Review of Series Hybrid Drive-System: Advantages for Velomobiles

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Abstract
The basic function of a human powered series hybrid (SH) drive is the same as that of today's electric bicycle drives, which are parallel hybrids (PH). A SH drive is more versatile for the same cost. There are no mechanical transmission elements so that maintenance is simplified. The paper reviews the technology in brief and this technology is being utilized by our project group which is intended to make a series hybrid vehicle as a final year project.

Introduction
Velomobiles: A Velomobiles, is a human-powered vehicle (HPV) enclosed for aerodynamic advantage and protection from weather and collisions. Nearly all Velomobiles are single-passenger vehicles. They are derived from recumbent bicycles and tricycles, with the addition of a full fairing (aerodynamic shell). Most Velomobiles have three or four wheels. Fully faired two wheel road going machines are included within the more general category "human powered vehicle" (HPV). Pedal powered faired vehicles intended primarily for racing are usually called streamliners. Streamliners have set many speed and distance records. [10]

In a parallel hybrid (PH) human-electric drive, an electric motor converts electricity to mechanical power and this is added to the mechanical human power by adding the respective torques at a common element, e.g. wheel or chain wheel.

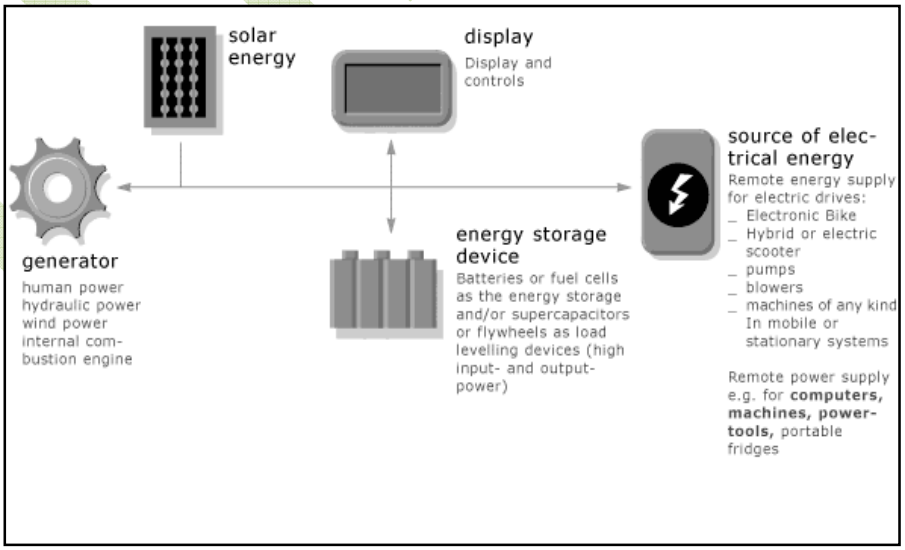

Figure 1: Expansion of SH system. [11]

In an electrical series hybrid (SH) human-electric drive, the human power is converted into electricity using a pedaled generator, added electrically to the available stored electricity, and the total converted to mechanical power using an electric motor. The term “chainless transmission” is used for vehicles which didn't necessarily require the use of a storage battery. More recently the terms parallel hybrid (PH) and series hybrid (SH) have been used. The figure below shows how the SH drive can be expanded to systems with multiple inputs and outputs for any mobile or stationary device. In a further type which might be called a mechanical series hybrid drive, the two inputs are combined using differential gears by adding the respective speeds at a common torque. The motor must therefore handle the torque available in the lowest pedal gear. [3]

How a Series Hybrid Human Power Drive works

Mechanical human power output is converted into electric power by a generator driven by pedals and appropriate gearing. The electrical and hence also mechanical load on the generator is controlled by power electronics which not only optimizes the generator's operating point in terms of voltage and current, but also the human's, by providing a good "feel" in terms of resistance (torque) and speed (cadence). [1] The SH drive is a transmission in the sense that the electrical energy from the generator need not be used to charge a battery, but can be fed directly to one or more motors via suitable electronic controllers. If the vehicle needs less power than is being produced by the generator, the energy can be stored in a battery of accumulators or capacitors.

Components

Number	Module	Remarks
1	Generator-Module	Replaces the traditional mechanical bicycle drive system
2	Motor-Module, e.g. hub motor	The SH-motor handles the total available power, PH-motors only that from the storage battery.
3	Battery or Capacitor Module	As with a PH-vehicle, but can be smaller.
4	Human-Machine Interface Module	Chooses the type of operation and degree of assistance, also determines the “feel” of the drive.
5	Wire harness	Transmits the power. Easy to accommodate awkward geometries, long distances and many inputs/outputs.

[Table 1 Modules used to build a SH drive system

History of the SH Drive System

The first research with Velomobiles was conducted at the University of Applied Sciences in Berne during 1994 to 1999. The initial research using mechanical SH drives based on planetary gears was discontinued because they were thought to be too expensive, unreliable and complex to be developed further. The electrical SH drive was conceived in order to radically simplify the drive system. Tests of working models conducted in 1997 and 1998 yielded positive results.
At the time, high torque, low speed, brushless electric machines of high efficiency was not available at a reasonable price, so together with M. Lindegger and J. Gilgen custom prototypes were developed. Today this type of electric machine is produced by circle motor. [5]

The first generator prototype ran below 1000 rpm. These machines were too heavy and smaller generators running between 1000 and 2000 rpm were produced.

Between 2000 and 2002, under the name of Autork Ltd., a decentralized SH control system was developed for the "Urban Quadra cycle" using the Circle motor electric machines. Development stopped when a major shareholder of Autork went into bankruptcy.

