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Design and Fabrication of a Pedal Operated Power Generator

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Abstract
Energy conservation is a topical issue and this design proffered an efficient method of doing so. The design was originally conceived to meet the energy needs of those living in rural areas, due to poor access to electricity and also as a model for gym centers and cycle workout studios. Most persons living in these rural areas possess at least a cell phone but lack the means to charge them. This study focused on the design and fabrication of a pedal operated power generator, for the intents of burning fats while yet generating electricity. The power generator was designed to be simple, cheap, durable and easily maintained. It was fabricated using locally sourced materials and is intended to encourage local ingenuity and empower aspiring entrepreneurs especially in developing countries. Its purpose is to efficiently transfer human foot motion less than 60 rpm via a treadle and sprocket-chain step-up to drive a 24V DC permanent magnet generator. The inverter converts the direct current (DC) into alternating current (AC) which is needed to charge low voltage devices like mobile phones, laptops etc. Upon completion, it was found to produce a voltage of 15V and 2.5A at a speed of 483rpm generator speed. The overall efficiency of the system was about 66.6%.
Keywords: Energy, pedal, generator, inverter, diode

1. Introduction

The use of fossil fuels and other non-reusable sources of energy must be reduced in order to keep emissions low and alleviate the use of diminishing resources. The idea of human powered generation has been implemented in many different situations. Some examples include hand-crank radios, shaking flashlights, and receiving power from gym equipment (William and Jeffrey, 2012). The use of exercise equipment for a clean source of energy would turn out to be an even more fun experience for participants; it would provide them a means to exercise while indirectly generating power.

The pedal operated power generator utilizes human energy to produce electricity quickly and efficiently. The goal is to provide technological solution to problem in the rural world by using detailed opportunity recognition, evaluation, and development of prototype. The prototypes are then turned over to the developing world for manufacturing, distribution and use. Less commonly, pedal power is used to power agricultural and hand tools and even to generate electricity. Some applications include pedal powered laptops, pedal powered grinders and pedal powered water wells. Some third world development projects currently transform used bicycles into pedal powered tools for sustainable development.

Using human powered generation gives a power source that is not directly derived from natural sources. An example is that a human powered generator can be operated if there is no sun for solar generation, no wind for wind generation, and no water for hydro generation. The power generated from pedal is perfect for remote areas, hilly regions, strategic location, Islands etc., where electricity generation is scanty if not nil. In these situations, a small portable power generating unit would be of great help to provide power supply to charge battery-operated gadgets like mobile phones, lamps, radio, communication devices, etc. It is important to visualize new ways to bring power to the people as population continues to grow and power shortages continue to occur. Much of the power that is provided to people today is done in very un-sustainable ways; new ideas are needed to transit into a post cheap-petroleum era. This design relates to very compact and easily portable power-generating unit, which besides being used as a power generator can also be used as cycle exerciser. It serves dual purpose of power generation and helping the person to maintain physical fitness through exercise of muscles of legs. It can be pedaled or cranked by hand/foot to charge 12 volt batteries and run small appliances.

2. LITERATURE REVIEW

2.1 Short History on Pedal Powered Machines

Throughout human history, energy has generally been applied through the use of the arms, hands, and back. With minor exceptions, it was only with the invention of the sliding-seat rowing shell, and particularly of the bicycle, that legs also began to be considered as a "normal" means of developing power from human muscles (Wilson, 1986). Over the centuries, the treadle has been the most common method of using the legs to produce power. Treadles are still common in the low-power range, especially for sewing machines. Historically, two treadles were used for some tasks, but even then the maximum output would have been quite small, perhaps only 0-15 percent of what an individual using pedal operated cranks can produce under optimum conditions.

However, the combination of pedals and cranks, which today seems an obvious way to produce power, was not used for that purpose until quite recently. It was almost 50 years after Karl von Krais invented the steerable foot-propelled bicycle in 1817 that Pierre Michaud added pedals and cranks, and started the enormous wave of enthusiasm for bicycling that has lasted to the present.

Ever since the arrival of fossil fuels and electricity, human powered tools and machines have been viewed as an obsolete technology. This makes it easy to forget that there has been a great deal of progress in their design, largely improving their productivity. The most efficient mechanism to harvest human energy appeared in the late 19th century: pedaling. Stationary pedal powered machines went through a boom in the turn of the 20th century, but the arrival of cheap electricity and fossil fuel abruptly stopped all further development (Kris, 2011).

Otto Von Guericke is credited with building the first electrical machine in 1660. This form of electricity precedes electromagnetic energy which dominates today. The landscape for today's electricity usage practices bloomed from 1831 to 1846 with theoretical and experimental work from Faraday, Weber and Gauss in the relationship of current, magnetic fields and force. These theories enabled the design modern motors and generators. From 1880 to 1900, there was a period of rapid development in electrical machines. Thus this section reviews the works that has been done on human power generation.

2.2 Early Development

Studies in power generation shows that bicycling is one of the most efficient form of power generation known, in terms of energy expended per person. McCullagh, (1977) gives us an insight into the test conducted by Staurt Wilson using a 24V (at 1800rpm), 20A generator to charge a 12V car battery. A belt-drive was used to connect a 15.5" diameter bike flywheel to a 2.5" diameter pulley that turned the generator. During this test, an average cyclist produced 75W of sustainable electrical power 12V (900rpm) for a period of one hour.

