Human Powered Jump Starter

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Abstract
This project aims to design a device capable of providing an assisted start to a car with a discharged battery. Currently available solutions depend on previously stored and prepared electrical energy; in contrast this project addresses that dependency by capturing the kinetic energy exerted by a person and converting it to electric energy. The target cost of the device is $100. Product design involved calculation of electrical energy required to start a car, evaluation of mechanisms that convert kinetic energy to torque, and comparison of devices that convert torque into electric current. Properties of lead-acid batteries were studied to design for optimal charging conditions. Specifically, experimentally-verified calculations were performed to determine (a) the energy required for a single engine start and (b) the battery conditions required to operate a starter motor. For the final design, a reciprocating pedal-pressing action was identified as the best method of exerting kinetic energy, because human legs have a higher exercise capacity than arms. Miniature DC motors were selected as a means of converting torque into electric current, due to low cost and wide availability. A prototype is currently under construction. The finished product will be 11” long by 5” wide by 6” tall, under 8 pounds, and operable while seated inside a car.

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The Need for Project

All of currently available assisted starter devices depend on preliminary electric charge. All of currently available approaches to charging a ‘flat’ car battery involve some embodiment of a backup battery. They include portable battery packs, or simply a connection to another car battery. In all cases, the backup battery requires charge prior to use and periodic maintenance charge to ensure fail-safe operation. A human-powered jump starter positions itself as the solution that works under the circumstances where currently available products will fail, for example after prolonged storage of the device without maintenance charge or in an isolated location where another car battery cannot be reached. One envisioned target user is a driver who is stranded and unprepared to contact aid, or receive a jump, or who does not wish to exit the car.

The Design Project Objectives and Requirements

The objective of this project is to design an assisted starter device independent of preliminary charge.

**Design Objectives**

The project is set to develop a device that combines some embodiment of an energy input mechanism operable by a person, a transducer, and necessary electronics. Secondary design criteria are convenience, simplicity of operation, and portability. The convenience criterion specifically refers to allowing operation of the device while seated inside of a car, and complete lack of required preparation (beyond having the device). The simplicity of use criterion refers to eliminating the need to unlatch the car hood and connect clamps directly to the car battery. The device has to be small enough to fit into a backpack to satisfy the portability criterion.

**Design Requirements**

The primary design requirement is to enable an assisted start to be performed in 10 minutes or less. In order to produce the required 19 kJ of electric energy in this time frame, an average power of 31.7 W must be sustained, equivalent to approximately 27 nutritional calories per hour, or a total exertion of 4.6 nutritional calories.

The secondary design requirement is to maintain a current of less than 15 A during the charge cycle, in order to enable operation via the automotive industry standard 12 V accessory power plug.

The last design requirement is to keep the weight under 10 pounds to make the device lighter than competitor’s solutions, and feasible to lift while seated within a car.
Design Concepts Considered

Three energy input mechanisms were evaluated. Power transmission system received multiple design iterations. Alternating and direct current were considered.

Alternative design concepts considered for this project included various energy input mechanisms, various transmission systems, various energy conversion methods, and designs with and without onboard energy storage.

Three variations of energy mechanisms were considered: a bicycle pedal, a hand crank and a pedal. Mock design models were built to test the motion while sitting in a car. The bicycle pedal motion proved to be unattainable due to space constraints inside of the vehicle. The hand crank was feasible, but had some inconveniences associated with the design, for example the device had to sit on the person’s lap and occupied the user’s hands during operation. Operating the hand crank inside of the car seemed ‘silly’ to test subjects.

The initial concept of the power transmission system was a single-shaft design. In this embodiment, a single shaft received torque from the energy input mechanism and connected directly to a geared DC motor. This design produced an undesirable L-shaped enclosure, and was rejected. A non-parallel shaft connection with helical gears was considered because of the quiet operation of helical gears. This design was retired because it produced higher than desired loads on the power train components due to point load on crossed helical gears.

Three types of devices were considered for converting mechanical torque into electric current: alternators, dynamos and DC motors. Researching available alternators on the market determined that they are costly, bulky, and heavy. Furthermore, they [alternators] generate alternating current while the car battery requires direct current for charging; thus, an inverter would be necessary in addition to an alternator. Dynamos are devices specifically designed to generate direct current. They were considered as prime candidates to become a component in the design, but their limited selection and higher than desired price forced their exclusion from the final concept.

The initial approach included an intermediate energy storage component. Both lithium ion batteries and super-capacitors were considered. Due to the prohibitive price of both of those components they were eliminated from the design in lieu of using the car’s battery as the intermediate energy storage.
Recommended Design Concept

A pedal mechanism with a multi-stage, compact power transmission system and a miniature DC motor is recommended as the optimal design concept.

(1) Design Description

In the recommended embodiment of the design, kinetic energy is captured via a reciprocating pedal pressing motion, similar to an interaction with a foot-operated air pump. The pedal is connected to a shaft via a set of backstop bearings. Backstop bearings permit torque transfer in only one direction, allowing the pedal to return to its initial position in between strokes. On the shaft there is a large spur gear which mates with a smaller spur gear on a parallel shaft. The parallel shaft connects axially to a planetary gear box, which provides a significant boost in the gear ratio. A miniature DC motor is mounted onto the gearbox. When a force is applied to the pedal, a torque is generated in the system. This torque is transferred to the shaft of the DC motor and causes angular acceleration. Under these conditions the DC motor acts as a generator and outputs electric current. That current is passed through a voltage regulator and delivered to the car battery via the automotive industry standard 12 V accessory plug.

(2) Analytical Investigations

The amount of electric energy required to start a four cylinder engine was calculated to be 19 kJ from the power rating and efficiency of the starter motor, and the approximate ignition engagement time. This energy requirement was divided by the target operation time of the assisted start device to obtain the necessary power output. For the charger, the required velocity of the DC motor shaft was calculated based on the motor’s torque constant and electromotive force constant. A gear ratio was inferred based on that shaft velocity and a reasonable pedal engagement frequency, which was approximated as 30 strokes per minute. Stress calculations were performed on the shafts and the linkages of the pedal to ensure fail safe operation.

(3) Experimental Investigations

Electrical energy requirement was verified by performing repeated charge - discharge cycles on a 550A car battery. The battery’s ability to start a car was confirmed after every cycle. The results were within 1 kJ of the calculated values.

(4) Key Advantages of Recommended Concept

Advantages included: hands-free operation; largest torque input of all candidate designs; ability to switch legs to avoid fatigue.
Financial Issues

Manufacturing custom components could significantly reduce unit cost but incurs R&D costs. Initial cost of plastic injection molding requires capital investment.

The most expensive components of the design are the gearbox ($75), and the backstop bearings ($25 each). Ordering a custom manufactured DC motor with a factory-configured gearbox can significantly reduce unit production cost. Manufacturing a custom backstop bearing and pedal assembly could further reduce unit cost, but will incur additional design and testing costs. The casing for the prototype was created by rapid prototyping. Production model would require creating an injection mold, which requires a significant capital investment. The cost of the initial prototype was $180.

Recommended Improvements

Using multiple custom designed DC motors could decrease the time required to perform an assisted start.

Creating a custom DC motor design can enable the system to operate in the most efficient regime, which will decrease the time required to generate sufficient electric energy for an assisted start. A system with multiple DC motors connected in a parallel electric circuit may also be considered to further decrease the time to perform an assisted start. The transmission system can be outfitted with helical gears, which typically operate more quietly than spur gears.