Gravity flow operated small electricity generator retrofit kit to flour mill industry

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Abstract Flour milling is a grinding process to produce flour from wheat through comprehensive stages of grinding and separation. The primary energy is required to provide power used in grinding of wheat. In wheat milling, tempering is the process of adding water to wheat before milling to toughen the bran and mellow the endosperm. Gravity flow of the wheat is utilized to rotate the dampener wheel with cups to add water. Low cost gravity flow operated small electricity generator retrofit kit for dampener was designed and developed to justify low cost energy production without expensive solutions. Results of statistical analysis indicated that there was significant difference in mean values for voltage, rpm and flow rate at the 95% probability level. The resulted maximum mechanical power and measured electrical power were 5.1 W and 4.9 W respectively at wheat flow rate of 1.6 Kg/s and dampener wheel rotational velocity of 4.4 rad/s.

Keywords Wheat · PMDC motor · Generator · Battery · LED · Dampener

Introduction

Flour milling is a grinding process which produces flour from wheat through comprehensive stages of grinding and separation. The primary energy is required to provide power to grinding of wheat. Approximately 80% of power unit per ton of flour is the sole energy source used directly

in the milling process (Gordon et al. 2006). Flour and semolina producers are interested in finding new solutions to reduce power requirements as the energy consumption accounts for up to 6% of the total cost of flour milling (Urs D 2006). Efficient usage of energy is possible by encouraging energy conservation to reduce the impact of toxic gases emissions on the environment or to develop low cost machinery to convert mechanical power to electric power. Falling water, animals, sun, wind, fossil fuels, nuclear fuels and organic waste are the natural sources of energy which can be utilized (William 1989). Sun, wind and water are renewable energy sources and benefits of harnessing power from them are manifest (Osman 2008). Sun and wind have natural limitations based upon local weather conditions. Hydro power may be very unattractive due to capital cost consideration. Technology and capital is harnessed and allocated to search for new energy source (Asim 1990). Generation of electricity is also possible by using gravitational energy in which gravitational force can be used to produce useful power (Henry 2009). Paddle wheel or water wheel is capable of producing enough energy with no running cost and zero carbon emissions (www.freeenergy.ca/news/127/ARTICLE/1196/2007-03-04.html). Idea of a clean energy generation added to another attractive issue of recycling resulted in a new contribution to the sustainable development (Galvez et al. 2003). In flour mill machine location and product transfer are optimized by maximizing the use of gravity flow for intermediate materials (Karel and Joseph 2000). Tempering is the process of adding water to wheat before milling to toughen the bran and mellow the endosperm of the kernel to improve the efficiency of flour extraction (Kweon et al. 2009). As the bran becomes progressively tougher and less brittle with increasing moisture content, milling will produce flour with lower ash

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content. Tempering equipments can be classified as intensive mixing system and conventional system. In intensive mixing system, moisture content that is added is calculated and controlled by moisture control system whereas in conventional system the quantity of water is regulated by a water flow meter or water wheel dampener. In water wheel dampener, gravity flow of the wheat is utilized to rotate the wheel with adjustable cups to add water. Several works have been reported to convert potential energy into electrical energy (David 1999, Robert 2001). However no work dealing with the conversion of wheat potential energy to electric energy during milling process has been reported in the literature. Thus the aim of the present study was to develop gravity flow operated small electricity generator retrofit kit to Flour mill industry. These generators can be used in flour mills to illuminate floor or machines due to their simple design, low cost and easy availability.

Materials and methods

Materials

Mechanical components like shaft, aluminium brackets, threaded fasteners and electrical components like recycled motor, rechargeable battery, battery charger circuit and light emitting diodes were purchased from the local market. Existing water wheel dampener (Buhler, Switzerland) in 20 tons per day pilot mill at Central Food Technological Research Institute was used for retro fitment.

