	1.98
III	10	130	3.98
IV	15	130	5.88
V	5	252	8.3

Table 2. Combined masses of hub, blade, flange and discs.

Disc	Mass of hub, disc & blade, kg	Radius of hub, disc & blade, mm
I	0.975	165
II	2.655	180
III	4.655	180
IV	6.555	180
V	8.975	302

For a rotating body (Chernilevsky *et al.* 1984),

$$\int_0^\theta M(\theta) = 0.5I(\omega^2 - \omega_0^2) = 0.5I\omega^2 - 0.5I\omega_0^2, \quad (1)$$

where: M = turning moment; θ = angular displacement; ω_0 = initial angular velocity; and ω = final angular velocity.

The parameter $(0.5I\omega^2 - 0.5I\omega_0^2)$ is a measure of the change in the kinetic energy of the body. It is equal to the work done during angular displacement θ . Neglecting friction in the device, this energy is equal to the work done by the disc and blade to cut the top and base of the sugarcane.

For the calculation of the kinetic energy KE of the flange, hub and freewheel assembly, the assembly has to be divided into geometrical components for easy calculation (Fig. 2). Each component has its own dimension (Table 3) and mass.

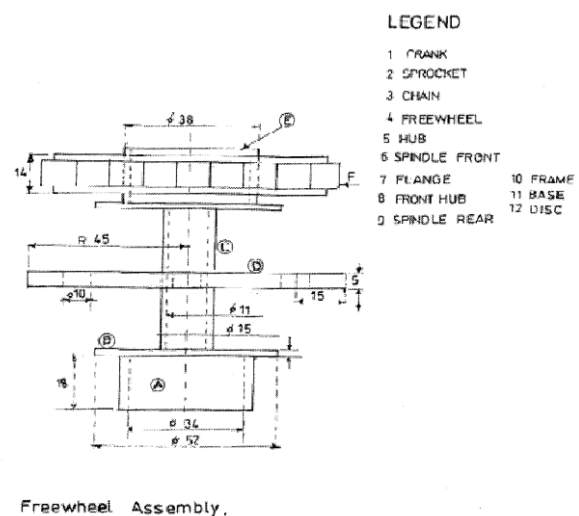


Fig.2. Components of the freewheel assembly.

Table 3. Dimension of the disc and freewheel assembly.

Component	Length, m	Inner diam., mm	Outer diam., mm	Thickness, mm
Freewheel hub A	18	34	38	2
Spokes Flange B		11	52	2
Pipe C	50	11	15	2
Flange D		15	90	5
Cover E		11	34	2
Freewheel F		38	78	14

2.2 The Mass of the Hub and Flange Assembly

The mass of each part is calculated from the relationship between density ρ , mass m and volume v . The density of the material of the assembly is $\rho_s = 7.828 \times 10^{-6} \text{ kg m}^{-3}$. The mass of each component is calculated as follows:

$$\text{Mass} = \text{Volume} \times \text{Density}. \quad (2)$$

Freewheel hub A:

$$\text{Volume of A, } V_a = 18\pi(19^2 - 17^2) \text{ mm}^3,$$

$$\text{Mass of A, } m_a = 18\pi(19^2 - 17^2) \times \rho_s,$$

$$\text{Mass of 2 freewheel hubs} = 2 \times m_a.$$

Spokes flange B:

$$\text{Volume of B, } V_b = 2\pi(26^2 - 5.5^2) \text{ mm}^3,$$

$$\text{Mass of B, } m_b = 2\pi(26^2 - 5.5^2) \times \rho_s,$$

$$\text{Mass of 2 spokes flanges} = 2 \times m_b.$$

Pipe C:

$$\text{Volume of C, } V_c = 50\pi(26^2 - 5.5^2) \text{ mm}^3,$$

$$\text{Mass of C, Mass } m_c = 50\pi(26^2 - 5.5^2) \times \rho_s.$$

$$\text{Flange D (by weighing)} = 0.242 \text{ kg.}$$

Cover E:

