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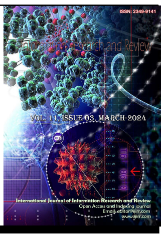

RESEARCH ARTICLE

DESIGN CONSIDERATIONS OF A DUAL PEDAL EXERCISER WITH A POWER STRORAGE DEVICE

***Dr. Mathew S. U., Engr. Eseonu Obi and Dr. Briggs, T. A.**

Department of Mechanical Engineering, University of Port Harcourt, Port Harcourt, Rivers State, Nigeria

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ABSTRACT

This research presents the design of a dual pedal exerciser equipped with an energy storage device. The design concept is based on the principle of conservation of energy, faradays law of electromagnetic induction and Newton's law of motion. The design drawing was produced using Cad software (solid works), fabricated with locally sourced materials in a welding workshop and tested using a tachometer and multimeter. This workpresents a brief insight on human body energy analysis, comprising of the maximum oxygen consumption of 2.5 litres per minute which gives energy over at the rate of 10.5 kcal/min. The exerciser when used for one hour generates about 153.43watts of power while burning 10.5kcal/min of body fat. The power generated can be used to power 3phones and a laptop for about 2hours. However, this work is limited by the ability of the user to maintain the pedaling speed for long period of time.

INTRODUCTION

Pedal powered machines have been used over the years to do work by utilizing human energy. This energy is converted into work by converting mechanical energy of the pedaling action into useful work, such as transportation, cooling, grinding, exercising (physical fitness) and power generation. The most common application of the pedal powered machine is for transportation. Various designs of bicycles have been invented over the years, and today many design of the bicycle is available for use in transportation and for sporting. The use of pedal exerciser for physical fitness is also another common application of pedal powered machines. A Pedal exerciser is a perfect alternative to traditional stationary bikes because they are portable, easier-to-use and offer more variety. The machine can be used for upper and lower body exercises to improve circulation, muscle strength, joint range of motion, and coordination. Pedal exercisers are convenient, affordable, time efficient, and a perfect home exercise machine. They are compact, lightweight and can be easily packed, moved and taken on trips and stored. In Nigeria today, inadequate power supply is a major challenge which affects so many rural areas and prevents them from achieving desired goals. The implementation of pedal power was made to serve as a supplement to the unstable power supply in most rural areas and even cities of developing countries.

Pedal power is the transfer of energy from a human source through the use of a foot pedal and crank (1). This technology is most commonly used for transportation and has been used to propel bicycles for hundreds of years. Some contemporary development projects currently transform used bicycles into pedal powered tools and equipment for sustainable development. However, almost all current works on the utilization of pedal power for power generation have all centered on the use of leg pedal system. More so, almost all pedal exercisers build recently use the leg pedaling system. Only a few pedal exercisers built use the hand pedaling system. Whenusing such machines for body exercise.

The leg muscles and lower abdomen will receive the needed impact (for leg pedaling systems) while the hand muscles and the upper abdomen (for hand pedaling systems). To this effect, the amount of electric power generated will be solely dependent on the capacity of the leg or hand muscular power of the individual respectively. It is also worthy of acknowledgement that this machine will be of no use to those who are handicapped on foot or hand for the leg or hand pedal systems respectively. However no exercisers, no matter how sophisticated and technologically advance it is, have been built to combine both hand and leg pedaling system. Therefore there is need to build a *dual pedal power system that integrate both hand and leg pedal system* for more effectiveness. This kind of machine will not only serve as a source of power generation, but also for performing exercise.

Corresponding author:** ***Dr. Mathew S. U.,
Department of Mechanical Engineering, University of Port Harcourt, Port Harcourt, Rivers State, Nigeria.

LITERATURE REVIEW

A Preamble: Over the years, pedal powered machines have gone through several stages of development and modification. These machines use the human energy to generate power, which is applied through the hands and legs. One of such machines which has existed and is still in used today is the treadle. The treadle is an ancient mechanism operated with pedal, for generating power by converting reciprocating motion into rotating motion. (2)Proclaimed that 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 where used for the same tasks, the maximum output is 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 and 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 most steerable foot-propelled bicycle in 1817 that Pierre Michaud added pedals 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 wake of the 20th century, but the arrival of cheap electricity and fossil fuel abruptly stopped all development (3).