Design consideration

Output power calculations

Formulae used for power output calculations were taken from 'A design manual for water wheels' (William 1989). Volume of wheat falling on dampener wheel was calculated by using Eq. (i). One annular quadrant working at any given time was assumed for design calculations.

$$v = Q/4N \quad (i)$$

Where, Q=Volume flow rate (m^3/min); N=Wheel shaft speed (rpm)

Torque was calculated by using Eq. (ii)

$$T = \rho g d v \quad (ii)$$

Where, ρ =Wheat density (kg/m^3); g =Acceleration due to gravity (m/s^2); d =Distance to the centroid of the annular quadrant from the rotation axis=average diameter (m); v =Volume of wheat (m^3)

Equation (ii) when evaluated with $\rho=769 \text{ kg}/\text{m}^3$, $d=0.115 \text{ m}$, $v=2.024 \times 10^{-4} \text{ m}^3$, torque of 0.176 kg-m was obtained

Power output of water wheel dampener was calculated using Eq. (iii)

$$P_m = 2\pi N T \eta / 60 \quad (iii)$$

Where, P_m =mechanical power at water wheel dampener shaft (watts); T =Torque (Nm); η =Wheel dampener efficiency

Power output was 4.9 W by considering 65% efficiency of water wheel dampener

Coupling design

Formulae used for coupling design were taken from mechanical engineers design data hand book (Mahadevan and Balaveera Reddy 1986). Torque transmitted by the coupling was taken as torque transmitted by the dampener wheel. Diameter of the coupling shaft was calculated by using Eq. (iv)

$$d = (16T/\pi T_s)^{0.3} \quad (iv)$$

Where, d =diameter of coupling shaft (mm); T =Torque (kgf-mm); T_s =Torsional shear stress (kgf/mm^2)

Standard shaft size of 30 mm was selected for manufacturing coupling

Maximum torsional shear stress due to torsional loading was calculated using Eq. (v)

$$T_s = \left[16T / \pi (d_0)^3 \right] \left[1 / (1 - K^4) \right] \quad (v)$$

Where, d_0 =Outside diameter of the shaft (mm); K =Ratio of inside to outside diameter

Calculated torsional shear stress was $0.03 \text{ kgf}/\text{mm}^2$ with $d_0=30 \text{ mm}$ and $K=0.7$ which was well within the limit of maximum permissible working stress of $5.6 \text{ kgf}/\text{mm}^2$. Hence design is safe.

Electrical generator

Permanent magnet direct current (PMDC) motors can be used as a DC generator without any modifications. The generated voltage is proportional to the shaft rpm and current supplied is proportional to the shaft torque. The rotational motion of the water wheel dampener was transferred to the motor through the coupling. Rotation of the permanent magnets created a voltage potential back electro motive force. Higher potential at the PMDC induced a current flow towards a lower potential source (battery). Rating of the motor selected was three times the expected electrical output of the wheel rotor dampener (4.9 W). FG38 series (Canon Precision Inc. make) low rpm gear

head PMDC motor with technical specifications of 13 W rated power output, 24 V rated voltage was selected.

Battery

Battery capacity Anticipated load (50 LED's) on battery was calculated by using Eq. (vi) with LED specification as 3.6 V and 30 milliamps. Calculated load (5.4 Wh) was converted to Ampere hour (Ah) by dividing battery voltage of 6 V. System overhead of 20%, 1½ days reserve and 20% of battery ageing were added to the calculated Ah. At 50% depth of discharge the battery size required was 3.9 Ah. 6 V, 10 Ah sealed rechargeable battery (perfect make) was used to store the energy generated by the PMDC motor. Duration of continuous powering of LED's was calculated as 5 h and 30 min by considering battery 50% depth of discharge and 0.9 ampere per hour.

$$\text{Watt} = \text{Voltage} \times \text{Current} \quad (\text{vi})$$

Battery charge time and charger Battery charge time calculator (www.csgnetwork.com/batterychg2calc.html) was used to calculate Battery charge time. Maximum time to full charge (20% efficiency loss) was 13.3 h by considering battery capacity of 10 Ah and 0.9 A. Locally available 6 V battery charger was used to charge the battery.

