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# Design and Development of a Human-Powered Electrical Generation System Using a Stationary Gym Cycle

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**Abstract—** The mechanical work performed on gymnasium exercise equipment is dissipated as heat in friction brakes and is entirely wasted. This paper describes the design and development of a system that recovers that work as electrical energy. A 24 V permanent-magnet DC motor is coupled through a belt-and-flywheel transmission to the front wheel of a stationary exercise cycle and operated as a generator; the direct current produced is regulated by a charging circuit, stored in a lead-acid battery held at 12.8 V, and made available either as direct current or, through an inverter and step-up transformer, as alternating current for conventional appliances. The flywheel and battery together decouple the intermittent and irregular output of a human rider from the steady supply that a load requires, so that no constant pedalling speed is needed. A design analysis based on the transmission, generator and charge-controller efficiencies of the system gives an end-to-end conversion efficiency of 72.7 % from crank to stored energy, corresponding to a net charging power of 54.8 W at a cadence of 60 rev/min and a crank torque of 12 N·m, or 54.8 Wh and 4.28 Ah of battery charge over a one-hour session. Output rises approximately linearly with cadence, from 36.5 W at 40 rev/min to 73.1 W at 80 rev/min. The energy recovered from a single one-hour session is sufficient to run a 9 W LED lamp for six hours or to charge several mobile telephones, and the concept is directly applicable to the un-electrified villages that still exist in large numbers in India.
***Keywords—*** *Human power; energy harvesting; exercise cycle; DC generator; battery charging; renewable energy; off-grid electrification*

## 1. INTRODUCTION

Energy consumption and human development have historically moved together, and the growth in demand has not been matched by growth in supply: consumption rises by the order of ten per cent a year in India while generation lags behind, producing load shedding and rising tariffs. At the same time the reserves of fossil fuel from which most of that generation comes are finite. The steady substitution of renewable sources for fossil fuels has therefore become a principal concern of energy policy in most countries, and solar, wind, tidal, biomass, geothermal and fuel-cell technologies have all been advanced as candidates.

Human power belongs on that list and is usually omitted from it. The kinetic energy produced by people exercising is among the most widely available and least exploited energy streams in the built environment. In a gymnasium the work a rider does against the brake of an exercise cycle is converted, without exception, into heat in the brake and then into a slightly warmer room; the mechanical energy is real, it is delivered continuously for the duration of the session, and it is thrown away. Over the past decade engineers have designed a variety of energy-harvesting systems drawing on unconventional sources, and exercise equipment is among the most promising of them precisely because the energy is already being expended for another reason. Nothing has to be persuaded to move; the movement is the point of the activity.

The case is strengthened by the distribution of the need. India still contains a very large number of un-electrified villages — of the order of nineteen thousand seven hundred at the time of the study on which this work is based. For a community at that scale, a source that produces tens of watts continuously, requires no fuel, no grid connection and no maintenance beyond the replacement of a

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battery, and that can be built from a bicycle and a scrap motor, is not a curiosity. It is a practical proposition.
The objectives of the present work were therefore to design a pedal-driven generation system around a standard stationary exercise cycle; to select a transmission and a generator that would deliver useful electrical output at the cadences a rider can actually sustain; to provide storage and conditioning so that the intermittent output of a human being becomes a usable supply; and to establish, from the properties of the components selected, how much energy a session of ordinary length actually yields and what that energy is good for.

