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OPTIMAL DESIGN AND PERFORMANCE OF A SELF- INDUCTING POWERED BICYCLE GENERATOR

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Abstract: The insufficiency of energy is a global challenge so also is the effect of burning fuel to generate power a threat to the earth. Hence, the need for a sustainable and renewable source of energy that can be used to supplement and with time substitute the burning of fuels to generate power. The research work is focused on optimizing on existing design models of the Chas Campbell free energy generator by incorporating a bicycle system for initial excitation as opposed to electric power. The system is supported with a flywheel which will store kinetic energy to keep the system working before the motor is connected to the generator. The system generated a power of 96w and stayed self-inducting at maximum cyclist speed of 58rpm for a period of 35 seconds. The kinetic energy stored in the flywheel as a result of the flywheel is the major determinant of the duration of self-inducting for the system.
Keywords: clean energy; free energy; flywheel technology; power generation; performance evaluation

INTRODUCTION

The need for a clean, cheap and sustainable power source has been a key area where researchers have directed their efforts over the years in order to counter and minimize the effect and dependence on fossil fuels for both domestic and industrial applications. Demand for energy storage in flywheel have increased because of it high power and efficiency which are of essence in commercials areas of application includes Uninterrupted Power Supply (UPS) systems for backup to temporarily provide power until another source of power is switched to during power outage, sustaining and regulating frequency of power channeled to the power grid, provide power for acceleration in automotive engines [1]. The use of flywheel for energy storage can be dated to 1973 when Dr Richard Post proposed the construction of a 200-tonne, 10 megawatt-hour flywheels for electricity storage for the United States power grid.

The material used for the flywheel were of composite materials thus making it difficult to achieve dynamic stability and structural integrity made difficult with high cost production.

Technology has improved and other electricity storage devices have been made such as: fuel cells, pumped hydro, compressed air energy storage (CAES), ultra-capacitors also referred to as super capacitors batteries, super-conducting magnetic energy (SMES) and flywheel [2].

Several works have been done as to generating electricity through the motor-generator mechanism. Some of the notable arrangements for this systems that will be further discussed in this research work include Chas Campbell's Power Generation System which he demonstrated at a science community in Australia [3], The Tesla Switch popularly called the 'cigar box' which was built by John Bedini at the Tesla Tech Conference in 1984, The Ronald Brandt converter constructed in 1983, The Phi Transformer, The Clem motor built by Richard Clem in 1992 at his residence in Texas, The Papp Engine [4].

From history, human power has been used to power devices. The first human powered device recorded to give a rotary motion is the potter's wheel around 3,500 B.C. Pedal power and Cranks became one of the most devices to couple human power to applications and in the 19th Century, the use of bicycle pedal with the electric dynamo for self-transportation and to generate electric power [5]. This research will be integrating and making modifications to the Chas Campbell Power Generation System by applying the flywheel technology to save energy and the system which will be initially driven by a cyclist on a bicycle and the flywheel is being connected to the generator for electricity generation.

The aim of this work is to develop a simple and easy to use power generating system that is safe for the environment, sustainable and cheap. This research work is a modification to the existing designs of motor-generator systems incorporating human power by using a bicycle pedal cycling to give initial excitation to the flywheel before connecting the AC motor to the output from the generator.

MATERIALS AND METHOD

The following materials were used to carry out this research work: Flywheel, System support frame, Shaft, Bicycle frame, 18V, 3.2A DC motor with rotational speed of 300 rpm,12V, 8A, 350rpm DC motor, Ø60mm single groove pulley, Double groove Ø130mm pulley.

Table 1 shows the materials and ratings of the components employed for the powered bicycle generating system.