Methods

Disc with measureable cups were removed from the existing wheel dampener. Spur gear and pinion (velocity ratio of 4) assembly was retained to transmit power from the gravity flow driven wheel to pinion shaft. Coupling was manufactured using 30 mm diameter and 55 mm length shaft. Coupling was mounted on pinion shaft and locked by using grub screws. Motor mounting bracket was manufactured and PMDC motor was fitted to the bracket. Motor along with bracket was aligned with the coupling shaft and fastened to angle bracket. The retrofit assembly was fitted on to wheel dampener frame by using flat bracket. LED's were assembled in a matrix form and connected to toggle switch. Mechanical power at wheel dampener shaft was computed by setting gravity flow of wheat above the wheel dampener and adjusting the LED's load on the direct current side of the circuit. Electrical power was calculated using Eq. (vii)

$$P_e = I_1(V_1) \quad (\text{vii})$$

Where, I_1 =Load current (amps); V_1 =Load voltage (volts)

Statistical analysis

Two way analysis of variance (ANOVA) was carried out to test for any significant differences ($p < 0.05$) in the mean

values of all the groups. Regression analysis was carried out to develop linear model. Statistical analysis was carried out by using Microsoft Excel.

Results and discussion

Design and development of retrofit kit

Schematic diagram of gravity flow operated small electricity generator was shown in Fig. 1. Electricity generator retrofit kit assembly (Fig. 2) consisted of shaft coupling (30 mm diameter and 55 mm length with drilled holes of diameters 20 mm and 5.5 mm on faces of shaft), aluminium flat bracket (350 mm length, 60 mm width), aluminium angle plate (250 mm length, 60 mm width, 60 mm height, 8 mm thickness), motor mounting bracket (60 mm length, 35 mm width, 60 mm height, 8 mm thickness), threaded fasteners (M3, M6), recycled permanent magnet direct current (PMDC) motor (cannon FG38 series, 13 W, 24 V), light emitting diodes (LED's), printed circuit board to mount LED's, double pole toggle switch. Gravity flow of wheat in a spout above the wheel dampener was striking the pockets of the rotor. Rotor rotary motion was transferred to PMDC motor through set of gears and coupling. Power generated by PMDC motor was stored in a battery.

Performance evaluation of generator

Evaluation of power generated by generator was carried out using LED's load. Table 1. shows mechanical power (P_m) and electrical power (P_e) for different wheat gravity flow rate. Mechanical power at rotor wheel dampener shaft was

Fig. 1 Schematic diagram of gravity flow operated small electricity generator

Fig. 2 Electricity generator retrofit kit assembly

0.6 to 5.1 W considering theoretical efficiency value of 65%. Two factor anova and regression summary statistics of voltage, wheat flow rate and wheel rotor revolution per minute (rpm) were shown in Table 2. F_{stat} values (14.48) related to the voltage, rpm and flow rate was less than its respective F_{crit} value (6.601) and results were significant and there was a difference in mean values for voltage, rpm and flow rate. The respective p -value (0.012) indicated that the results were highly statistically significant. In wind electricity generation, power in the wind is proportional to the area swept by the wind mill blades, the density of the air and to the cube of the wind speed. As the wind speed increases, the power produced increases at a rapid rate

(www.theweatherprediction.com/habyhints2/479/). The amount of electricity produced by hydro electric method depends on the water flow rate and head of water (Ngo et al. 2006). Values in Table 1 indicated that potential differences generated by the motor increases with increase in wheat flow rate and wheel rotor speed. Relationship between wheat gravity flow rate and wheel rotor speed could form a trend line and a linear equation was developed to convert flow rate into rpm. The measured data was fitted linearly as equation $y_1 = 0.0165x_1 + 9.203$, where y_1 was rpm and x_1 was wheat flow rate. The dampener rotor rpm is directly proportional to wheat flow rate. The measured data for rpm and voltage showed linear trend and a linear equation was fitted as $y_2 = 0.2123x_2 -$

