Development of Mathematical Model for Forage Cutting Process Energized By Human Powered Flywheel Motor.

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ABSTRACT

Forage cutter is equipment in the domain of agriculture or dairy, for cattle feeding. Presently cutting machines are electric motor driven as well as hand operated. But today there is a huge scarcity of electricity almost everywhere in India which results in six to twelve hours load shedding. To overcome this, we can replace the electric motor driven process units by manually driven process units consisting a flywheel to store pedaled energy. Also we all know that hand muscles are weaker than the leg muscle. One can operate the cutter without fatigue and smoothly for a longer period if we replace hand operated straw cutting by pedal operated straw cutting. The dependent and independent parameters affecting the cutting process were identified. The experimentation was carried out to establish empirical relationship for resistive torque, number of cuts and process time using dimensional analysis. A higher coefficient of exponent predicts dominancy of that particular variable on cutting process.

Keywords: Forage cutter, Human power, Flywheel, Modeling

INTRODUCTION

It may sound inhumane to look upon the human as a source of energy and as a component of physical system. But there is no denying fact that human labor is a very important source of power, particularly in agricultural activity. In this era of energy crises the object should not to be release the human from doing petty jobs, but to improve upon the system to make better use of human power

In India, animal husbandry is an integral part of the rural economy. The forge (dry or wet) production requires high labor, coupled with a lack of sufficient land for forge. Production and forge scarcity during the dry season, it means that available forge must be efficiently used and waste minimized.

Traditionally, the farmers chop into small pieces for easy consumption by the animals as shown in figure1. This method is tedious, time consuming and quite dangerous to operator, as well as low output and lack of Uniformity. Presently mechanized forge cutter are electric motor driven as well as hand driven. But today there is huge scarcity of electricity almost everywhere in India, which results in six-twelve hours load shedding. The power cut (load shedding) badly affects daily needs requiring power supply such as water supply etc. Also we all know that hand muscles are weaker than leg muscles. So it is proposed to replace the electric driven cutting unit by the manually driven flywheel motor.

Nomenclatural:

Where:

d = Hub Diameter of blade

W_b = Width of cutting blade

t_b = Thickness of cutting blade

D = Tip diameter of blade

g = Acceleration due to gravity

I = Moment of inertia of flywheel

E = Young's modulus of elasticity of cutting blade

α = Cutting blade angle

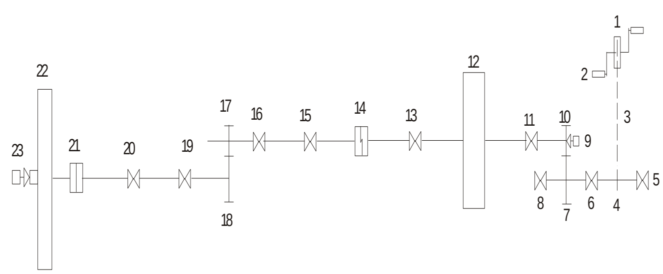
G = Gear ratio
n = Number of blades
e = Kinetic energy of flywheel
ω = Angular velocity
T_c = Instantaneous torque on cutting blade
C_p = Number of cuts during cutting
t_p = Process time for cutting

MATERIALS AND METHOD:

The Human powered Flywheel motor comprises of three sub systems namely (i) Energy supply unit (peddling mechanism to supply power or to store energy in flywheel) (ii) Appropriate clutch and transmission and (iii) a process unit.

The complete unit consists of a bicycle mechanism, appropriate clutch and transmission system and a process unit which could be any process device needing power up to 5 hp intermittently. Referring Figure 4, the rider sits on the seat and paddles the bicycle mechanism while the clutch is in disengaged position. Thus the load on the legs of the rider is only the inertia load of the flywheel. The Flywheel is accelerated to the speed of 600 rpm in minutes time by a young rider of the age group of 20 to 35 physically fit of height about 165 cm. The Flywheel size is 1m rim diameter, 10cm rim width and 2cm rim thickness. Such a Flywheel when energized to the speed of 600 rpm, it stores energy to the extent of 3200 kgf-m. At the end of one minute, speed about 600 rpm is reached. Then the peddling is stopped, clutch is engaged and a stored energy in the flywheel is communicated to the process unit through the clutch. Obviously the clutch is subjected to sever shock on account of instantaneous momentum transfer. This is so because as the clutches engaged, the flywheel is subjected to the process load and the process unit consumes energy of the flywheel. The energy stored in a Flywheel gets exhausted in 15 to 25 seconds for application tried so far (ref [1] to [7], [10]). The capacity of such a system is in the range of 1 to 8.5 Hp. The functional feasibility and economic viability of this system has also been confirmed ([2], [5]).