## 2. LITERATURE BACKGROUND

Work on recovering energy from human and vehicular motion has concentrated on two families of device. The first captures the energy of vehicles passing over a surface. Kaur and co-workers described power generation using a speed breaker coupled to automatic street lighting, closing the loop between the energy harvested and a load immediately adjacent to it [1]. Padma Rao, Kiran Kumar and Suresh developed a rack-and-ratchet mechanism for the same duty, using the ratchet to rectify the reciprocating motion of the depressed plate into unidirectional rotation of the generator shaft [2]. Venkata Rao and colleagues carried the concept through to design and fabrication and reported the output of a working installation [4]. The mechanical problem these studies address — converting an intermittent, irregular, reciprocating input into steady rotation — is the same problem that arises in pedal generation, and the ratchet-and-flywheel solution transfers directly.
The second family concerns the transmission itself. Because the power available from a human rider is small, every percentage point of transmission loss is significant, and the choice between chain, belt and direct drive matters more here than in a machine with power to spare. Published data on high-efficiency belt drives establishes the efficiencies attainable in practice and provides the basis for the transmission efficiency assumed in Section 4 of this paper [5]. General treatments of electric generator design supply the corresponding figures for the machine [3].
What is less well covered in this literature is the system-level question. Individual studies report peak instantaneous outputs, but the quantity that determines whether a pedal generator is useful is the energy delivered over a realistic session at a cadence a rider can hold, after all the losses in the chain from crank to battery. The analysis in Section 4 is framed to answer that question.

## 3. SYSTEM DESIGN

### *3.1 Working principle*

The kinetic energy generated by pedalling is transmitted through the gear system to a flywheel. An alternator or DC machine is connected to the flywheel through a coupling belt and converts the rotational energy into electrical energy. A charging circuit conditions that output and charges the battery, in which the generated energy is stored. Because the energy is stored rather than consumed as it is produced, a constant pedalling speed is not required: the rider may accelerate, slow, or stop entirely without interrupting the supply to the load. When alternating current is required, the direct current from the battery is inverted and raised to mains voltage by a step-up transformer.
The gear system is proportioned so that the machine reaches its useful speed range at a cadence the rider finds comfortable, which is what makes the equipment usable as exercise equipment as well as as a generator. At low shaft speed the machine produces little power at low frequency; at high shaft speed it produces more power at higher frequency. The variation in speed affects the instantaneous output but not the overall energy recovered, because the output is rectified and stored in the battery in either case.

### *3.2 Components and their functions*

Table 1. Principal components of the pedal generation system.

| Component | Function |
|---|---|

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| Component | Function |
|---|---|
| Stationary exercise cycle | Human–machine interface; converts muscular effort into crank rotation |
| Gear system and flywheel | Steps up crank speed to generator speed; smooths the pulsating torque of the pedal stroke |
| Coupling belt | Transmits power from flywheel to generator shaft with low loss and inherent overload slip |
| 24 V DC machine (generator) | Converts rotational mechanical energy into direct-current electrical energy |
| Charging circuit / regulator | Conditions generator output and regulates battery charging at 12.8 V |
| Storage battery | Stores generated energy; decouples supply from the rider's irregular output |
| Inverter and step-up transformer | Converts stored DC to AC at mains voltage for conventional appliances |
| Monitoring and display | Indicates instantaneous power and cumulative energy generated to the rider |

***3.3 System modules***

The design is organised into functional modules. The *mechanical module* comprises the pedals, gearing and flywheel, and is assessed on transmission efficiency, durability and the smoothness with which it delivers torque to the generator. The *electrical module* comprises the generator, wiring and conversion circuitry, and is assessed on electrical efficiency, voltage regulation and power output. The *energy conversion module* addresses the crank-to-battery chain as a whole, and it is here that the losses accumulate. The *load module* covers the battery, any grid connection and the appliances served, and is assessed on load compatibility and system stability. A *monitoring module* reports instantaneous power output and cumulative energy generated to the rider, which serves the double purpose of confirming that the system is working and giving the rider a reason to keep pedalling.

***3.4 Fabrication***

The frame of the exercise cycle was modified to carry a mounting bracket for the generator, fabricated from mild steel section and joined by arc welding. Arc welding was selected for the structural joints because the process is inexpensive, requires no elaborate equipment, tolerates the section thicknesses involved, and can be carried out on site during installation or repair — a consideration that matters for a machine intended for rural deployment. The bracket was positioned so that the belt centre distance could be adjusted for tensioning, since belt tension governs both the transmission efficiency and the slip torque at which the drive protects the generator from a sudden rider input.

The generator was aligned with the flywheel so that the belt runs true; misalignment is the principal cause of belt wear and of the additional loss that would erode the 95 % transmission efficiency assumed in the analysis below. The charging circuit, battery and inverter were mounted in an enclosure attached to the frame, with the display positioned where the rider can read it while pedalling.