In 2003 the system was put onto a two-wheeled EZ1 recumbent cycle equipped with electric machines to test if a SH drive is feasible not only for "Ultra light-Mobiles", but also for e-bikes.[4]

It was found that the range using a typical e-bike battery was competitive compared to the ranges of commercial parallel hybrid e-bicycles, as tested by Extra Energy in 2001 and 2002.

During 2004 to 2005 a recumbent tricycle was equipped with a fully encapsulated SH drive. The gear ratio of the pedaled generator was no longer around 1:50 as in the first working models from 1997/98, but 1:30 to 1:20.

Qualities of a SH Drive System

Type of Drive System	**Operational Task for User**	**Ease of operation**
E-Bike, PH	User has to operate two drive systems in parallel.	Dynamic riding requires learning.
Pedelec, PH	User has to operate only the mechanical gears since the electric system is automatically operated.	Learning still required for optimal operation, because the electric and mechanical components behave differently.
mechanical SH (Kutter: Velocity,	Mechanical gears have to be changed only when the slope changes.	Starting on slopes requires the correct gear, otherwise simple operation.

Dolphin, Swizzbee)		

[Table 2] Ergonomics

Drive Dynamics

In a SH vehicle, human and machine (electric motor) are only coupled by electrical means. The motor of a SH vehicle needs to provide 100% of the power, that is, the sum of human and electric power. The motor of a SH vehicle is therefore about twice as strong as in an equivalent PH vehicle. [7] The gear ratio between pedal and wheel of a SH drive is infinity. This particularly suits Velomobiles which are slow uphill and fast on the flat. Downhill recuperation is standard and saves brakes while promoting safety.

Efficiency

The SH drive system does not compare with a purely mechanical chain drive e.g. of a racing bike but was not made to replace such drives, but rather to replace mechanically complex hybrid drive systems.

The first working models of the SH drive were equipped with brushed generators with peak efficiencies of between 55 and 70% and with brushed motors with about 80% peak efficiency. Thus it is possible to build SH vehicles with better efficiencies than the poorer PH bikes.[8]

If the average efficiency during the whole trip is considered, the efficiency of SHs compared to that of PHs starts to look interesting. In urban traffic a vehicle is on constant speed only for a minor part of the travel time. Therefore the advantage of high peak efficiency at one operating point of a parallel PH remains advantageous only if the efficiency at other operating points is also good and/or if the gears are used effectively to stay in the optimal region. [2]

People not trained in optimal operation of traditional bicycle gears often pedal off their peak efficiency because humans have a quite narrow peak of high efficiency at some power levels. A major advantage of the SH is that the system can react more quickly than mechanical gears. The efficiency of the system can be maximized electronically at every moment. The human being can be optimally loaded: the "load-leveling" capability of SH's very advantageous from a physiological point of view. The experiences are too few to draw final conclusions yet, but it cannot be easily discounted that the physiological advantages of a SH could over-compensate the disadvantage of peak efficiency of a SH compared to a PH.

Cost

the main difference between a PH drive and a SH drive is the generator. To compare the cost of these drive systems it is sufficient to compare the cost of the generator with the cost of a mechanical bicycle drive system.

A pedalled generator can be made for approximately the cost of a hub wheel motor and motor controller. Compared to continuously variable mechanical or hydraulic transmissions for bicycles (not on the market),

there is no cheaper and simpler CVT (continuously variable transmission) than a drive with pedalled generator! A pedalled generator contains about the same sub-modules as modern electric drills available at reasonable prices.

The main initial cost is that of developing the system (software and power electronics) and the components not available on the market. Overall cost reductions are possible by the simplification of the vehicular mechanical design. The channels for chains or intermediate axles can be eliminated completely.

Weight

The generator module shown in Figure 2 weighs 4.3 kg including pedals and pedal arms. This is about the same as a chain drive with derailleur or less than a drive with 3 x 7 gear hubs.

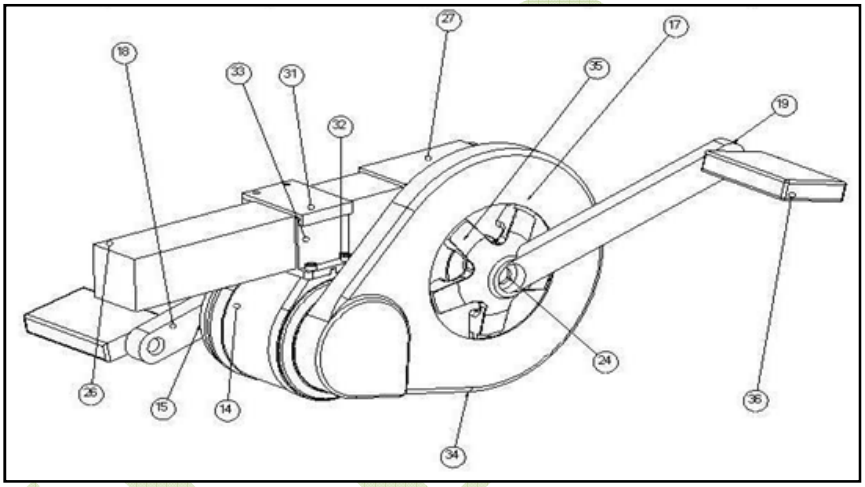

Figure 2: generator module. [11]

Conclusions

During the last decade's work on preparing the SH drive system for industrialization, we can conclude that,

An SH drive can be operated very dynamically.

The weight difference between SH and PH drives is small.

An SH drive does not have to cost more than a PH drive.

The efficiency of an SH drive is sufficient for practical use and excellent if physiological effects are taken into account.

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