Schematic arrangement of the complete unit:



1-Chain Sprocket 2-Pedal 3-Chain 4-Freewheel 5,6-Bearings for bicycle side 7-Gear-I 8-Bearing 9-Speed sensor for flywheel shaft 10-Pinion-I 11-Bearing for flywheel shaft 12-Flywheel 13-Bearing for flywheel 14-Two jaw clutch 15,15-Bearing of intermediate shaft 17-Pinion II 18-Gear II 19,20-Bearing for process unit shaft21-Coupling 22-Chaff Cutter blade 23- Speed sensor for chaff Cutter shaft

Figure1: Schematic of Human Powered Flywheel Motor.

Thus the load on thighs (legs) of the rider is only the inertia load of the flywheel. Rider pumps energy in the flywheel at an energy input rate convenient to him. Thus, this man-machine system brings out ways for energy conversation of human muscular energy into rotational kinetic energy of flywheel. It felt

necessary to develop the energy unit of this man-machine system for chaff cutter scientifically. The parameters affecting process were identified. The experimental setup is as shown in figure 2.
An approach of methodology of experimentation [10] is adapted and worked out detailed design of experimentation for chaff cutter.

Figure 2: View of the experimental set-up.

The design of Experimentation for chaff cutter energized by human powered flywheel motor is as under:

1. Identification of dependent, independent and extraneous variables.
2. Dimensional Analysis.
3. Development of mathematical model using dimensional analysis.
4. Deciding / finalization of test, envelopes, Test point and Test sequence.
5. Experimentation.

Dimensional Analysis of the parameters affecting the chaff cutter energized by Human powered flywheel motor was identified, listed in table 1. Dimensional analysis was used to express the required functional relationship between the different of the chaff cutting process. The main advantage of this analysis is the reduction of the number of variables.

Table 1: Dimensional Matrix

	d	W_b	t_b	D	g	I	E	α	n	ω	t_c	e	G	T_c	C_p	t_p
M	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0
L	1	1	1	1	1	1	-2	0	0	0	0	2	0	2	0	0
T	0	0	0	0	-2	-2	-1	0	0	-1	1	-2	0	-2	0	1

When the dimension matrix is solved the dimensionless π terms are obtained listed in table 2. The dimension less π terms are combined and arranged depending on the nature of basic physical quantities. Thus each dependent π terms are assumed be the function of the available independent π terms.

$$\frac{D}{gI}\, T_c = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7, \pi_8) \text{ ---------(1)}$$

$$Cp = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7, \pi_8) \text{ ---------(2)}$$

$$\sqrt{\frac{g}{D}}\, t_p = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7, \pi_8) \text{ ---------(3)}$$

Table 2: Dimensionless ratio or π terms.

Sr. No.	Independent dimensionless ratio or π terms	Nature of basic physical quantities
1	$\pi_1 = \frac{d w_b t_b}{D^3}$	Geometric Variables
2	$\pi_2 = \frac{D^4}{g}\frac{E}{I}$	Material of blade
3	$\pi_3 = \sqrt{\frac{D}{g}}\,\omega_c$	Instantaneous Terminal velocity of cutter
4	$\pi_4 = G$	Gear Ratio
5	$\pi_5 = \alpha$	Cutting blade angle
6	$\pi_6 = \mathrm{n}$	No. of cutting blade
7	$\pi_7 = \sqrt{\frac{g}{D}}\; t_c$	Cutting time
8	$\pi_8 = \frac{D}{2g}{\omega_f}^2$	Terminal speed of flywheel
9	$\pi_{D1} = \frac{D}{gI}\; T_c$	Resistive torque
10	$\pi_{D2} = C_p$	No. of cuts by cutter
11	$\pi_{D3} = \sqrt{\frac{g}{D}}\; t_p$	Process time

Test Envelope and Test Point:

It is necessary to decide the range of parameters which would be varied during experimentation. The test envelope, test points and test sequence for every independent π terms is given in table 3.

Table 3: The test envelope, test points and test sequence.