**4. PERFORMANCE ANALYSIS**

***4.1 Conversion chain and efficiency***

The mechanical power delivered at the crank follows from the crank torque T and the cadence N as
$P = 2\pi NT / 60$

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That power is then reduced by three successive efficiencies before it reaches the battery: the belt transmission, taken as 95 % on the basis of published data for high-efficiency belt drives; the generator, taken as 85 %, the figure specified for the machine used; and the charging circuit, taken as 90 %. The end-to-end efficiency from crank to stored energy is therefore

$\eta = 0.95 \times 0.85 \times 0.90 = 0.727$

so that slightly less than three-quarters of the rider's mechanical work reaches the battery. The remaining 27 % is dissipated as belt slip and windage, as copper and iron loss in the machine, and as switching and conduction loss in the regulator.

### *4.2 Output as a function of cadence*

Table 2 evaluates the chain over the cadence range a rider can hold for a sustained session, at a crank torque of 12 N·m corresponding to a moderate brake setting. Mechanical input, gross electrical output at the generator terminals, net charging power at the battery, and the battery charging current at the 12.8 V regulation point are given for each cadence.

Table 2. Calculated power output against pedalling cadence at 12 N·m crank torque.

| **Cadence (rev/min)** | **Mechanical input (W)** | **Generator output (W)** | **Net to battery (W)** | **Charging current at 12.8 V (A)** |
|---|---|---|---|---|
| 40 | 50.3 | 42.7 | 36.5 | 2.85 |
| 50 | 62.8 | 53.4 | 45.7 | 3.57 |
| **60** | **75.4** | **64.1** | **54.8** | **4.28** |
| 70 | 88.0 | 74.8 | 63.9 | 4.99 |
| 80 | 100.5 | 85.5 | 73.1 | 5.71 |

Output rises linearly with cadence, as the torque-speed relation requires, from 36.5 W at 40 rev/min to 73.1 W at 80 rev/min. At the reference condition of 60 rev/min the system delivers 54.8 W to the battery, drawing 75.4 W of mechanical work from the rider. That mechanical figure is a useful check on the realism of the analysis: 75 W of sustained mechanical output is a moderate effort for a healthy adult, comparable to a brisk but unstrenuous ride, and it is the level at which an ordinary gym session is actually conducted. The system is therefore sized to the rider rather than the rider to the system.

### *4.3 Energy recovered and its uses*

Over a one-hour session at the reference cadence the system delivers 54.8 Wh to the battery, which at the 12.8 V regulation point corresponds to 4.28 Ah of charge. Table 3 sets that quantity against some loads it might serve.

Table 3. Loads that can be served by the energy from one one-hour session (54.8 Wh).

| **Load** | **Rating** | **Duration or number served** |
|---|---|---|
| LED lamp | 9 W | Approximately 6 hours |
| Mobile telephone charge | ≈ 15 Wh each | About 3 full charges |
| Laptop computer charge | ≈ 50 Wh | About 1 full charge |
| Radio or small music system | 10 W | Approximately 5 hours |
| DC ceiling fan | 25 W | Approximately 2 hours |

The figures put the concept in proportion. A single rider and a single machine will not power a household, and no claim of that kind should be made for the technology. But a gymnasium with twenty machines in use for eight hours a day would recover of the order of nine kilowatt-hours daily, enough to make a visible difference to the facility's own lighting bill; and in an un-electrified village a single machine that yields six hours of light and three telephone charges for an hour of exercise addresses a real and immediate need with equipment that can be built and repaired locally.

***4.4 Voltage regulation and battery management***

The voltage produced by the machine depends on two variables: the field strength and the speed at which the field is rotating. Since a rider's cadence varies continuously, so does the generated voltage, and an unregulated output would alternately fail to charge the battery and overcharge it. The regulator holds the voltage across the battery at approximately 12.8 V, the appropriate float voltage for a 12 V lead-acid battery, and it is this regulation rather than the generator itself that makes the system usable. The battery is the shortest-lived component and its life is governed by the depth and frequency of its discharge cycles, so a system intended for long service should be sized so that the daily energy drawn is a modest fraction of the battery's capacity.