In 1980, Carl Nowiszewski a mechanical student at the Massachusetts Institute of Technology worked with Professor David Gordon Wilson on a design of a human powered generator which when built will serve as an auxiliary control function in a sail boat in an Atlantic crossing. The energy storage was primarily for automatic steering while the pilot sleep and the pedaling was a way of keeping warm and avoid boredom. The overwhelming problem in the design was the cramped quarters which Nowiszewski eventually solved. And then in 1988, George Alexander Holt III designed a human powered generator using recumbent bicycle technology for use in a sail boat using 6061-T6 aluminum; he built a light weight foldable apparatus. The human power requirement was 120watt at 75rpm (George, 1988).

2.3 Recent Development

Mohd and others (2013) discussed charkha device in India, stated that spinning wheel horizontally could be rotated by a cord encircling a large, hand-driven wheel where the fiber is held in the left hand and the wheel slowly turned with the right. Holding the fiber at a slight angle to the spindle produced the necessary twist. Jansen and Slob (2003) improved the power generation system known as "Better Water Maker" (BWM) water disinfection system. The BWM was designed for use where water is unsafe for drinking and electricity is scare. The BWM utilizes a manual hand crank to provide power to its pump. They also studied one hand cranking and found that 50w of power could be sustained for up to 30 minutes, which is more than double the 17w required by the BWM.

As early as 2007, fitness facilities around the world have begun researching applications for converting human power to electricity. The California Fitness facility in Hong Kong was one of the first gym establishments to incorporate human powered machines. Started by French inventor Lucien Gambarota and entrepreneur Doug Woodring, the gym began a program called "Powered by YOU" in which the excess energy generated by members on 13-step cycling and cross training machines is diverted and converted to power lighting fixtures in the gym (Gerard, 2008).

Maha and Kimberly (2010), in the Proceedings of ASME 2010 4th International Conference on Energy Sustainability made us to understand that other gyms in the United States began to harness human power as well. The Dixon Recreation Center at Oregon State University (OSU) is one of the many facilities retrofitted between the years 2008 and 2009 by the Clearwater, Florida based company known as ReRev. The company retrofitted 22 elliptical machines at OSU so that the excess energy generated by patrons was diverted to the electric grid. According to the company's website, "An elliptical machine in regular use at a gym using ReRev technology will generate one kilowatt-hour of electricity every two days."

Dean (2008) revealed that human legs are up to four (4) times more powerful than human arms. On average, a human can sustain about 100W of power through pedaling for an hour but only hand crank about 30Ww of power in an hour. Wilson (2004) demonstrates that a person's oxygen consumption, and consequently their potential power output, decrease with age, with the peak of potential power output being between 20-40 years of age

According to Jamie and Aaron (2012), Windstream, Convergence Tech and Magnificent Revolution have manufactured stationary pedal powered generators. Typical design included a back-wheel stand that elevates the bicycle and causes the back wheel to come in contact with a smaller wheel that is hooked up to a "bicycle dynamo" and a large battery.

3. MATERIALS AND METHODS

3.1 Mechanism of Operation

The Pedal Operated Power Generator (POPG) is a type of generators in which the source of mechanical power is provided by the human effort while spinning a shaft, with its corresponding angular speed (ω_{human}) and torque (T_{human}). Usually, a sort of mechanical transmission system is needed to adapt these variables into the generator's required ones (ω_{gen} and T_{gen}). Then, this mechanical power is turned into electric power by the generator (P_{out} gen). Eventually, P_{out}gen is converted with the aim of being stored (P_{in} storage), without damaging the storage system. The principle of using your pedal motion to create the same motion as a motor can be translated to almost any device, and the parts needed are all the same, and in the case of the pedal powered electrical device, the components include:

A stationary bike or exercise bike, belt and pulley system, chain drive system, generator,blocking diode, fuse, battery and inverter system

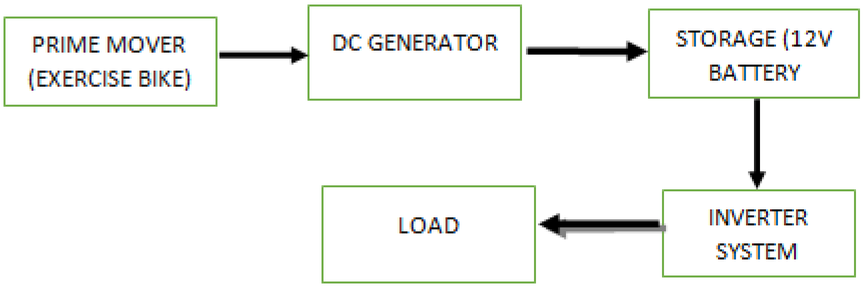


Figure 3.1 Block Diagram of the Generation System

The voltage induced across the terminals of a wire loop when the magnetic flux passing through the loop varies can be calculated using the following equation:

$$E = N_{turns} \cdot \frac{\Delta \emptyset}{\Delta t} \quad (3.1)$$

Where: E = the voltage induced across the terminals of the wire loop, expressed in volts (V).
$N_{turns}$is the number of turns of wire in the loop.
$\Delta\emptyset$is the variation in intensity of the magnetic flux passing through the wire loop, expressed in Webers (Wb).
$\Delta t$is the time interval during which the magnetic flux variationoccurs, expressed in seconds (s)