Sr	Ratio	Test Envelop Range	Test Point	Test Sequence							
				1		2		3		4	
01	π_1 =dWbtb/D^3	5.33×10^{-3}	Constant								
02	π_2 =(D^4/gI)E	1.46×10^{9}	Constant								
03	π_3= G	2,3,4		2.3.4	2.3.4	2.3.4	2.3.4	2.3.4	2.3.4	2.3.4	2.3.4
04	$\pi_4 = \alpha$	0.122	Constant								
05	π_5 =n	2,3		2	3	2	3	2	3	2	3
06	π_6= (D/2g)ωf^2	31.428-62.857		31.426		41.904		52.380		62.857	

Note: π_3 = It can't be predefined as the angular velocity change during experimentation. The reading will be noted during experimentation.

π_7 = The specific time instant during cutting is a dynamic term. It is noted during experimentation.

Instrumentation and Measurement:

1. **Linear Measurement:** For linear measurement digital calipers and micrometers were used. The blade angle is measures by bevel protector.
2. **Angular Velocity:** Angular velocity of cutter shaft and flywheel shaft is to be measured. The slotted opto-couplers were mounted on the shaft. These sensors measure the angular velocity with real time clock. This angular velocity is recorded and stored via micro controller 89C51 RD2 which is connected to personal computer through USB port.
3. **Variation in torque:** The variation of torque on cutter shaft will be evaluated on the basis of speed plots of cutter speed verses time.
4. **Number of cuts:** It was decided to evaluate number of cuts on the basis of speed of cutter obtained during experimentation. No. of cuts = No. of blade X no, of revolution.
5. **Process time:** It can be evaluated on the basic of π terms obtained from dimensional analysis.

$$\text{Process time} = \pi_7 = \sqrt{\frac{g}{D}}\, t_c \text{ ------------- (4)}$$

Where tc = Time required for cutting between two fixed time interval.

Model Development:

The prediction equation is established by allowing one π term to vary at a time while keeping other π terms constant and observing the resulting changes in the function of the cutter.

An approximate generalized empirical prediction model chaff cutter energized by Human powered flywheel motor has been established. There are three dependant variable i.e. resistive torque (π_{D1}) number of cats (π_{D2}) and process time (π_{D3}). Accordingly three models were developed.

1. Model for Resistive torque : π_{D1} -- (5)

$$\pi_{D1} = -0.03165(\pi_1)^{-0.00578} (\pi_2)^{0.00833} (\pi_3)^{-0.04258} (\pi_4)^{-0.00266} (\pi_5)^{0.06515} (\pi_6)^{-0.04162} (\pi_7)^{0.02176} (\pi_8)^{-0.00171}$$

2. Number of cuts by cutter: π_{D2}-- (6)

$$\pi_{D2} = 3.94432(\pi_1)^{0.00126} (\pi_2)^{0.00276} (\pi_3)^{0.05510} (\pi_4)^{0.02564} (\pi_5)^{0.02309} (\pi_6)^{0.00458} (\pi_7)^{-0.01041} (\pi_8)^{0.00025}$$

3. Process time : π_{D3} -- (7)

$$\pi_{D3} = 24.4279(\pi_1)^{0.00173} (\pi_2)^{0.00066} (\pi_3)^{-.000172} (\pi_4)^{0.00529} (\pi_5)^{0.00925} (\pi_6)^{-0.02496} (\pi_7)^{-0.02270} (\pi_8)^{0.00368}$$

Result and Discussion:

Effect of Individual independent variable on

(A) Resistive Torque :

The geometric variable i.e hub diameter width of blade and thickness of cutting blade have a inverse relationship.

If the hub diameter, width of blade and thickness of the blade increases the resistive torque decreases where as the tip diameters of the blade increase the resistive torque increases.

Resistive torque increases with the increase in young modulus of elasticity of blade.

The terminal velocity increases the resistive decreases.

The gear ratio increases the torque decreases.
Resistive torque increases with increase in blade angle.
The increase in kinetic energy the Resistive torque decreases.

B) Number of cuts by cutter:

There is linear relationship of number of cuts by cutter with geometric variables, material of blade, Terminal velocity of cutter, gear ratio, cutting blade angle., No. of blades and Terminal speed of flywheel.

C) Process time:

The process time increase due to increment in geometric variables, gear ratio, cutting blade angle. The process time decreases with increase of Young modules of blade, velocity of cutter, Number of blades and terminal speed of flywheel.

Conclusion: A mathematical models for predicating the chaff cutting phenomena energized by human powered flywheel motor was established using dimensional analysis. The developed relationship describes Resistive torque, number of cuts and process time. The experimentation shows the effect of each independent variable on dependent variables. The level of exponent in the empirical equations show the significance of effect on variable and it is logically appropriate.

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