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Design and fabrication of a home scale human powered flywheel motor operated forge cutter

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ABSTRACT

This paper addresses the development of a Human Powered Flywheel Motor (HPFM) operated forge cutter. This set-up is used to cut forage crop residues like maize Stover, sorghum Stover in dry condition. This cut Stover can be feed to cattle directly. The current practice by small livestock farmers is to cut forage manually by axe or machetes. The mechanized cutters also available which are hand operated as well as electric motor driven. But today there is severe power shortage in country like India, particularly in rural and remote area. It is convergent to the fact that the hand muscles are weaker than leg muscles. The concept of human powered flywheel motor is used to develop the pedal operated forge cutter. In this set-up flywheel is used as a motor or a store for energy. The operator pumps the energy into flywheel by pedaling bicycle- drive mechanism with a speed rising gear pair. After a one minute pedaling is stopped, and then flywheel shaft is connected to cutter shaft through spiral jaw clutch. The stored energy is enough to operate cutter effectively and efficiently. The test performance of developed cutter shows the remarkable improvements over hand operated forage cutter.

Introduction

In dry season the green forage is hardly available for cattle, the forage crop residues like maize stovers, sorghum stovers, pearl millet stovers etc are being used to feed the cattle. The crop residue can be feed to the cattle but they can’t able to consume whole stovers and thereby 20-30% wastage. In India most of farmers have 2-3 cattle to meet their milk requirement as well as to earn some money for daily expenses. These farmers used to collect crop residues to feed directly or cut manually by crude methods using machetes into 3-4 pieces for easy intake by the cattle. This is perhaps the cost and output of electric operated cutter is high which is not appropriate for small farmers. In addition to this, in rural and remote area power supply is frequently unavailable. The cutting process of hand operated cutter is characterized by slow operation, fatigue and low production rate. Also it is facts that hand muscles are weaker than leg muscles. It is necessary to apply human power in such a way that drudgery is minimized by applying concept of human powered flywheel motor (HPFM). Ordinarily, pedaling a stationary bicycle is a form of exercise performed for pleasure or to keep fit. It is gratifying if during such exercise the much needed power is also being supplied for cutting.

Human Power

The maximum power output from a human being occurs in a rowing action because most muscle groups in the body are used. However, these outputs are loosely approached by those obtained from the legs applied to moving pedals. Little advantage appeared to be gained from pedal motions other than simple rotating cranks as on a bicycle and use of cranks gives a fairly smooth rotary motion at speeds of 60-80 RPM. Hand cranking is frequently used but as the arm muscles are smaller than the thighs, power output is reduced. The power output to be expected from normal peddlers are around 0.1HP.This output can be maintained for 60 minutes or more. Higher outputs can be produced for shorter periods. In static applications, the outputs available tend to be lower than those measured from the performance of cyclists because of the effect of winds in reducing body temperature. It may prove advantageous to provide fans for peddlers in static situations to improve output.

The power levels that a human being can produce through pedaling depend on how strong the peddler is and on how long he or she needs to pedal. If the task to be powered will continue for hours at a time, 75 watts mechanical power is generally considered the limit for a larger, healthy non-athlete. A healthy athletic person of the same build might produce up to twice this amount. A person who is smaller and less well nourished, but not ill, would produce less; the estimate for such a person should probably be 75 watts for the same kind of power production over an extended period [8].

Human Powered Flywheel Motor (HPFM)

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 schematic is shown in Figure 1, 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 25 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 2800 kgf-m. At the end of 1 minute, speed of 600 rpm is reached and pedalling energy is stored in a Flywheel. Afterwards the peddling is stopped, clutch is engaged and 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

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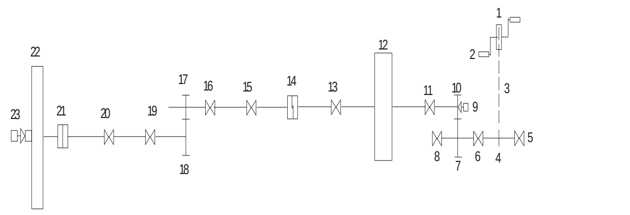
transfer. This is so because as the clutches engaged, the flywheel is subjected to the process load and the process unit consumes energy of the flywheel. After the clutch engagement, the energy stored in a flywheel gets exhausted in 5 to 15 seconds for application tried so far ([1] to [7]. The capacity of such a system is in the range of 1.5 to 7.5 Hp. The functional feasibility and economic viability of this system has also been confirmed [6].