***4.5 Benefits, limitations and fields of application***

The benefits of the arrangement fall into three groups. It is sustainable, in that it draws on an energy stream that is otherwise discarded and displaces generation that would otherwise come from fossil fuel. It saves money, since a gymnasium that generates part of its own lighting and ventilation load reduces its electricity bill directly. And it motivates, because a rider who can see the energy accumulating has a reason to ride longer and harder than a rider working against an anonymous friction brake.

The limitations are equally clear and should not be understated. Output is inconsistent, because it depends on who is riding and how hard, so storage or a supplementary supply is essential rather than optional. Continuous use for generation adds load to bearings, belt and frame and increases the maintenance the equipment requires. Retrofitting existing gymnasium machines, which are not designed with a power take-off in mind, can be awkward and costly, and it is generally cheaper to build the capability into new equipment than to add it to old.

Three settings suit the technology particularly well. Gymnasiums and fitness centres gain both a sustainability claim and a reduction in running cost. Off-grid locations gain a renewable source that requires no fuel supply chain and no grid connection. And public spaces such as parks can install power-generating equipment that serves the double purpose of encouraging exercise and lighting the space in which the exercise occurs.

***4.6 Comparison with other small-scale sources***

It is worth placing the pedal generator against the alternatives available at the same scale, because its advantages are not the ones usually claimed for it. Table 4 compares it with a small photovoltaic array and a micro wind turbine of broadly similar output.

Table 4. Qualitative comparison of small-scale generation options.

| Criterion | Pedal generator | Small PV array | Micro wind turbine |
|---|---|---|---|
| Availability of source | On demand, whenever a rider is present | Daylight only, weather-dependent | Wind-dependent, site-specific |
| Predictability | Fully controllable | Diurnal and seasonal variation | Highly variable |
| Capital cost | Low; can use salvaged parts | Moderate | Moderate to high |
| Maintenance | Belt and bearings; local repair | Cleaning only | Rotating machinery at height |
| Co-benefit | Physical exercise | None | None |
| Scalability | Limited by number of riders | Area-limited | Site-limited |

The pedal generator does not compete with photovoltaics on energy per rupee of capital, and it never will, because a human being is an expensive prime mover measured in watts. What it offers

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instead is dispatchability without storage cost, a source that is available at three in the morning as readily as at noon, that needs no meteorological luck, that can be built from a bicycle and a salvaged motor by anyone able to weld, and that produces a benefit to the operator independent of the electricity. Those are the grounds on which it should be judged, and on those grounds it is competitive in exactly the settings — gymnasiums and un-electrified villages — identified in this paper.

## 5. CONCLUSIONS

- A human-powered generation system was designed around a stationary exercise cycle, using a 24 V DC machine driven through a belt-and-flywheel transmission, with regulated battery storage and an inverter for alternating-current loads.
- The end-to-end conversion efficiency from crank to stored energy is 72.7 %, the product of a 95 % belt transmission, an 85 % generator and a 90 % charging circuit.
- At a cadence of 60 rev/min and a crank torque of 12 N·m the system delivers 54.8 W to the battery for 75.4 W of mechanical input, a level of effort that an ordinary gym user sustains routinely. Output varies linearly with cadence from 36.5 W at 40 rev/min to 73.1 W at 80 rev/min.
- One hour of pedalling yields 54.8 Wh, or 4.28 Ah at 12.8 V — enough for approximately six hours of LED lighting, three mobile telephone charges, or one laptop charge.
- The flywheel and battery together remove the requirement for constant pedalling speed, so the system imposes no unnatural discipline on the rider and can be used as ordinary exercise equipment.

The most productive directions for further work are the substitution of a purpose-designed low-speed generator for the adapted DC motor, which would raise the electrical efficiency above the 85 % assumed here; the addition of flywheel speed control and voltage protection so that a bank of machines can be operated in parallel into a common bus; and the extension of the arrangement to other equipment in the gymnasium, since rowing machines and elliptical trainers present the same opportunity as the cycle. Instrumented measurement of a built prototype, logging cadence, terminal voltage and charging current simultaneously, should be undertaken to confirm the efficiencies assumed in the present analysis.

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