The cleverest innovation in applying human power to rotary motion only appeared in the 1870s. Some of us still use it as a means of transportation, but it is rarely applied to stationary machines anymore: pedal power. Initially, pedals and cranks were connected directly to the front (or sometimes rear) wheel. With the arrival of the 'safety bicycle' shortly afterwards, this direct power transmission was replaced by a chain drive and sprockets - still the basics of most present-day bicycles. Pedal power did not come out of the blue: some of the first bicycles were equipped with treadles, which could be considered the predecessor of the pedal (3). From 1876 onwards, pedals and cranks were attached to tools like lathes, saws, grinders, shapers, tool sharpeners and to boring, drilling and cutting machines. These machines - which became very popular - were intended for small workshops and households without electricity or steam power. They were made with heavy cast-iron bodies that could be collapsed for shipping (3). Stationary pedal powered machines went through a boom at the turn of the 20th century, but the arrival of cheap electricity and the fossil fuels abruptly stopped all further development. 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 of today's electricity boomed from 1831 to 1846 with theoretical and experimental work from Faraday, Weber and Gauss in the relationship of current, magnetic fields and forceenabled the design of modern motors and generators. Subject to achievement of these great scientist and inventors, the era of 1880 to 1900, was a period of rapid developments in electrical machines. With the invention of the bicycle came a veritable avalanche of pedal and machines. The bicycle influences all aspect of life, work, sports, leisure and transportation. Pedaled powered machines where applied in the following devices; Trash Can Washing Machine, the Wood Saw, Water Pumping ,The Pitcher Pump, Log Splitter, Cider Press, etc. Studies in power generation have shown that bicycling is one of the most efficient forms of power generation known, in terms of energy expended per person. (4)givesan insight into the test conducted by Staurt Wilson using a 24 V (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 can produce 75W of sustainable electrical power about 12V (990rpm) for a period of one hour. In 1980, Carl Nowiszewski, a mechanical student at the Massachusetts Institute of Technology (MIT) worked with Professor David Gordon Wilson on a design of a human power 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 slept and the pedaling was a way of keeping warm and avoid boredom. In 1988, George Alexander Holt III designed a human powered generator using recumbent bicycle technology for use in a boat using 6061-T6 aluminum. The equipment was alight weight foldable apparatus. The human power requirement was l20watts at 75rpm. In recent times, the innovation of exercisers came about-with more efficient portability to be used anywhere. A pedal exerciser which is a simple device that simulates the same motion as an exercise bike, can be used nearly anywhere where there is a seat and flat floor. It is exercise equipment that looks like nothing more than a pair of pedals set around a fulcrum. Though the pedal exerciser is very small, it can provide a workout similar to that of a traditional bicycle (2). It has a number of advantages and disadvantages.

One major advantage to purchasing a pedal exerciser is cost. Such machines are substantially cheaper than a traditional exercise bike. They are also much cheaper than buying a regular bicycle. Even the most expensive models often can be purchased for a fraction of the cost of the real thing. Another advantage to the unit is its ability to be easily moved. The portable pedal exerciser is one of the easiest pieces of exercise equipment to move. Many models weigh less than five pounds and often, can be disassembled. Therefore, for those who travel, especially by plane, this is one of the most mobile cardiovascular exercisers available. The pedal exerciser also has the advantage of being able to be used by more than one person without making significant adjustments. Changing the seat height on exercise bikes may be difficult for some individuals but with a pedal exerciser, changing the height to fit an individual's legs is as simple as bending over and moving the machine closer to the chair, couches, or wherever the individual happens to be seated. One disadvantage of this exerciser is its lack of automation. There are no electronics on the pedal exerciser, therefore those used to having bikes that automatically change resistance levels to provide a full and balanced workout will not have that available. There is usually a knob on the machine that can be used to adjust the resistance manually. Those with enough flexibility may be able to do this while they are still pedaling. Sometimes, resistive component is made of magnets. A magnetic pedal exerciser is not as portable as other models because it is larger and heavier.

Another disadvantage related to the lack of electronics is that most do not provide feedback such as the distance traveled and calories burnt. This feedback may be very important for some who like to keep track of their progress. This limitation can be overcome as some models offer a small readout, usually powered by batteries. A bicycle pedal provides an inexpensive, reliable and highly efficient way to transfer power having a requirement of 60 - 80 watts which is within the 100 watts limit generally recommended for human powered devices (3).

Knowledge Gap: In the reviewed literatures, pedal power was generally employed for motion, in case of the bicycle, and for body fitness. This design combines the process of using pedal for pedal for exerciser to keep physically fit and a simultaneous power generation during the process. In the design, the hand pedal was also incorporated in order to improve the power output for the fitness of the hands and arms.