3.2 Energy Analysis

Heslin and Annette (2005) provided an insight into the average daily consumption of an average male as 2440kcal, this is about 119W of power in, 10.299MJ or 2861Wh of energy every single day. This is approximately the same amount of energy stored in the typical car battery (2400Wh). The primary fuel used in the production of human power is consumed food. The human body utilizes energy stored in the chemical bonds of consumed compounds such as carbohydrate, proteins, fats and fibre to fuel metabolic processes. These processes include basal metabolic function that sustain life, and advance metabolic function used during physical activities. Food energy is commonly measured in the empirical units of Kilocalories (Kcal) or food calories (C), 1Kcal is equivalent to 1C. In the metric system, is measured in Joules, where 1C is equivalent to 4184J.

3.2.1 Measurement of Energy Expenditure (Human Power Input)

Different methods of energy measurement are available: Direct Calorimetry based on the heat production, Indirect Calorimetry based on the volume of oxygen consumed, Open circuit Spirometry based on the measurement of ventilatory volumes, Open-flow system etc. for the purpose of this report, the indirect calorimetry method is adopted. This method includes:

- Measurement of oxygen consumption
- One litre of O_2 consumed = 21KJ used (varies slightly with metabolic fuel consumption – carbos/fats)
- Oxygen consumption is measured by difference method:

$Volume\ of\ O_2\ inspired - Volume\ of\ O_2\ expired$

3.2.1.1 Maximal Oxygen Consumption – The VO_2 max

According to Stephen (2009), VO_2 max is the maximum volume of oxygen that the body can consume during intense, whole-body exercise, while breathing air at sea level. This volume is expressed as a rate, either liters per minute (L/min) or millilitres per kg bodyweight per minute (ml/kg/min). Because oxygen consumption is linearly related to energy expenditure, when we measure oxygen consumption, we are indirectly measuring an individual's maximal capacity to do work aerobically.

The "typical" young untrained male will have an absolute VO_2 max of 3.5liters/min, while the typical same-age female will be about 2 liters/min. This is a 43% difference! Where does it come from? Well first, much of the difference is due to the fact that males are bigger, on average, than females. We humans are all (sort of) geometrically similar, so heart size scales in proportion to lean body size. If we divide VO_2 by bodyweight, the difference is diminished (45ml/min/kg vs. 38ml/min/kg) to 15 to 20%, but not eliminated. Young untrained women average about 25% body fat compared to 15% in young men. So, if we factor out body composition differences by dividing VO_2 by lean body mass (Bodyweight minus estimated fat weight) the difference in maximal O_2 consumption decreases to perhaps 7-10%. By measuring oxygen consumption (VO_2) during the exercise on a bicycle ergometer, the energy expended as well as the mechanical efficiency can be determined. VO_2 can be converted to energy units to give power input, so long as the exercise does not require oxygen at a rate greater than the highest rate at which a person can consume oxygen (i.e. VO_2 max).

As a rule of thumb, 1-litre of oxygen consumed is equivalent to 5kcal of energy "turned over" in aerobic metabolism. Therefore if we assume the person's VO_2 consumption as 2.5L/min, we know that this person is turning over energy at the rate of 10.5kcal/min. this is equal to:

$$\frac{10.5kcal}{1hr}\left[\frac{4.19\,J}{1\,calorie}\right]\left[\frac{1hr}{3600sec}\right] = 12Watts$$

3.3 Design Analysis

3.3.1 General Design Considerations

Generally, the design of this system depends primarily on the ratings of the DC permanent magnets which produce the DC and the required output power. The output power to be produced affects the dimensioning as well as the input parameters like torque, speed, etc. In light of the above constraints, the following design considerations and assumptions has been made for this project design;

1. **Sizing and economic considerations:** This system is design to compact in consideration of the power requirement as well as reduction in the cost of fabrication. For affordability, the device is relatively small.
2. **Safety Considerations:** This system is design in such a way that women and children can use it for sustained period of time. It preserves the safety of our immediate environment from noise and air pollution because it's noiseless and smokeless. Stability of the unit was also considered to ensure that the equipment remains upright at all time, i.e. it should not drift or bend to one direction and it should remain stationary.
3. **Ergonomics:** The ergonomics aspect has to do with optimizing the physical contact between human and the equipment. Four important areas of bike ergonomics are usually considered:
   - The strain of the arm and shoulder
   - The muscle support and the position of the lower back
   - The work of proper pedaling
   - The crank length
4. **Technological consideration:** The design of this system is well considered in such a manner that it can be produced within the technology of our immediate environment.