Table1: Summary of materials with their rating/properties

S/N	Component	Material	Rating/Specifications
1	Flywheel	Cast Iron	18 Kg, 350mm rim with web
2	Shaft	High carbon steel	400mm, Ø30mm
3	DC Motor	-	57.6W, 18V, 3.2A, 300rpm
4	Generator DC	-	96W, 12V, 8A, 350rpm
5	Pulleys	Cast steel	Ø150mm, Ø130mm, Ø60mm
6	Bicycle Frame	Mild steel pipe	500mm rim size
7	Belt	Synthetic rope	1200mm long

— Free Energy

Free energy refers to a method of generating power without fuel combustion from the environment. Furthermore, free energy can be generated through the following methods; Battery-Charging Pulsed Systems, Moving Pulsed Systems, Energy- Tapping Pulsed Systems, Aerial Systems and Electrostatic Generators, Motionless Pulsed Systems, Fuel-less Motors, Magnet Power, passive Systems and Gravity Powered Systems [3].

— Flywheel Technology

A flywheel serves as an energy reservoir in the form of inertia which has a motor/alternator attached to feed it [6], [7]. It is a mechanical battery that typically consists of a high speed inertia composite rotor to store kinetic energy consisting of a control system and magnetic bearing support, a vacuum support housing and containment, compact heat removal and exchangers, instrumentation monitoring and control, an electrical machine that can run either as a motor or a generator to undertake the energy transfer to and from the flywheel and power electronics for electrical conversion as represented in Figure 1 [8]

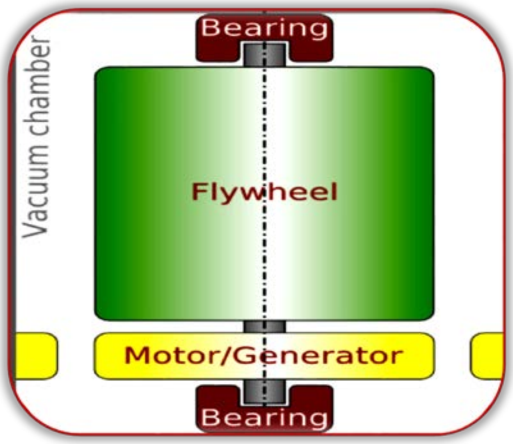

Figure 1: Schematic diagram for a flywheel's storage system [8]

Unlike the failings of all chemical batteries, a flywheel has the ability to discharge cyclically to zero energy without any degradation whatsoever [9].

Flywheel energy storage systems are attractive for the types of applications for which a designer might not want to consider the common conventional electrochemical batteries or superconducting magnetic energy storage [8] Flywheel is a storage device which stores mechanically generated energy in the flywheel and the energy stored is then converted to drive a device which most times produce electrical power or to stabilize the electricity produced. With lower energy densities compared to batteries but the density is sufficient to meet the requirements for many high power applications and still give better performance than batteries [10], [11].

Several researchers have proposed methods and ideas to alleviate these problems, but a fundamental limitation remains in all present designs which are that the rotating mass is far from the axle while the stabilization system (bearings and actuators) operates directly on the axle.

If the harbor or spokes are flexible enough to expand as rotational speed increases, then the stabilization system must transmit control forces to the rim through a "floppy" structure – an impossible task – but if the structure is rigid it will delaminate under high radial stress. So far, the only way to resolve this conflict has been restricting the composite flywheels to small diameters [2].

Energy stored in a flywheel is based on the rotating mass principle which is stored in the device as rotational kinetic energy and the source of its input energy is usually electrical [12].

The energy that is stored in a flywheel can be expressed by equation (1), where E is the kinetic energy stored in the flywheel in N-m, ω is the velocity of the flywheel in rad/s and I is the moment of inertia.

$$E=\frac{1}{2}\cdot I\cdot\omega^2 \qquad (1)$$

The moment of inertia I for a flywheel can be expressed as the product of the mass of the flywheel, m the radius of the flywheel, r and the shape-factor for the flywheel geometry, k as expressed in equation (2).

$$I=kmr^2 \qquad (2)$$

For a hollow flywheel, the moment of inertia can be expressed as,

$$I= km({r_2}^2 - {r_1}^2) \qquad (3)$$

where, r_1 and r_2 are the internal and external diameters respectively.

Table 2: Shape-Factor for different planar geometry [13].