Research Significance: The dual pedal exerciser with a power storage device integrate both the hand and leg pedaling system for conversion of human energy to electrical energy and is very useful in providing a technological supplement to electricity generation in our rural environments. With this machine, electricity can be generated without discharging carbon mono oxide to the environment as in the case of fossil fuel generators. While the exerciser helps in burning body calories and keeping fit, electricity is generated and stored for immediate or future use. This machine is very useful in Nigeria as it mitigates the problem of inadequate power supply and do not contribute to environmental pollution. The system in view is still prone to more technological advancement.This could be a channel for investment and maximization of profit if properly adopted for mass production.

MATERIALS AND METHODS

Preamble: The power level that can be produce by an average healthy athlete is 75W maximum (5). A person can generate more or same amount of power for a longer time if they pedal at a certain rate. The simple rule is that most people engage in delivering power continuously for an hour or more will be more efficient when pedaling rate is in the range of 50-70 rpm (2)

Design Methodology

Materials Utilized: The materials utilized for this research project include the following:

- Mild steel angle bar
- DC generator
- 12V battery
- 4" link belt
- Bolts
- Screws
- Wire DC Voltmeter
- Aluminum flywheel
- Derailleur gears (sprockets, chains)

These materials were locally sourced.

Equipment and Tools Used: The following tools and equipment were used for the fabrication.

- Measuring tape
- Hacksaw
- File
- Wire cutter
- Welding tools
- Screw driver
- Hand grinding machine
- Tachometer
- Multimeter

Fabrication Procedures

- Mathematical modeling
- Cad design (solid works)
- Sourcing of materials
- Fabrication of frames
- Assembly of other mechanical parts (pedals, chains, sprockets, etc.)
- Connection of electrical parts (DC generator, battery, inverter)
- Testing of the exerciser

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 generators required ones (ω_{gen} and T_{gen}). Then, this mechanical power is converted into electric power by the generator (P_{out}gen). Eventually, P_{out}gen is converted with the aim of being stored ($P_{in\ storage}$).In the case of 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. 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;

$$E = N_{turns} \cdot \frac{\Delta\emptyset}{\Delta t} \tag{1}$$

Where

E--voltage induce across the terminals of the wire loop, expressed in volts (V).
N_{turns}--number of turns of wire in the loop
ΔΦ--variation in intensity of the magnetic flux passing through the wire loop, expressed in webers (Wb).
Δt--time interval during which the magnetic flux variation occurs; expressed in seconds (s)

Energy Analysis: (2) provided an insight into the average daily consumption of an average male as 2440kcal, this is about 119KW of power or 10.299Wh of energy every single day. This is approximately the same amount of energy stored in the typical car battery. 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 fiber during 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), IKcal is equivalent to 1C. In the metric system, it is measured in joules, where 1C is equivalent to 4184J.

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 of the measurement of ventillatory volumes, open-flow system etc. For the purpose of this research, the indirect calorimetry method is adopted. This method includes;

- Measurement of oxygen consumption.
- One liter of O_2consumed is equivalent to 21KJ (varies slightly with metabolic fuel consumption-cabos/fat).
- Oxygen consumption is measured by difference method:

Volume O_2 inspired= Volume of O_2 expired.

Maximal Oxygen Consumption: According to (6), VO_2max 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 milliliters 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 2litres/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 sizes scales in proportion to lean body size. If we divide VO2 by bodyweight, the difference is diminished (45ml/min/kg vs. 38ml/min/kg) to 15 to 20%, but not eliminated (8). Young untrained women average about 25% body fat compared to 15% in young men. So, if we factor out body composition differences by dividing VO2 by lean body mass (Bodyweight minus estimated fat weight) the difference inmaximalO2consumption decreases to perhaps 7-10%. By measuring oxygen consumption (VO2) during the exercise on a bicycle ergometer, the energy expended as well as the mechanical efficiency can bedetermined.VO2canbeconverted to energy units to give power input, so long as the exercise does not require oxygen at a rate greater thanthe highest rate at which aperson can consume oxygen (i.e. VO2 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 VO2 consumption as 2.5L/min, we know that this person is turning over energy at the rate of 10.5kcal/min.

Design Approach: The design of this machine is primarily based on the rating of the Direct Current (DC) generator which provides the DC output power. The output power to be produced influences the geometry of the frames and the transmission mechanism used in the design of this work. The user amount to be spent for the production of the machine, and the nature of the material used was also put into consideration to obtain a suitable project.

In light of this, the following design considerations and assumptions have been made for this project.