3.3.2 Frame Design

3.3.2.1 Choosing Frame Material

One of the key elements of the design process of objects under cyclical changing loading is the knowledge of service load history. It is especially important in the case of the bike exerciser in which components are under threat of fatigue damage formation because of the diversified influence of many factors of deterministic and random nature. Bike frames encounter a complex set of stresses which in most cases cannot be calculated by hand. Therefore, in designing a frame, engineers usually makes use of an older design which has proven reliable as a starting point. The frame of the POPG was designed to replicate a typical Schwinn DX bike exerciser with little modifications on the materials used in order to minimize cost and also considering availability of materials. The materials used for exercise bike frames have a wide range of mechanical properties. For most bike builders, steel is the material of choice; steel bikes impart a certain level of confidence in the ability of the bike. It provides the ideal combination of performance and purchase cost. They can be inexpensively repaired and have the ability to reveal frame stress injuries before they become failures. When a steel frame breaks, it tends to break slowly rather than suddenly and they have the ability to store and release energy at different degrees of the pedal strokes. The table below shows a breakdown of all the component part of the pedal system and the materials used.

Table 3.1: Breakdown of components and materials used

Component	Material	Source
Main frame (support)	¾ carbon steel rectangular bar	Locally sourced
Flywheel	1" steel plate with stainless steel edge	Locally sourced
Pedal with sprocket	Galvanized steel	Purchased
Handle	2" hollow carbon steel tube	Locally sourced
Generator holder	Steel angle bar	Locally sourced
Battery plate	Steel plate	Locally sourced
1st stage drive	Chain drive	Purchased
2nd stage dive	Flat belt	Purchased

3.3.2.2 Frame Dimensions

To ensure the safety of the user and promote efficient cycling, the dimensions of the bike and cyclist must be taken into account, along with the amount of lateral and vertical clearance needed, in the planning and design of bicycle facilities. The dimensions of a typical bicycle are a handlebar height of 0.75 - 1.10 m (2.5 - 3.5 ft.), handlebar width of 0.61 m (2 ft.), and bicycle length of 1.5 - 1.8 m (5 - 6 ft.). They often provide little traction. The general dimensions adopted for the design was (1200 x 200 x 860)mm (Mn/DOT, 2007)

3.4 System Force Torque and Power Input

This system is designed assuming the average mass of 65kg and pedaling time as 60mins. From reviewed literatures, the pedal input force, torque and power can be computed as below:

Input force

$$F = \frac{mv}{t} \tag{3.2}$$

Input Torque

$$T = F \times R \tag{3.3}$$

Input Power

$$P = \frac{2\pi NT}{60} \tag{3.4}$$

3.5 Power Output of the pedal systems

Work on a bike exerciser is determined according to the basic work equation

$$Work = Force\ x\ distance \tag{3.5}$$

The force is a friction resistance (T_1) provided by the belt around the large flywheel. This belt can be tightened to varying degree to apply different amount of resistance. One revolution of the flywheel is equal to a distance computed as follows the circumference of the flywheel

$$distance = 2\pi r \tag{3.6}$$

Therefore, the work can now be computed as

$$work = f * d = T_1 * 2\pi r \tag{3.7}$$

To determine the power, we now substitute the number of revolution done in a given period.

$$power = {}^{work}/_{time} = T_1 * 2\pi r * N \tag{3.8}$$

Pedal Mechanical Efficiency

Using the volume of oxygen consumed during exercising, the persons overall or gross mechanical efficiency can be computed as follows:

$$Power\ output = T_1 * 2\pi r * N \tag{3.9}$$

This power output is equivalent to 2.1Kcal/min

$$\text{Pedal } Power\ input = P_{inpedal} = VO_2/\min * 5Kcal/VO_2 \tag{3.10}$$

Expended Power in the Pedal system = P_{out} - P_{in}

$$Efficiency = {}^{P_{out}}/_{P_{in}} * 100 \tag{3.11}$$

3.6 Generator Selection

The choice of generator to use for the project was one of the major problems encountered as regards to the design of this project as much emphasis was given to "low speed" considering the pedaling speed of an average human and in order not to exceed maximum gear ratio.

LabVolt (2011) provided an insight into the use of a permanent magnet (DC) as the generator which is a brushless-type DC; a diode is use to block the flow of current back to the generator. Since 12volt controllers, chargers and appliances are common, a generator that produces 100 to 200 watts at 24volts DC was found to be a good choice and also one designed to deliver optimum output at speeds under 1,000rpm. DC Permanent magnet generator for its simple, pre-assembled and required low RPM when compared with a car alternator was the best option chosen because it produces direct current (DC) and batteries need DC for charging, that is, with the charge produced from this generator, the battery can be charged without any special modification. Considering the amount of voltage required to charge a 12V battery, the generator use is actually a 24V permanent magnet DC at 800rpm.

3.7 Battery Selection

The battery was selected based on the amount of time we wanted to operate the system at full load. As mentioned in the specifications, we wanted to be able to power 4-mobile phones, 1-ipod and i-pad and 1-laptop for about one to two hours. Generally the relationship between the energy stored in the battery and the time of discharge is given by the expression below:

$Power = Voltage\ x\ current$ [Watts] (3.12)

$Energy = Current\ x\ time$[Watt-hr] (3.13)

Fulfilling the 12 VDC battery requirements, a battery with 18 Ah was opted for. If the battery is discharged to 40% at most, this battery leaves us with 9 Ah. Our load of 3-mobile phones and 1-laptop uses about 65 watts. With a 12 VDC battery and a 65 W load, we have about 5.4A of current, which gives us about 2.2 hours of use at full load – this is consistent with our design specifications.