$$\text{Volume of E, } V_e = 2\pi(17^2 - 5.5^2) \text{ mm}^3,$$

$$\text{Mass of E, } m_e = 2\pi(17^2 - 5.5^2) \times \rho_s,$$

$$\text{Mass of 2 covers} = 2 \times m_e.$$

$$\text{Freewheel F (by weighing)} = 0.275 \text{ kg.}$$

2.3 Determination of Mass Moment of Inertia for the Hub and Flange Assembly

To calculate the mass moment of inertia for each component, the moment of inertia was taken about an axis passing through the centre of gravity of the assembly, which is the axis of

rotation. Hence, it is a polar moment of inertia of a hollow cylinder (Chernilevsky *et al.* 1984):

$$I = 0.5m(r_0^2 - r_h^2). \quad (3)$$

The mass moment of inertia for A being a hollow cylinder of mass m_{hub} is obtained from Eq. (3), where: r_0 = radius of disc = 0.019 m, and r_h = radius of hole = 0.017 m. Similarly, Eq. (3) is used to obtain the mass moments of inertia of: spokes flange, pipe section, flange, cover, and freewheel,

The mass moment of inertia of the assembly is given by the sum

$$I_{assembly} = I_A + I_B + I_C + I_D + I_E + I_F. \quad (4)$$

2.4 Calculation of the Kinetic Energy

To calculate the kinetic energy of the disc, the angular velocity of the disc ω is computed (Stropel 1953):

$$\omega = 2\pi N/7, \quad (5)$$

where N = number of revolutions of the disc in 7 seconds. For example, the angular velocity of disk III was $\omega = 21.89 \text{ rad s}^{-1}$.

The mass moment of inertia of the disks is obtained from Eq. (3). The mass moment of inertia of the disc assembly is calculated with:

$$I = I_{disk} + I_{assembly}. \quad (6)$$

The kinetic energy of the disc and hub assembly,

$$KE = 0.5 I \omega^2. \quad (7)$$

Neglecting friction, this KE is equal to the work done in cutting the tops by the disc.

The mass of the rotating body = mass of disc + mass of hub assembly. The acceleration $a = r \omega^2$, the inertial force $F = ma$, and the torque $\tau = F r$. The power generated by the disc is $P = \tau \omega$.

2.5 Operation of the Tool

To operate the tool, it was taken to a field of mature sugarcane and placed very close to the plants to be cut.

The crank was turned by hand for 10 revolutions by one person while another person recorded the time in seconds using a stop watch.

At the end of the tenth revolution, the crank was stopped along with the chain. Sugarcane plants were instantly introduced for

cutting by the disc and blade which were rotating due to their inertial forces.

3. Result and Discussion

The energy generated in the disc and blade is a kinetic energy. It was used to overcome the resistance to rotation and to cut the sugarcane stalks and tops. The mathematical principle in calculating the kinetic energy was used to determine the energy required to cut sugarcane.

The experiment was conducted on burnt sugarcane in fields being harvested. It was repeated ten times. The gear ratio between the two sprockets was 2.44:1. Therefore, 10 revolution of larger sprocket produced 24.4 revolutions on the small sprocket and the disc.

The result of the impact of each blade and disc on the top and base of the sugar cane is shown in Table 4. Test result showed that disc III was able to cut the top of the cane only, while discs IV and V cut both the stem and top of the sugarcane.

Table 4. Time of 10 revolutions and action of the disc and blade on sugarcane.

Disc	Times of 10 revs., sec.	Cutting of tops	Cutting Stalks
I	7	No	No
II	7	No	No
III	7	Yes	No
IV	7	Yes	Yes
V	7	Yes	Yes

The cutting energy, inertial force and power of disc are shown in Table 5. The friction is neglected for practical purposes.

Table 5. Cutting energy, inertial force and power of the discs.

Disc	Cutting Energy, J	Inertial Force, N	Power, W
III	15.71	401.5	1,581.99
IV	23.83	572.27	2,254.86
V	92.37	1,310.35	8,662.3

For the purpose of this study, 23.83 Joules is the cutting energy of disc IV and was taken for the design because disc III could only cut the top of the sugarcane.

4. Conclusion

The objective of this study was to empirically calculate the energy requirements for cutting sugarcane to help design the tractor-operated sugarcane harvester. The principle of kinetic energy was successfully used to determine the energy of cutting sugarcane plant. The design of the harvesting machine can be based on the results obtained from this simple tool. The tool can be used to calculate the cutting energy of other crops. The helpful tool successfully solved the problem of lack of tools for research which could be very frustrating and hinder development.

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