- ***Usability*** **-** Easy to operate for anyone capable of riding a bicycle.
- ***Cost/sizing*** **-** Cost minimization by considering portability.
- ***Safety consideration*** **-** The system is designed to be mechanically safe such that women and children can use it for a sustained period of time. It is also an environmentally friendly machine as it is noiseless and produces no exhaust flame.
- ***Stability-*** The equipment is designed to be upright and stable. It should remain stationary as it should not shift or drift in use to prevent a possible fall by the user.
- ***Ergonomics-*** The aspect of ergonomics has to do with optimizing the physical contact between the human and the equipment. Four important areas of bike ergonomics are usually considered. These are: (a) the work of proper pedaling(b) The muscle support and the position of the lower back(c) The strain of the arm and shoulder and (d) The crank length
- ***Portability*** **-** The apparatus and its components are light weight allowing the user topack move it with ease to multiple locations.
- ***Maintainability-*** The system must be able to be self-maintained with instruction forrepairs and cleaning.

Frame Design: One significant factor of a design process of objects under cyclical changing loading is the knowledge of service load history. This is an important aspect in the case of an exercise bike where components are under threat of fatigue damage formation because of the diversified influence of many factors. Bike frames encounter a complex set of stress which in most cases cannot be calculated (7). Therefore, in designing the frame, we made use of existing designs which have proven reliable as reference point from which several calculations and rigorous research were carried out for modification and to ensure greater efficiency. The materials used for exercise bike frames have a wide range of mechanical properties and for this exerciser, mild steel is the material of choice because mild steel impact a certain level of confidence in the ability of the bike. It provides the ideal combination of performance and cost. They can be easily repaired because they have good weldability, and have the ability to relief frame stress injuries before they fail. When a steel frame fails, it breaks slowly due to its high ductility. It also has high resistance to breakage.

Frame Dimensioning: To ensure the safety of the user and promote efficient cycling, the dimension of the bike and the cyclist were taken into consideration as well as the stability and clearance needed in the planning and design of the exerciser. The dimensions of a typical bicycle as given by Mn/DOT (2007) are stated below:

- Handle bar of height 0.75 -1.10m (2.5-3.5ft)
- Handle bar of width 0.61m (2ft)
- exerciser length of 1.5 – 1.8m (5 – 6ft)

System Torque and Power Input: This system is design assuming an 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

$$F = \frac{mv}{t} \quad (2)$$

Input torque

$$T = F \times R \quad (3)$$

Input power

$$P = \frac{2\pi NT}{60} \quad (4)$$

Where;

F--input force (N)
T --input torque (Nm)
t—time (s)
R--radius of the sprocket (m)
N--angular speed of the sprocket (rpm)
P--input power (W)

Power Output of the Pedal Systems

The work input to the pedaled system is determined according to the basic work equation.

$$Work = force \times distance \quad (5)$$

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 a distance equivalent to the circumference of the flywheel.

Therefore the work input is expressed as:

$$Work = T_1 \times 2\pi r \quad (6)$$

The input power is given as:

$$Power = \frac{Work}{time} = T_1 \times \frac{2\pi rN}{60} \quad (7)$$

Where;

T_1--force of friction provided by the belt round the large pulley (N)

N—rotational speed (rpm)

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

$$Power\ Output = \frac{Work}{time} = T_1 \times \frac{2\pi rN}{60} \quad (8)$$

This power output is equivalent to 2.1Kcal/min

$$Pedal\ power\ input = P_{in\ pedal} = VO_{2/min} \times \frac{5Kcal}{VO_2} \quad (9)$$

Expended power in the pedal system = Pout-Pin (10)

$$Pedal\ mechanical\ efficiency = \frac{Power\ output}{Pedal\ power\ input} \quad (11)$$

Where;

VO_2--volume of oxygen consumed liters/min)
P_{out}-- output power (W)
P_{in}-- is input power of the pedal systems)W)

Gear Systems

Gear Ratio: The gear ratio also known as 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 a double drive system. The teeth on gears are designed so that the gears can roll on the chain link smoothly without slipping. According to (9), the number of teeth on a gear is proportional to the radius of its pitch circle, which means that the ratios of the gear's angular velocities, radii and number of teeth are equal.

Mathematically,

$$\frac{\omega_A}{\omega_B} = \frac{R_B}{R_A} = \frac{N_B}{N_A} = \frac{D_B}{D_A} \quad (12)$$

Where

ω_A and ω_B angular speed of sprocket A and B respectively (rad/s)

R_A and R_B Radius of sprocket A and B respectively (m)

N_A And N_B Number of teeth on sprocket A and B respectively

D_A And D_B Diameter of sprocket A and B respectively (m)

Leg Pedal Gear System: This gear system consists of 4 stages of power transmission mechanism.

First Stage Gear System: This is a system of chain drive, consisting of two sprockets and a chain.The input torque and power is applied to the larger diameter sprocket.