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

Figure 1: Schematic of Human Powered Flywheel Motor

Design Features

The main Frame- The frame is constructed with 65×5 mm mild steel which support all the housing for pedstals shafts for flywheel, speed rising gear pair as well as torque amplification gear pair.

The operator's Unit- This is constructed with complete bicycle unit without its wheels. It is supported by mild steel stand at front side and rear side is supported on main frame. The sproket outer diameter is 180 mm, number of teeths are 43 and freewheel outer diameter is 70 mm, number of teeths are 17 .

Energy Unit- This unit consists of consists of a flywheel, appropriate clutch and trasmission shafts. The dimensions of flywheel, hub diameter is 50mm, outer diameter is 620mm, rib width 620 mm.and weight of flywheel is about 50 kg, one side of the flywheel shaft, speed rising gear coupled with freewheel shaft, here the pinion has pitch circle diameter 50mm, face width of 28mm and number of teeths 15whereas gear used has pitch circle diameter 250mm, face width of 28mm and number of teeths 80. The specialy designed spring loaded sprial jaw clutch is used to connect flywheel shaft and cutter shaft via a intermidiate torque amplification gear pair. There is a provision to change the gear for maintaining the diferent gear ratio such as 1:2, 1:3 and 1:4.

The Cutting Unit- This unit consists of following parts:

1. Cutter shaft: It is 30mm in size supported by two bearing of appropriate size. This shaft carries three armed cutter head for fixing cutting blades, angle between the arms is 120 degrees.
2. Shear plate : It supports the fodder material at the time of cutting.
3. Feed roll: A gear syetem is used to feed the fodder continiously. The feed roll gives horizontal force to fodder to avoid bending or buckling during shearing . Feed rolls 250 mm long, 80mm in diameter squre tooth profile gears.
4. Cutting blade: . The thickness of cutter 2mm with the hardness of 63 HRC, width of blade 136mm, cutting blade angle 07 degrees.
5. Tip diameter of cutter: It is distence between the center of axis of cutter and point of contect of cutter with fodder stem. First point of contect of cutter is at 64 mm from the center of 30mm shaft. So the minimum tip diameter 79mm and last point of contact of cutter at a 280mm
6. Cutting clearance: It is distence between cutting edge of cutter and shear plate. It ranges from 0.5mm to 1.5mm, if clearance is more then there will be folding or bending of fodder stem and too small distance create unnesessary friction between blade and shear plate, loseing energy. The clearance maintained 01mm. The cutting unit is mounted on mild steel frame.

Design Analysis and Calculations

The genral design consideration in designing this man-machine system that can be easily assembled. The feeding tray allows the forage material into cutter,

Feeding Tray Design

A feeding tray is rectangular cross section is considered. the volume of which was obtained is as followes;

$V = L*B*H \ m^3$

Where V = Volume of the feeding tray, L = feeding tray length, B = feeding tray breath and H = feeding tray height.

The mass of feeding tray is given by,

$M = \rho. V$ kg.

ρ = dencity of material.

Flywheel Design

$$\Delta E = \left(\frac{W}{g}k^2\right)K_s\omega_m^{\ 2}$$

Where,

K_s = Coefficient of speed Fluctuation.

Δ E = The maximum fluctuation of energy.

k = Radius of gyration

$= \{0.12[D_o^{\ 2} + (D_o - 2h)^2]\}^{1/2}$

ω_m = mean velocity in radians/second, h = rim thickness, b = rim width

$\therefore$ Considering Δ E = 42,035 J

$$(\Delta E = \left[\frac{1}{2}I\omega_{max}^{\ 2} - \frac{1}{2}I\omega_{min}^{\ 2}\right])$$

$$K_s = \frac{N_{max} - N_{min}}{N_{mean}}$$

$$\Delta E = \left(\frac{W}{g}k^2\right)K_s\omega_m^{\ 2}$$

$$= \left(mk^2\right)K_s\omega_m^{\ 2}$$

$$= IK_s\omega_m^{\ 2}$$

Where, I = Moment Of Inertia of Flywheel

Chain Drive

Rated Power, PR= 900 W

Design Power(P_d) : Pr $\times$ K_1

Where, K_1 =Load Factor, From design data book it should be 1.2 for moderate shock and service of 10 hours per day [30,31,32].