FLYWHEEL GEOMETRY	CROSS SECTION	SHAPE FACTOR. K
Disc		1.000
Modified constant stress disc		0.931
Conical disc		0.806
Flat unpierced disc		0.606
Thin film		0.500
Shaped bar		0.500
Rim with web		0.400
Single bar		0.333
Flat pierced bar		0.305

Possible applications for a highly efficient flywheel energy storage system include: In road vehicles, as well as other applications, flywheels are being considered as a replacement for electrochemical batteries [14]-[15]. Flywheels have high energy per kilogram, are light weighted, low charging times and have been found to have a longer lifetime than batteries.

Batteries need to be replaced during the life of a hybrid vehicle, which can be costly and hazardous to the environment, the flywheel's main use in cars is to convert the power from the engine and transfer it to the clutch plate, dealing with intermittency, providing ride-through for fast instantaneous events such as demand spikes or clouds with PV, renewable integration. Storing during generation and extracting it during demand; in train systems which extracts energy from the flywheel during acceleration and returns the braking energy to the flywheel during deceleration [16].

— Bicycle cycling for power generation

Human rotational performance is a function of the skeletal muscle to generate power and also sustain the power generated which can be possible by resisting fatigue [17]. While riding bicycle, humans are capable of generating approximately 150W of electrical power which goes waste without being put to use. This power can be used to power many electrical devices by incorporating a dynamo or alternator to harvest the energy generated by the pedaling cyclist and the energy can also be stored in a battery [18]. As long as there is continuous pedaling and the system is working fine, we can get power whenever needed. Generating power through this medium is free and eco-friendly [19].From an experiment carried out for three people at average physical condition during an indoor cycling experiment conducted and each session lasted for 50 minutes. The result reveals a dominant range of speeds of 200rpm to 250rpm. The average speed from the experiment is close to 242 rpm, and the rotational speed will be above 200 rpm for 80% session of the time [20].

The idea of adding a flywheel to a bicycle is very appealing because it can increase the efficiency of what is already considered a very efficient machine. This means at its peak, the flywheel is only making up for the efficiency lost by its additional weight [9].

— Shaft Design

The design calculation for the selected shaft for the system as shown in Figure 2

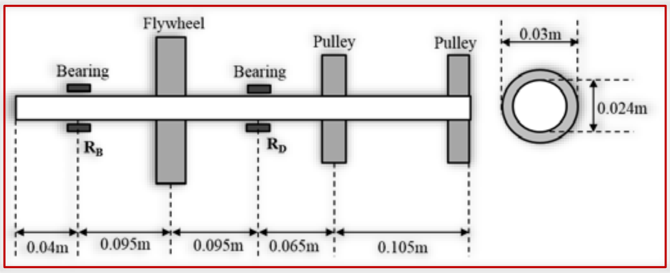

Figure 2: Schematic diagram of loads on the shaft

The direction and magnitude of the forces acting on the shaft are shown in the schematic diagram of the loaded in Figure 2

The Reaction Forces R_B and R_D from the supporting bearing system are calculated as;

Summing the forces in one direction about point B,

$$(0\times0.04) + (180\times0.095) - (R_D\times0.19) + (20\times0.255) + (20\times0.36) = 0$$

$$0 + 17.1 - 0.19R_D + 5.1 + 7.2 = 0$$

Rearranging,

$$0.19R_D = 17.1 + 5.1 + 7.2$$

$$0.19R_D = 29.4$$

Divide through by 0.19

$$R_D = 154.74 \text{ N}$$

Summation of upward forces = Summation of downward forces

$$R_D + R_B = 180 + 20 + 20$$

$$154.74 + R_B = 180 + 20 + 20$$

$$R_B = 180 + 20 + 20 - 154.74$$

$$R_B = 65.26 \text{ N}$$

The Shear Force, F acting at each point of the shaft loading is calculated,

$$F_A = 0$$

$$F_B = 65.26\text{N}$$

$$F_C = 65.26\text{N} - 180\text{N}$$

$$F_C = -114.74\text{N}$$

$$F_D = -114.74\text{N} + 154.74\text{N}$$

$$F_D = 40\text{N}$$

$$F_E = 40\text{N} - 20\text{N}$$

$F_E = 20N$

$F_G = 20N - 20N$

$F_G = 0$

The Shear force diagram is represented in Figure 3.