The angular speed of gear B can be obtained as;

$$w_B = \frac{N_A}{N_B} w_A (13)$$

Where

ω_A--angular speed of gear A (rad/s)
N_A--number of teeth of gear A
N_B--number of teeth of gear B

Second Stage Gear System: The second stage gear system consists of sprockets of different diameters. The input torque and speed at this stage is the output torque and speed of the first stage gear system (w_C=w_B).

The angular speed of gear D can be computed as;

$$w_D = \frac{N_C}{N_D} w_C \tag{14}$$

Where;

ω_D--speed of sprocket D(rad/s)
N_C--number of teeth of gear C
N_D--number of teeth of gear D

The third Stage Power Transmission: This stage of power transmission connects the the output of the second stage gear system to the flywheel. The input angular speed at this stage is the output angular speed of stage two ($w_E= w_D$). The output angular speed can be computed as follows;

$$w_G = \frac{N_E}{N_G} w_E \tag{15}$$

Where;

ω_G--angular speed of gear G (rad/s)
ω_E--angular speed of gear E (rad/s)
N_E--number of teeth on gear E
N_G--number of teeth on gear G

The Fourth Stage Power Transmission: This stage of power transmission transmits power and torque to the dc generator. The speed of the dc generator can be obtained as follows

$$w_I = \frac{D_H}{D_I} w_H \tag{16}$$

Where

ω_I--angular speed of dc generator (rad/s)
ω_H--angular speed of the flywheel (rad/s)
D_I--diameter of the dc generator shaft (m)
D_H--diameter of the flywheel (m)

Hand Pedal Gear System: This gear system consists of 3 stages of power transmission mechanism.

The First Stage Gear System: This is a system of chain drive, consisting of two sprockets and a chain. The larger diameter sprocket is where the input torque and power is applied.

The angular speed of gear E can be obtained as;

$$\omega_E = \frac{N_F}{N_E} \omega_F \tag{17}$$

Where;
ω_E--angular speed of gear E (rad/s)
ω_F --angular speed of gear F (rad/s)
N_E --number of teeth on gear E
N_F--number of teeth on gear F

The Second Stage Gear System: The second stage gear system also consists of two sprockets which transmits power from the first stage gear system to the flywheel. The input angular speed at this stage is the output angular speed of the first stage gear system. The output angular speed at this stage can be obtained as stated below

$$\omega_G = \frac{N_E}{N_G} \omega_E \tag{18}$$

Where;

ω_E--angular speed of gear E (rad/s)
ω_G--angular speed of gear G (rad/s)
N_E--number of teeth on gear E
N_G--number of teeth on gear G

The Third Stage Power Transmission: This stage of power transmission is the same as that discoursed in the fourth stage of power transmission of the leg pedaling system. This is where output power and torque is transmitted to the dc generator.

DC generator selection: Choosing a generator to use for the project was an important factor to the buildup of this device considering the speed needed to attain maximum gear ratio. (9)Provided an insight into the use of permanent magnet DC motor as a generator which is brushless-type DC. A diode is used to block the flow of the current back to the generator. Since 12 volts controllers, chargers and appliances are common, a generator that produces 100 to 200 watts at 24 volts DC was found to be a good choice and also one designed to deliver optimum output at speeds under 1,000 rpm. Thus, DC permanent magnet generator for its simple, pre-assembled and low speed requirements when compared with a car alternator was the best option chosen. 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 modification. Considering the amount of voltage required to charge a 12V battery, the generator used is a 24V permanent magnet DC at 800rpm.

Battery Selection: The battery used for this project is selected based on the amount of time needed to operate the system at full load. As mentioned in the specifications, the design is to power up to five mobile phones, an I-Pad and a laptop at a go for about one to two hours. Generally, the relationship between the energy stored in the battery and time taken for it to discharge is expressed as:

Power = Voltage × Current (Watts)

$$P = V \times I \tag{19}$$

Energy = Current×Voltage × Time (Watt-hr.)

$$Energy = IVt \tag{20}$$

Where;

P--electrical power (W)
E –electrical energyWatt-hr)
t –time (s)

Fulfilling the 12V DC battery requirements, a battery with 18Ah would be the best option. If the battery is discharged to 50% at most, this battery leaves us with 9Ah. Our load of 3mobile phones and 1 laptop use 75Watts. Using a 12V DC battery and a 75W load, there would be about 6.25A of current which gives approximately 2hrs of use at full load.

Pulleys: The system comprises of pulleys of different diameters as shown in figure 1 below. It consists of a system of pulleys where the bigger pulley is the driver and the smaller is driven to increase the angular velocity. The three pulleys are connected by a belt drive system that facilitates the transmission of torque during exercise (10).