Pitch Diameter of smaller Sprocket (D_{p2})

$$D_{p2} = \frac{p}{\sin\left[\frac{180}{T_2}\right]}$$

T_2 = No. of teeth on smaller sprocket = 24

$$D_{p2} = \frac{1.1875}{\sin\left[\frac{180}{24}\right]} = 106.5 \text{ mm}$$

Pitch Line Velocity(V_p) :

V_{p2}= ($\pi \times D_{p2} \times N_2$)/60

Power capacity per strand :

$$P = p^2\left[\frac{V}{104} - \frac{V^{1.41}}{526}\left(26 - 25\cos\frac{180}{T}\right)\right]\times 10^3$$

where, p= chain pitch=15.875mm, V $=V_{p2}$ =0.66m/sec , T $=T_2$ =21

Gear Design (Stage 1)

P_d = 2000 W, Module = m, pitch diameter, $D_p=20\times m$,

$V_p = 0.8373\times m$,

$F_t = P_d/V_p$ = 2000/0.8373m = 2388.63/m

Assuming 1045 steel with heat treatment, S_o= 210 MPa

Bending strength,

$F_b = S_o.C_v.b.Y.m$

Design of shaft

The shafts considered for satisfactory performance to be rigid enough while transmitting load under various operating conditions. To achieve this a solid circular shaft is considered for analysis of combined torsional and bending stresses.

$d3 = 16/\pi Ss[(KbMb)^2 + (KtMt)^2]^{1/2}$

where Mt = Torsional moment, Mb = bending moment, Kb = combined shock and fatigue applied to bending moment(1.5), Kt = combine shock and fatigue applied to torsional moment (1.0) and Ss = allowable stress.

For a shaft transmitting power (kW) at a rotational speed (RPM) the transmitting torque is given as:

Mt = Power/ Speed

Result of Design Calculations and Specifications

Flywheel dimensions:

b = rim width = 100 mm, h =rim thickness = 19.7mm, D_o = outer diameter= 1000 mm, No. of arms = 6.

Stresses in the flywheel: Centrifugal stress = 13.53 MPa, Bending stress = 187.21 MPa, resultant stress = 56.79 MPa, mass = 47.48 kg

Chain Dimensions:

Pitch diameter of larger sprocket = 232.17 mm, Center distance C = 120.82 mm, Recommended C_{min} = 285.42mm, Length of chain in pitch Lp = 72.75, Outer Diameter of the smaller sprocket = = 130.10 mm, Outer Diameter of the larger sprocket = 251.73mm, Width of the sprocket 9 mm.

Shaft Dimension:

By Calculation, D = 22.5 mm. Select D = 25 mm.

Similarly by calculations, Diameter of shaft 2, D = 25.13 mm. Select D = 30 mm., Diameter of shaft 3, D = 25.51 mm. Select D = 30 mm.

Bearing Dimensions:

For required dynamic load carrying capacity, Bearing No. 6005 is suitable at B1 & B2.

Inner diameter of the bearing = 25 mm, Outer diameter of the bearing = 47 mm,

Axial width of the bearing = 12 mm.

Similarly by calculations,

Bearings available for shaft 2 and 3,

i) No. 61806 (C =3120 N), ii) No. 16006 (C = 11200 N),

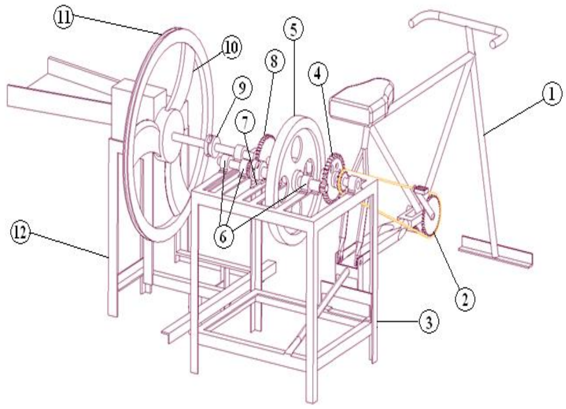
iii) No. 6006 (C =13300 N).

For required dynamic load carrying capacity, Bearing No. 16006 is suitable at B3 & B4.

Inner diameter of the bearing = 30 mm, Outer diameter of the bearing =55 mm,

Axial width of the bearing = 9 mm.