The Bending Moment, M at each point of the shaft loading is calculated,

$M_A = 0$

$M_B = 0$

$M_C = 62.26 \times 0.095$

$M_C = 6.2Nm$

$M_D = 0$

$M_E = 154.74 \times 0.065$

$M_E = 10.06Nm$

$M_G = (154.74 \times 0.17) - (20 \times 0.105)$

$M_G = 24.21Nm$

The Bending Moment diagram is shown in Figure 3.

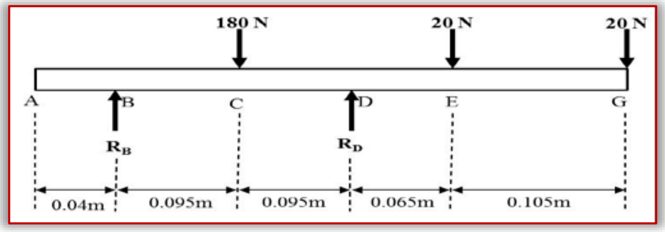

Figure 3: Direction and magnitude of the forces acting on the shaft

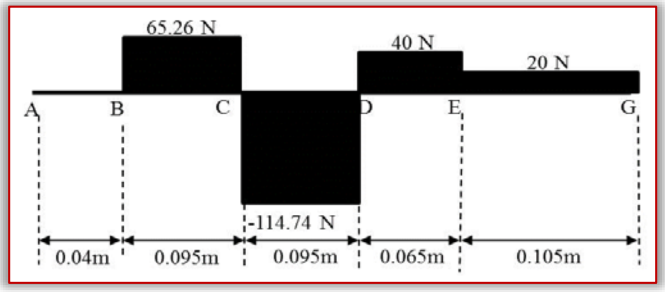

Figure 4: Shear force diagram for the shaft

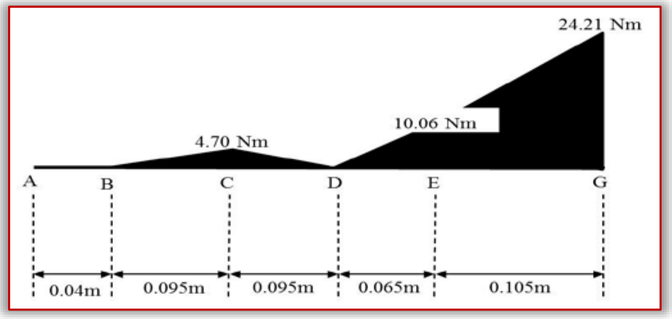

Figure 5: Bending Moment diagram for the shaft

Diameter of shaft

$$r = \frac{\sigma_a \times I}{M} \quad (4)$$

where:

σ_a = maximum allowable stress = 40 MPa

I = Moment of inertia

M = Maximum bending moment,

$I = \pi \times r^4 \times 0.25$

$I = 0.785r^4$

$$r = \frac{\sigma_a \times I}{M}$$

r = 10.9mm

D = 22mm

The Maximum Bending moment is M_G = 24.21Nm

$$\text{The Bending Stress, } \sigma_b = \frac{32M}{\pi d_0^3(1\text{-}\varnothing^4)} \quad (5)$$

where,

M = Maximum Bending Moment = M_G = 24.21Nm

d_0 = shaft outer diameter = 0.30

$\varnothing$ = ratio of shaft inner to outer diameter

$$\varnothing = \frac{0.024}{0.030}$$

$\varnothing = 0.8$

$$\text{The Bending Stress, } \sigma_b = \frac{32 \times 24.21}{\pi 0.03^3(1\text{-}0.8^4)}$$

The Bending Stress, σ_b = 9.13MPa

For commercial steel, allowable design stress to steel shafting is 40MPa (Kharagpur, 2010)

The shaft cannot fail by bending since the Bending stress σ_b is less than allowable design stress for steel, that is, 9.13MPa<40MPa

$$\text{The Stress due to Torsion, } \sigma_b = \frac{16T}{\pi d_0^3(1 - \varnothing^4)} \quad (6)$$

T = Torque on shaft

d_0 = shaft outer diameter = 0.30

$\varnothing$ = ratio of shaft inner to outer diameter = 0.8

Torque on Shaft, T = load on shaft × radius of shaft

T = 220N × 0.03m

T = 6.6Nm

$$\text{The Stress due to Torsion, } \sigma_t = \frac{16T}{\pi(0.03^3)(1\text{-}0.8^4)}$$

σ_t = 2.11MPa

The shaft cannot fail from torsional stress since the torsional stress σ_t is less than allowable design stress for steel, that is, 2.11MPa < 40MPa.