3.8 Inverter Selection

The power of the inverter must be selected according to the way it will be used. The sum of the power of the entire load must not exceed the rated power of the inverter. The maximum power of the inverter must be able to cover the starting current of the loads. Generally, pure sine wave inverters is preferred to the so called square wave or trapezoidal inverters as it produces a real and precisely controlled sine wave (red sine wave) at its output, it offers no significant noise and no loud background noise is heard on a connected radio.

3.9 Gear Ratio

Khurmi and Gupta (2012) stated the gear ratio is also known as its speed ratio, is the ratio of the angular velocity of the input gear to the angular velocity of the output gear. The gear ratio can be calculated directly from the number of teeth on the gears in the system. This system is made up of 2 stage gear systems. The teeth on gears are designed so that the gars can roll on the chain link smoothly without slipping. The number of teeth on gear is proportional to the radius of its pitch circle, which means that the ratios of the gears' angular velocities, radii and number of teeth are equal. Mathematically,

$$\frac{\omega_A}{\omega_B} = \frac{R_B}{R_A} = \frac{N_B}{N_A} = \frac{D_B}{D_A} \quad (3.14)$$

Where $\omega_{A,B}$ = angular speed of sprocket A and B respectively
$R_{A,B}$= Radius of sprocket A and B respectively
$N_{A,B}$ = Number of teeth on sprocket A and B respectively
$D_{A,B}$ = Diameter of sprocket A and B respectively

First stage gear system: The first stage gear system is comprised of the input pedal system and the output sprocket which is shown in the figure below:

The gear system is made up of a driver toothed gear (A) which has 44 teeth and the driven gear (B) with 18 teeth. The 2 gears are linked with a chain.

Jansen and Slob (2003) stated that a human can pedal an average of 60rpm comfortably. In the light of the above, the rpm of the sprocket can be determined by rearranging equation (1) to obtain:

$\frac{\omega_A}{\omega_B} = \frac{N_B}{N_A}$ OR

$$\omega_B = \frac{N_A}{N_B}\omega_A \quad (3.15)$$

The pitch P of a gear which is the distance between equivalent points on neighboring teeth along the pitch circle can be expressed as:

The pitch of the driver gear A can be computed from the number of teeth N_A and the radius R_A of its pitch circle as:

$$P_A = \frac{2\pi R_A}{N_A} \quad (3.16)$$

While the pitch of the driven gear B can be computed as:

$$P_B = \frac{2\pi R_B}{N_B} \quad (3.17)$$

The speed ratio can be obtained as:

$$S_R = \frac{N_B}{N_A} \quad (3.18)$$

Second state gear system (sizing of the pulley diameter)

The second stage gear system is composed of pulleys of different diameters which can be seen in the figure below:

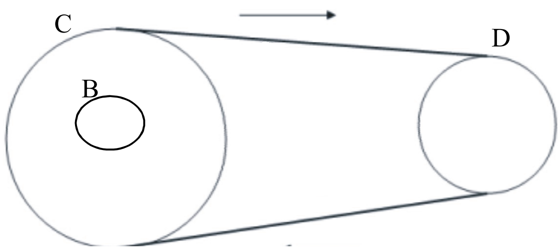


Figure 3.3: Flywheel and generator pulley arrangement

To get the speed (rpm) of the flywheel, since the smaller sprocket in the first stage and the flywheel form a compound gear arrangement, they rotate at same speed, that is $\omega_B = \omega_C$

Given the generator's specifications, the motor's pulley diameter can be calculated by rearranging equation (3.14)

$$\frac{\omega_C}{\omega_D} = \frac{D_D}{D_C} \quad (3.19)$$

From equation (3.19), the pulley's diameter can be calculated as:

$$D_D = \frac{\omega_C \, X \, D_C}{\omega_D} \quad (3.20)$$

Where $\omega_{C,D}$ = Angular speed of flywheel and generator pulley respectively

$D_{C,D}$ = Diameter of flywheel and generator pulley respectively

Hence the overall gear ratio of the system can be expressed as:

For the first stage gear system:

$$G_{R1} = \frac{N_B}{N_A} \quad (3.21)$$

For the second stage gear system;

$$G_{R2} = \frac{D_C}{D_D} \quad (3.22)$$

Then the overall gear ration (GR)

$$GR = G_{R1} \, X \, G_{R2} \quad (3.23)$$

3.10 Flywheel Design

Flywheels are designed to store and release kinetic energy. A Flywheel is disc-shaped, and true to its weight on all sides and locations of the disk. The flywheel is designed to provide a more steady flow of momentum. The size and weight of the flywheel will determine the amount of energy that can be produced from peddling the bike. The mechanical advantages of using a flywheel is that its energy output is consistent and, depending on the size of the flywheel, it is able to store and release great amounts of energy even after the peddling has ceased. The kinetic energy stored in the flywheel is given as:

$K.E = {}^{1}/_{2} * I * w$ (3.24)

Where I = polar moment of inertia
w = angular velocity of the flywheel

Two types of flywheel are available: Heavy and light flywheel;

- A heavy flywheel will take much more effort to get started but will be able to provide the steadiest flow of energy once the heavy weighted disk is in motion. The disadvantage in using a heavy flywheel to power a mechanical device is the individual peddling the bicycle would also have a hard time getting the wheel's momentum engaged and would require more energy input than is required.
- A light flywheel will be easy to engage through peddling power. The amount of momentum is not as great as a heavier flywheel but will be sufficient enough to rotate the pulley of the DC permanent magnet without causing much stress on the individual. A flywheel weighing about 25 - 35 pounds is light enough for an individual to mechanically power.