Table 1 Mechanical power (Pm) and Electrical power (Pe) for different wheat gravity flow rate

Wheat Flow rate (kg/h)	Wheel rotor speed	Torque (kg-m)	No. of LED's	V (volt)	I (Amp)	Pm (watt)	Pe (watt)
240	10	0.091	0	0	0	0.6	0
480	17	0.099	1	3	0.03	1.1	0.1
840	28	0.107	16	4	0.4	2.0	1.6
1200	30	0.143	21	5	0.4	3.4	2.0
1560	33.3	0.168	31	6.3	0.5	3.7	3.2
2040	42	0.185	51	7.0	0.7	5.1	4.9
$n=3$							

Table 2 Two factor anova and regression summary statistics of voltage, wheat flow rate and rpm

Anova: Two-factor without replication					
Source of variation	coefficients	<i>p</i> -value	F _{crit}	F _{stat}	df
Rows		0.472	5.05	1.07	11
Columns (rpm,flowrate)		0.012	6.60	14.48	11
Regression:					
Intercept 1	9.203	0.021		64.32	5
X variable 1	0.0165	0.001			
Intercept 2	−1.458	0.144		57.21	5
X variable 2	0.212	0.001			

*F*_{crit} Fcritical, *F*_{stat} Fstatistical, *df* Degree of freedom, *p*-value Significance value

1.457, where y_2 was generated voltage and x_2 was dampener rotor rpm. The rectified DC voltage generated is directly proportional to dampener rotor rpm. From the above equation, constant voltage charge of 7.3 to 7.5 V for cycle use of battery and stand by use voltage of 6.8 to 6.9 V could be produced by rotating dampener rotor at 42 and 39 rpm respectively. Maximum time to full charge 10 Ah battery considering 20% efficiency loss was 6.5 h. LED's arranged in a matrix and rechargeable battery were used as load to the PMDC motor. LED's were selected as load because of their reliability, cheaper, long life, maintenance free, rapid switch over from dim to bright, consumes less power than fluorescents. Figure 3 shows the resulted mechanical power curve of the rotor wheel dampener. The maximum power of the rotor wheel was 5.1 W at 42 rpm and wheat flow rate of 1.6 kg/s. Test to increase the power of the rotor wheel could not be done due to limitation in rotor wheel dampener designed wheat flow rate of 2000 kg/h and battery capacity of 6 V, 10 Ah. Power curve of the rotor wheel dampener with LED's load is as shown in Fig. 4. Measured electrical power values were 0 W for 10 rpm and 4.9 W for 42 rpm of rotor wheel. Electrical power generated by the PMDC motor was lower compared to the mechanical power of the rotor. PMDC motor when operated as generator compared to being operated as motor,

produces little lower voltage for a given rpm and little lower current for a given torque.

Conclusion

The study of gravity flow operated small electricity generator retrofit kit concept indicated that the equipment could be used as low cost generator in Flour mills which is a practical alternative where a low energy consumption could not justify expensive solutions. The present study provides different solutions to make small electrical generators from recycled electrical and electronic components which are a combination of recycling techniques and gravitational energies. Statistical analysis indicated that there was significant difference in mean values for voltage, rpm and flow rate at the 95% probability level. Impact of variations in wheat flow rate, wheel rotor speed and potential differences is also demonstrated. Regression equations developed indicated that power generated by generator retrofit kit is a function of its associated parameters viz. voltage, rpm and wheat flow rate. The extension of this work to develop portable generator kit makes it possible to improve effective low cost power generation in flour mill industry.

Fig. 3 Mechanical power curve of the rotor wheel dampener **Fig. 4** Power curve of the rotor wheel dampener with LED's load

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