Maximum shear stress the shaft is subjected, σ_{max} = Bending stress, σ_b + Torsional Stress, σ_t

$\sigma_{max} = 9.13 + 2.11$

$\sigma_{max} = 11.24$ MPa

The shaft cannot fail from shear stress since the maximum stress, σ_{total} is less than allowable design stress for steel, that is, 11.24MPa < 40MPa.

RESULT AND DISCUSSION

Considering the ambiguity and need for external electrical source of power for existing self-inducting generator, this system was designed to be powered using the rotational power from a cyclist for initial excitation. Locally sourced materials were used and the construction was done at a workshop. The design process was carefully done ensuring the alignment of every part to one another to avoid power losses due to friction and skidding of belt from the pulley while the flywheel was checked to be parallel to the axial direction of rotation.

A load/indicator (electric bulb) of 4 watt was connected to the generator to signal when the generator is drive above it synchronous speed when it starts generating useable power by lighting the bulb.

Six cyclists tested the system by riding the bicycle system until the indicator bulb powers on and the bulb lightening is stable. The speed of the cyclist is measured, the time taken for the bulb lightening to become stable (12v generated) and the time taken for the system to go off when the cyclist stops pedaling.

The result obtained from the experiment is shown in table 2.

Table 2: Time result from varying speed of cycling

Cyclist speed	Time taken to reach 12v output (sec)	Time taken for system to shutdown (sec)	Flywheel Max Speed (rpm)
40	251	30	315
43	225	31	315
45	218	31	318
49	205	32	320
55	185	33	345
58	165	35	352

The main observation from this result is that the more the speed of cycling, the lesser time it will take for the system to become stabilized in generating electricity and the longer it will take for the system to shut down after the cyclist stops pedaling as seen with the sixth cyclist with 58 rpm. Cyclist with 58 rpm speed of cycling took less time to power the system to a point whereby the bulb lightning was stable.

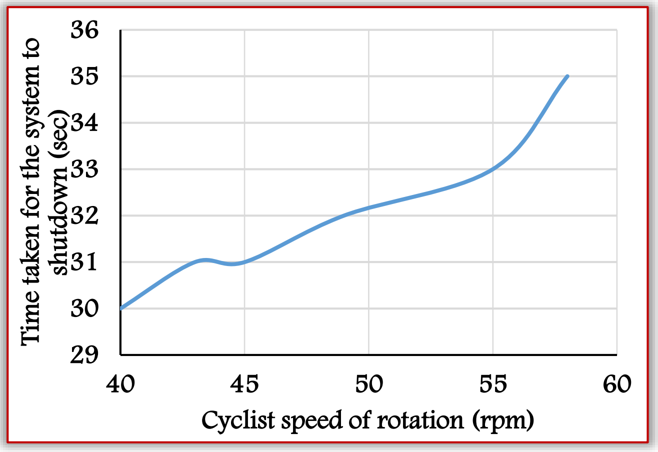

Figure 3: Graph showing relationship between the cyclist speed and time taken before the system shutdown

As shown in figure 3, the cyclist speed of rotation is very critical to the self-inducting duration of the system as the relationship is a linear one such that as the speed of the cyclist increases, the duration for self-inducting for the system also increases.

CONCLUSION

The performance evaluation of this experiment has proved the possibility of integrating a bicycle system into a self-inducting system for initial excitation rather than the existing designs using electrical power. The power out from the system is determined by the capacity of the generator in this case is a 96w DC generator. The duration for self-inducting for the system is a function of the cyclist speed which in turns affects the kinetic energy the flywheel can store in order to keep the system running.

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ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering
ISSN: 2067-3809