In the light of the above, the light flywheel scored higher than the heavy flywheel. Because the aesthetics of the drive is not crucial to the appearance of the design project in general, the use of the light flywheel for the final design is chosen over the use of the heavy flywheel.

3.11 Belt Selection

There are lots of factors to be considered when selecting the type of belt to be used;

- The speed of the driving or driven pulley
- The power to be transmitted;
- The center distance between pulleys
- Speed ratio
- Service condition

Considering the above, timing-belt will be use.

According to Khurmi and Gupta (2012), in analyzing, the following design equations are used to generate the parameters needed for the belt design;

Length of the belts

$L = \frac{\pi}{2}(D + d) + 2C + \frac{(D-d)^2}{4C}$ (3.25)

Belt Center Distance

$C = 2 \text{ x} \sqrt{(\mathrm{D} + \mathrm{d}) \text{ x d}}$ (3.26)

Where L = length of the belt
D= diameter of big pulley
d = diameter of small pulley
C = center to center distance

Angle of lap (arc of contact)

$\theta = (180 - 2\alpha)\frac{\pi}{180}$ (3.27)

Belt speed

The velocity at which a belt travels may be expressed as:

$V = \frac{\pi DN}{60}$ (3.28)

Belt tension:

When a belt is fitted around pulleys, it is given an initial tension which only exist while the system is at rest. Since the belt continuously runs over the pulleys, some centrifugal force is caused whose effect is to increase the tension on both the tight as well as the slack sides. The belt tension can be obtained from the following relationship;

$P = (T_1 - T_2)V$ (3.29a)

$2.3 log \frac{T_1}{T_2} = \mu\alpha$ (3.29b)

Where: P = power of motor
T_1 = Tension on the tight side (resisting side)
T_2 = Tension on the slack side (pulling side)
V = Velocity of the belt
μ = coefficient of static friction
α = contact angle

3.12 Chain Drive Selection

In order to select a chain drive, the following essential information must be known:

- The power to be transmitted;

- The speed of the driving and driven pulleys;

To calculate the:

Pitch of the chain

$$P = \frac{2\pi(R+r)}{T_1+T_2} \tag{3.30}$$

Centre distance

$$X = \frac{D+d}{2} + 30 \tag{3.31}$$

Length of chain

$$L = \frac{P}{2}(T_1 + T_2) + 2X + \frac{(\frac{P}{2}\text{cosec}\frac{180}{T_1} - \frac{P}{2}\text{cosec}\frac{180}{T_2})}{X} \tag{3.32}$$

Which can further be simplified as:

L = Y + 2X + Z

Where:

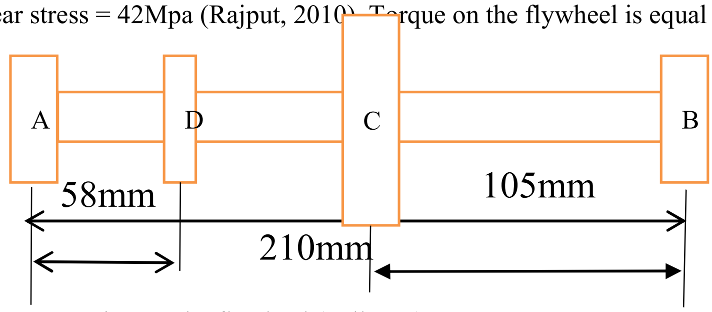
T_1 = Number of teeth on the driver sprocket
T_2 = Number of teeth on the driven sprocket
P = Pitch of the chain
X = Center distance

$Y = \frac{P}{2}(T_1 + T_2)$

$Z = \frac{(\frac{P}{2}\text{cosec}\frac{180}{T_1} - \frac{P}{2}\text{cosec}\frac{180}{T_2})}{X}$

3.13 Shaft Design

The shaft used for this design was designed based on a shaft subjected under combined bending and twisting moment. The following parameters were assumed for the design: Maximum allowable working stress = 63Mpa; Maximum shear stress = 42Mpa (Rajput, 2010). Torque on the flywheel is equal to that on the small sprocket.



Let T_1 = maximum tension on the flywheel (pulley C)
T_2 = tension on the slack side of the flywheel

Vertical load on the flywheel $W_C = T_1 + T_2$

Vertical load on compound sprocket $W_D = T_3 + T_4$ (3.33)

Torque acting on the flywheel $T = [T_1 - T_2]R_C$ (3.34)

Let T_3 = Tension on the tight side of the chain on sprocket D
T_4 = Tension on the slack side of the chain

Since the torque on both flywheel and sprocket (C and D) is same,

$$[T_3 - T_4]R_c = T \tag{3.35}$$

$$T_3 - T_4 = \frac{T}{R_D}$$

And

$$\frac{T_3}{T_4} = \frac{T_1}{T_2}$$

Horizontal load on shaft due to flywheel = 0
Horizontal load due to sprocket = 0
Reaction on the bearing support
Considering the vertical load on flywheel

$$R_{AV} + R_{BV} = [T_1 + T_2] \tag{3.36}$$

$$R_{BV}\ x\ 0.15 = [T_1 + T_2]\ x\ 0.075$$

Bending moment at A and B

$$M_{CV} = R_{AV}\ x\ 0.075 \tag{3.37}$$

$M_{DV} = R_{BV} \, x \, 0.038$ (3.38)