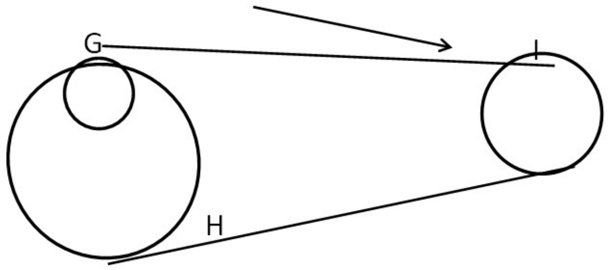

Figure 1. The Belt drive pulley system of the work-out cycle

To get the speed (rpm) of the fly wheel, w_G=w_H

Given the generators specification, the motor pulley diameter can be calculated by rearranging the equation

$$\frac{\omega}{\omega_I} = \frac{D_I}{D_H} \qquad (21)$$

From the equation, the pulley diameter can be calculated as

$$D_I = \frac{D_H \times \omega_H}{\omega_I} \qquad (22)$$

Where

ωI--Angular speed of the flywheel (rad/s)
ωH--Angular speed of generator pulley (rad/s)
D_H--Diameter of flywheel (m)
D_I--Diameter of generator pulley (m)

Flywheel: 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 pedaling exerciser. The mechanical advantage 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 pedaling has ceased. The kinetic energy stored in the flywheel is given as:

$$E_k = \frac{1}{2} I\omega^2 \qquad (23)$$

Where
I—polar moment of inertia (kgm^2)
ω--angular velocity of the flywheel (rad/s)

There are two types of flywheels namely the light and heavy flywheel. A light flywheel will be easy to engage through pedaling 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 – 35pounds is light enough for an individual to power mechanically. 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. For this exerciser we made use of a light flywheel.

Belt Selection: In other to ensure maximum efficiency and avoiding slip of the belt from the pulley, the following factors were considered when selecting a belt:

- The speed of the driven pulley
- The Centre distance between the two pulleys
- The power to be transmitted
- Service condition and
- Speed ratio

Based on this, the following parameters were derived.
Length of belt

$$L = \frac{\pi}{2}(D + d) + 2C + \frac{(D-d)^2}{4C} \qquad (24)$$

Centre Distance

$$C = 2 \times \sqrt{(D + d) \times d} \qquad (25)$$

The angle of wrap is expressed as:

$$\theta = (180 - 2C) \times \left(\frac{\pi}{180}\right) \qquad (26)$$

Where
L--length of belt (m)
D--diameter of the big pulley (m)
d--diameter of the small pulley (m)
C--center distance (m)
ɵ--Angle of lap (arc of contact) (rad)

Belt Speed

The velocity at which the belt travels is expressed as

$$V = \frac{\pi DN}{60} \qquad (27)$$

Where,

N—angular speed of driving pulley (rpm)

Belt Tension: When a belt is fitted around pulleys, it is given an initial tension which only exists while the system is at rest. However, since the belt continually runs over the pulleys, some centrifugal force is exacted and the effect is to increase the tension on the tight and the slack sides. The belt tension can be obtained from the following relationships.

$$P = (T_1 - T_2)V \qquad (28)$$

$$2log\left(\frac{T_1}{T_2}\right) = \mu a \qquad (29)$$

Where;

P --Power input from human operator (W)
T_1--tension on the tight side (N)
T_2--tension on the slack side (N)
V = velocity of the belt (m/s)

μ = coefficient of static friction
a = contact angle

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

Pitch of the chain

$$P_i = \frac{2\pi(R+r)}{T_1+T_2} \qquad (30)$$

Where;

D and d--diameters of the large and small sprockets respectively (m)

R and r--radii of the large and small sprockets respectively (m)
T_1 and T_2-- tensions in the tight and slack sides respectively. (m)

P_i—chain pitch

Inverter Selection: The power of the inverter is selected according to design specification. 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 are preferred.

Electrical Connection: The basic electrical connection involves only the generator and battery connected in series with diodes that ensured current would not flow in reverse direction. The electrical equipment includes a 12V DC battery and wires while the measuring equipment includes the voltmeter to measure the voltage and a tachometer to measure the speed in revolutions per minute (rpm).

RESULTS

The input parameters to mathematical models (Equations 1 to 29) is as in Table 1.