Figure 2. shows the design features of developed forge cutter energized by human powered flywheel motor.



1.Cycle Stand, 2.sproket, 3.Frame, 4.Speed Rising Gear Pair, 5.Flywheel, 6.Bearing, 7.Clutch, 8.Torque amplification gear pair, 9.Coupling , 10.Cutter shaft, 11.Cutter blade, 12. Cutter Frame.

Figure 2. Developed experimental set-up

Performance Test

For conducting trials five (05) personals from age group 22-35 were selected. The mean (+_ SD) of age, weight, height were 26.5 +_ 3.5 years, 68.62 +_ 21 kg, 176.30+_13 cm. respectively. All the trials started at 10 AM in the morning in our workshop where the room temperature varied from 25-30^{0}c and relative humidity was 50-60% during the experimentation. During the trials, gear ratio 1:2,1:3,1:4 and number of blades also varied to 2 &3.For each gear ratio there are 2 and 3 blades. The speed of the flywheel for each gear ratio will be 300, 400,500,600 RPM.

The rider operates the system similar to bicycle by peddling the pedals and spinning the flywheel to the desired speed in duration of one minutes thereby storing energy to the flywheel. After one minute peddling is stopped and flywheel shaft is connected to cutter through spiral jaw clutch and energizes the cutter.

Samples of dry sorghum with 20-30% moisture having 1.85 +_ .05 kg of about 80-120 cm tall were weighted using weighing scale. Theses samples were fed into the cutter via a feeding pan. Time taken to chop the sample was recorded with the help of real time clock integrated circuit DS1307 and microcontroller 89V51RD2.This data is saved in Personal computer by connecting microcontroller through USB connecter. Thus time was recorded at all gear ratio and speed, for two and three blades.

The chopped material was collected in a container and weighted to determine output. The average length of chopped material is measured by randomly selected quantity of chops.

The chopping efficiency was determined as-

$$C_e = \frac{Wf}{Wc} \times 100$$

Where, Ce = Chopping efficiency
Wf = Total weight of samples fed in
Wc = Total weight of chopped out.
The chopping rate was determined as-

$$\mathbf{Cr} = \frac{Wc}{tc}$$

Where, tc = Chopping time in seconds.

The experiment was replicated 25 times with all possible combinations of gear ratio, number of blades and flywheel speed.

Performance Evaluation Results

The results of human powered cutter shows that dry sorghum is chopped at the rate of 0.017 kg/sec at 300 RPM of flywheel when gear ratio is 1:2. The average length of chopped material was found to 20-25mm. The cutting efficiency was worked out to be 81%.The chopping rate was gradually increase with increase in the flywheel speed.

At 600 RPM of flywheel and gear ratio of 1:2, the chopping rate (Cr) was 0.032kg/sec.

The chopping rate at gear ratio 1:4 and flywheel speed 300RPM was found to be 0.25kg/sec. At 600RPM with the same gear ratio the chopping rate was 0.045 kg/sec and same cutting efficiency i.e. Ce=85%

The constructed cutter energized by human powered flywheel motor was found to be effectively less tedious, faster and safer as compared to hand operated cutter. The length of chops can be varied by varying the clearance between blade and shear plate and by number of blade or speed of flywheel.

When the paddling stopped, flywheel shaft (input) is connected to cutter shaft (output), due to the resistance offered by the material to be chop the cutter speed drastically decline and finally cutter stop. For this reason it is necessary to develop appropriate mechanical transmission system which can smooth out the continuously varying speed of flywheel and will maintain approximately constant cutter speed over an estimated range of variation in flywheel shaft. Also the cutting rate (Cr) of cutter can be increased if the constant speed of cutter shaft would maintain.

The performance is a remarkable improvement over hand operated chopping since chopped size was more uniform. Therefore human powered forge cutter will find its place of importance for dairy farmers particularly in remote rural and tribal area where reliability of availability of electric power is much low or no electric power.

Conclusion

1. A new type of cutter is fabricated which unlike other fodder cutting machines will work on non conventional energy source.
2. In countries like India where ample human power is available, such human powered man machine systems will help to a great extend to improve the economical condition and employability of such countries.
3. Such systems are of utmost importance in Asian countries as almost all Asian countries are facing electricity scarcity which results in ten to twelve hours load shedding in rural areas.

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