Maximum bending moment

$M = M_C$

Let d = diameter of shaft

Equivalent twisting moment

$T_e = \sqrt{M^2 + T^2}$ (3.39)

And

$T_e = \frac{\pi}{16} x \, \tau \, x \, d^3$ (3.40)

Equivalent bending moment

$M_e = \frac{1}{2}\left[M + \sqrt{M^2 + T^2}\right] = \frac{1}{2}[M + T_e]$

And

$M_e = \frac{\pi}{32} x \, \sigma_b \, x \, d^3$ (3.41)

3.14 Bearing Selection

Bearing dimensions have been standardized on an international basis. The dimensions are a function of the bearing bore and the series of bearing: Extra light (100); Light (200); Medium (300); Heavy (400). In order to select the correct bearing for the design, the basic dynamic radial load was calculated, multiply by the service factor. The bearing is then selected from the basic static and dynamic capacity table (Khurmu and Gupta, 2010). The mathematical relationship for the bearing selection is presented below:

Service life

$L_H = Years \, x \, 1 day \, x \, hrs/day$ (3.42)

Life of bearing in revolutions

$L = 60 \, x \, speed \, x \, L_H$ (3.43)

The following considerations are of importance in bearing design: Finish precision of bearing shaft, fillet radii of corners of shaft and the height of shoulder.

Table 3.2 Bearing Selection

Bearing No.	Bore (mm)	Outside diameter(mm)	Width
205	25	52	15

3.15 Electrical Circuit Connection

The basic circuit involved only the generator and battery connected in series with diodes that ensured current would not flow from the battery to the generator. The generator can also be characterized as a motor when generating no voltage and hence without the diodes, the battery would be able to drive the motor in reverse.

3.16 Equipment Used

The following equipments were used:

1. Tachometer – to measure the speed (rpm) of the generator
2. Multi-meter – to measure the voltage and current produced from the generator

4. RESULTS

This section presents the result of the input and output data. The results were obtained base on both the evaluation of the models presented in section three and the fabricated design. The input and output data are tabulated for clarity, also, graphs were used when necessary to show the dependence of some parameters on the others.

4.1 Input Parameters

The input parameters represent the known values from which the general design was based upon. It includes the operational speed of the human, generator to produce the required voltage which was obtained from the specification of the DC motor purchased.

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Table 4.1 Input Parameters for the Analysis

S/N	PARAMETER	SYMBOL	VALUE	UNIT
1	Human Input Rotational Speed	ω_A	60	RPM
2	Number of teeth on the large sprocket	N_A	44	-
3	Number of teeth on the small sprocket	N_B	18	-
4	Diameter of the large sprocket	D_A	7	In
5	Diameter of the small sprocket	D_B	3	In
6	Diameter of the Flywheel	D_c	12.5	In
7	Generator Power rating	P	100	W
8	Generator Speed rating	ω_D	800	rpm
9	Mass	M	65	Kg
10	Operational Time	T	60	Mins
11	Maximal oxygen consumption	Vo_{2max}	2.5	l/min

The power that is used during the cycle to turn the generator mostly depends on the pedaling speed of the individual and also the volume of oxygen consumed.

4.2 Output Parameters

Table 4.2 shows the results obtained from the evaluation of the models in chapter three. It shows the summary of the output data of the analysis of the system which include the selection of the chain and belt drive of the system, sizing of the pulleys etc.

Table 4.2: Output Parameters

S/N	PARAMETER	SYMBOL	VALUE	UNIT
1	Input Force	F	0.10085	N
2	Input Toque	T	8.966	Nm
3	Input power	P_{in}	56.334	W
4	Pedal Input Power	$P_{inpedal}$	10.5	kcal/min
5	Pedal Power Output	P_{out}	1.84	kcal/min
6	Pedal Mechanical Efficiency	M_A	17.489	-
7	Pitch Diameter for Gear A	P_A	12.695	Mm
8	Pitch Diameter for Gear B	P_B	13.299	mm
9	Speed Ratio	S_R	2.44	-
10	Speed of Small Sprocket	ω_B	146.667	rpm
11	Diameter of Generator	D_D	2.29	mm
12	First Stage Gear Ratio	G_{R1}	2.44	-
13	Second Stage Gear Ratio	G_{R1}	5.54	-
14	Overall Gear Ratio	G_R	13.3	-
15	Actual Length of Belt	L_a	1339.7	m
16	Belt Centre Distance	C	346.41	Mm
17	Contact/Lap Angel	θ	4.35	rad
18	Belt Speed	V	2.43	m/s
19	Tight Tension	T_1	30.68	N
20	Slack Tension	T_2	10.32	N
21	Chain Pitch	P	12.87	Mm
22	Chain Centre Distance	X	157	mm
23	Chain Length	L	713.3	Mm
24	Torque on Shaft	T	256.5	Nm
25	Maximum Bending Moment	M_e	138.4889	Nm
26	Shaft Diameter	D_s	32.8	Mm

4.3 Results from Fabricated System

Table 4.3 shows the results from the fabrication. It shows the dimensions obtained as measured from the fabricated machine.