Table 1. Input Data

S/N	Parameter	Symbol	Value	Unit
1	Human input Rotational speed	ω_A	60	(rpm)
2.	Number of teeth of the sprocket A	N_A	48	(-)
3.	Number of teeth of the sprocket B	N_B	16	(-)
4.	Number of teeth on sprocket C	N_C	28	(-)
5.	Number of teeth on sprocket D	N_D	14	(-)
6.	Number of teeth on sprocket E	N_E	28	(-)
7.	Number of teeth on sprocket F	N_F	48	(-)
8.	Number of teeth on sprocket G	N_G	14	(-)
9.	Diameter of sprocket A	D_A	8	(in)
10.	Diameter of sprocket B	D_B	3	(in)
11.	Diameter of sprocket C	D_C	4	(in)
12.	Diameter of sprocket D	D_D	2	(in)
13.	Diameter of sprocket E	D_E	4	(in)
14.	Diameter of sprocket F	D_F	8	(in)
15.	Diameter of sprocket G	D_G	2	(in)
16.	Diameter of the flywheel	D_H	12.5	(in)
17.	Diameter of generator shaft	D_I	0.236	(in)
18.	Generator power rating	P	100	(W)
19.	Generator speed rating	ω_I	800	(rpm)
20.	Mass	M	65	(kg)
21.	Operational Time	T	60	(mins)
22.	Maximum oxygen consumption	VO_{2max}	2.5	(l/min)

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

Table 2 and 3 show the results obtained from the evaluation of the design models.It is the summary of the output data of the analysis of the system which includes the selection of the chain, belt drive of the system and the sizes of the pulleys for both leg and hand pedal system. Tables 4 and 5 are the corresponding fabricated system summary for both leg and hand pedal system.

Table 2. Output Data of the leg pedal system

S/N	Parameter	Symbol	Value	Unit
1.	Input force	F	637	(N)
2.	Input toque	T	101.92	(Nm)
3.	Input power	P_{in}	640.38	(W)
4.	Pedal input power	$P_{inpedal}$	12.5	(Kcal/min)
5.	Pedal output power	P_{out}	1.84	(Kcal/min)
6.	Pedal mechanical efficiency	M_A	17.489	(-)
7.	Diameter of Generator	D_D	6	(mm)
8.	First stage gear ratio	G_{R1}	2.67	(-)
9.	Second stage gear ratio	G_{R2}	2	(-)
10.	Third stage gear ratio	G_{R4}	52.92	(-)
11.	Actual length of belt	L_a	959.736	(mm)
12.	Belt centre distance	C	88.062	(mm)
13.	Contact/Lap angle	θ	4.35	(rad)
14.	Belt speed	V	2.43	(m/s)
15.	Tight tension	T_1	30.68	(N)
16.	Slack tension	T_2	10.32	(N)
17.	Chain pitch	P	12.87	(mm)
18.	Chain centre distance	x	157	(mm)
19.	Chain length	L	713.3	(mm)
20.	Torque on shaft	T	256.5	(Nm)
21.	Maximum bending moment	M_b	138.4889	(Nm)
22.	Shaft Diameter	D_s	32.8	(mm)

Table 3. Output Data of the hand pedal system

S/N	Parameter	Symbol	Value	Unit
1.	Input force	F	637	(N)
2.	Input toque	T	101.92	(Nm)
3.	Input power	P_{in}	640.38	(W)
4.	Pedal input power	$P_{inpedal}$	12.5	(Kcal/min)
5.	Pedal output power	P_{out}	1.84	(Kcal/min)
6.	Pedal mechanical efficiency	M_A	17.489	(-)
11.	Diameter of Generator	D_D	6	(mm)
12.	First stage gear ratio	G_{R1}	3	(-)
13.	Second stage gear ratio	G_{R2}	2	(-)
14.	Third stage gear ratio	G_{R3}	2	(-)
15.	fourth stage gear ratio	G_{R4}	52.92	(-)
15.	Actual length of belt	L_a	959.736	(mm)
16.	Belt centre distance	C	88.062	(mm)
17.	Contact/Lap angle	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)
2.	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_b	138.4889	(Nm)
26.	Shaft Diameter	D_s	32.8	(mm)

The breakdown of fabrication costs is as presented in Table 6. While maintaining a good balance between the cost of material, the functionality and reliability of the system, the choice of locally sourced readily available materials was made for the fabrication of the machine parts.