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Table 4.3 Results from Fabricated System

S/N	QUANTITY	DIMENSION	UNIT
1	System Total Length	Mm	1708
2	Chain Center Distance	Mm	66
3	Belt Center Distance	Mm	48.5
4	Current	A	2.5
5	Voltage	V	15
6	Speed of the generator	Rpm	483
7	Power output	W	37.5
8	Overall efficiency	%	66.6

5. Discussion

5.1 Relationship between Speed at Bike Wheel (Flywheel), Generator Speed and Voltage Produced

From the computation and analysis carried out, it is observed that the speed of the flywheel and generator pulley have a linear relationship. Varying the size of either of the pedal input sprocket or the flywheel that is connected to the generator will have an effect on the amount of voltage produced and also the amount of work done on the system. Thus increasing either of them will result to an increase in the speed of the generator and thus increase in the voltage produced. A graph to show this relationship is shown below.

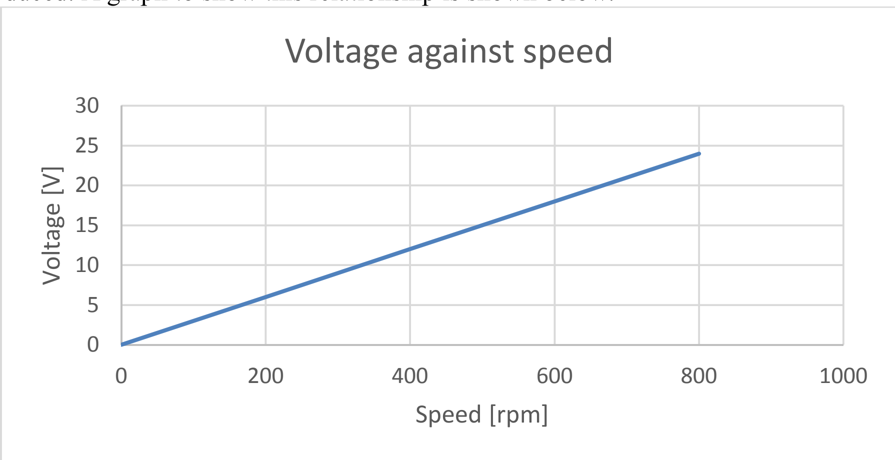

Figure 5.1 Graphical depiction of voltage against speed

5.2 Relationship between Generator Speed and Load

The speed (rpm) required to reach any particular voltage is determined by the load - the lighter the load, the lower the rpm needed to reach the specified voltage. The generator will generate electric current based on load. This means that if a battery is fully discharged, it will accept a great deal of power to charge it, but as it approaches a full charge, the amount of electricity accepted will be very little. In terms of the generator, it will be more difficult to turn when the battery is discharged and very easy to turn when it is full.

5.3 Generator Efficiency and Points of Losses in the System

The overall efficiency of small permanent magnet dc generators is determined by several independent factors, so there is no single efficiency figure that can be specified for any particular generator. Efficiencies range from 75% to 95%, with a mean of about 85%. Efficiency is affected by the following factors: Magnet type and strength, magnetic gap, winding resistance, heat, windage, load characteristics. Given that the final precise efficiency of a dc generator in a particular application is affected in some way by all the above factors - rpm, load characteristics, internal resistance, voltage, power output and temperature, as well as generator size, magnet type and magnetic gap, the only way to determine the exact efficiency is to measure it in the application and conditions it is to be used.

Also, it is important to note that there are number of energy losses associated with the system. This includes internal energy losses in the battery, the battery management system, other electronic parts, and the generator. These energy losses add up quickly: 10-35% in the battery, 10-20% in the generator, and 5-15% in the converter (direct current to alternating current).

5.4 Testing and Efficiency

Upon completion of the fabricated system, it was tested using a multimeter and tachometer to measure the voltage produced and the speed at which the generator is producing that voltage respectively. It was found to produce a voltage of 15V and 2.5A at a speed of 483rpm generator speed. The overall efficiency of the system which is 66.6% from equation 3.11

5.5 Cost of Evaluation and Optimization

While maintaining a good balance between the cost of material selected and the effect on the functionality and reliability of the system, it was resolved to source some materials (frame support, stainless steel, steel plate, steel angle bar, etc) locally while the generator was a fairly used one.

6. Conclusion

In conclusion, this project was designed to serve as a model/prototype to meet specific need in our locality. The device can also serve as an alternative power source in extreme case scenario even in urban centers. Since the device is manually operated, it can be used in areas where there is no power supply and would always be readily available.

The device is environmentally friendly as it produces no waste in the process of its operation, and the device work with little or no noise. The system proved efficient since even with a minimum pedaling speed, the system produced enough voltage required to charge the battery in order for the system to be usable by almost anybody at anytime.

7. Recommendation

Though, much was covered in the analysis but as a result of some constraints, some major components in the design where not incorporated thus the following were recommended:

a) For the battery used, future work could be made to have a higher Amp-hour range to make room for longer discharge time and to carry more load if it is to serve more number of persons at a time.
b) Further research should be made so as produce a mobile phone charger capable of charging phones while in motion.

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