Table 4. Fabricated system report for leg pedal system

S/N	Parameter	Value	Unit
1.	System total length	197.65	(mm)
2.	Current	6.97	(A)
3.	Voltage	22	(V)
4.	Speed of the generator	880	(rpm)
5.	Power output	153.43	(W)
6.	Overall efficiency	69.9	(%)

Table 5. Fabricated system report for hand pedal system

S/N	Parameter	Value	Unit
1.	System total length	197.65	(mm)
2.	Current	4.58	(A)
3.	Voltage	21	(V)
4.	Speed of the generator	840	(rpm)
5.	Power output	101.92	(W)
6.	Overall efficiency	62	(%)

The system generally does not require much maintenance performed since it is enclosed to avoid dirt and exposure to environmental elements. The major maintenance that could be carried out on the system includes:

- Regular greasing of the bearings
- Charging the battery when it drains out completely (at least after 360 charge cycle)

Table 6. Breakdown of Fabrication Cost

Materials/Process Description	Quantity	Amount (₦)
Permanent Magnet DC generator (Alternator)	1	5,500
2×2 square pipe	18ft	4,000
1×3 square pipe	2(18ft)	4,000
Round pipe	4ft	500
Welding electrode	1 packet	1,800
Cutting stone	1	700
Grinding stone	2	700
Gear freewheel	4	4,500
Pedal	2	2,400
Chain	4	4,000
Gear crank	3	4,500
Rod cup	2	3,000
Engine	2	3,000
Jerry crack	2	4,000
Balls	56	600
Spray paint	1 tin	1,500
Flywheel	1	2,400
12V battery	1	20,000
Inverter	1	5,000
Miscellaneous		2,000
TOTAL		74,100

DISCUSSION

From the design and analysis of the exerciser, it is observed that the speed of the flywheel and the alternator pulley have a linear relationship. Varying the size of either 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 also, an increase in the voltage produced. A graph that shows the relationship is shown in figure 1. The output power of the machine is 153.43W with an efficiency of 69.9% for the leg pedaling system and 101.92W with an efficiency of 62% for the hand pedaling system.

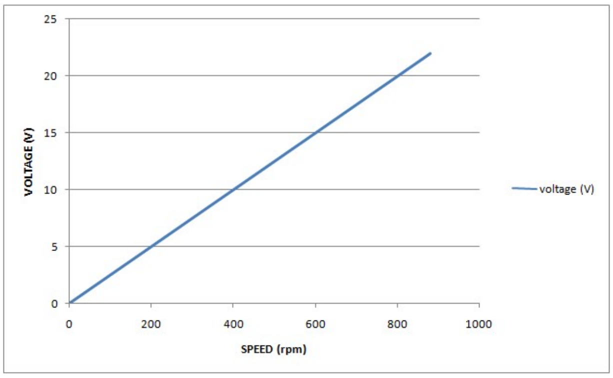

Figure 4.1. Graphical representation of Voltage against Speed

Relation between Alternator Speed and Load: The speed (rpm) required to reach any particular voltage is determined by the load. The lighter the load, the lower the speed in rpm needed to reach the specified. The generator will generate electric current based on load. This means that if a battery is fully discharged, it will take a great deal of power to charge it, but as it approaches a full charge, the amount of electricity accepted will be small. It was observed that the generator was subject to much greater resistance to rotate when the battery was fully discharged and much easier to turn when the battery was fully charged.

Generator Efficiency and Points of Losses in the System: The overall efficiency of small permanent magnet DC generator is determined by several factors so there is no single efficiency figure that can be specified for any particular generator. Efficiencies range from 75% to 95% with mean of 85%. Efficiency is affected by the following factors: magnet type and strength, magnet gap, winding resistance, heat, windage and load characteristics. The final precise efficiency of a DC generator in a particular application is affected by at least one or most of the above mentioned factors. It is also important to note that there are a number of energy losses associated with the system. This includes internal energy losses in the battery the battery magnet system, other electronic parts and the generator. These energy losses add up quickly to 10-35% in the battery, 10 – 20% in the generator and 5-15% in the converter.

RECOMMENDATIONS

Several improvements can be made to the machine to increase its efficiency and power generation capabilities. To accomplish this, the following additional innovations are recommended:

- A battery with better storage capacity can be used so as to achieve longer discharge time and better load carrying capabilities
- The velocity ratio can be improved for a higher speed and consequently, better power generation.
- A gear system can be introduced to ensure that the leg and hand pedal systems work independently and simultaneously

CONCLUSION

This research presents the generation of electricity for household gadgets and appliances while burning calories of energy with designed and fabricated dual pedal exerciser.

From the design and analysis of the exerciser, it is observed that the exerciser burns 10.5kcal of energy per minute. At a pedal speed of 60rpm it produced a voltage of 22volts and power of 153.43Watts which powered 3 phones and a laptop for 2hours with an efficiency of 69.9%. Hence the exerciser is a source of green energy devoid of environmental contamination and more importantly to work out the body muscles to attain perfect fitness.

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