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STUDY AND OPTIMIZATION OF AN INNOVATIVE CVT CONCEPT FOR BIKES

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ABSTRACT

The standard bicycle has a well defined form: two same-size in-line wheels with a triangular-shaped frame and an almost vertical riding position. This bike model is the “safety bicycle” 1870's model. May be it is not the most efficient form and, for sure, not the latest developed. The improvement had not been so important. There was indeed a big jump in the late 80's/early 90's, some of which could be attributed both to an increase in time trials and, may be, also to the doping practices of the time. In any case, doping of some form or another has been going on since the beginning of the Tour de France. Time trials are crucial for average speed and it may be they are entirely responsible for the improvement. In any case many other significant advantages have been made on the man-machine. Training and nutrition have been improved through the years.

Keywords: bicycle system, transportation, electric facilities.

INTRODUCTION

The standard bicycle has a well defined form: two same-size in-line wheels with a triangular-shaped frame and an almost vertical riding position. This bike model is the “safety bicycle” 1870's model. May be it is not the most efficient form and, for sure, not the latest developed. If you look at Figure-1, the improvement had not been so important. There was indeed a big jump in the late 80's/early 90's, some of which could be attributed both to an increase in time trials and, may be, also to the doping practices of the time. In any case, doping of some form or another has been going on since the beginning of the Tour de France. Time trials are crucial for average speed and it may be they are entirely responsible for the improvement. In any case many other significant advantages have been made on the man-machine. Training and nutrition have been improved through the years. From Figure-1 the technology improvement on performance seems to have been marginal.

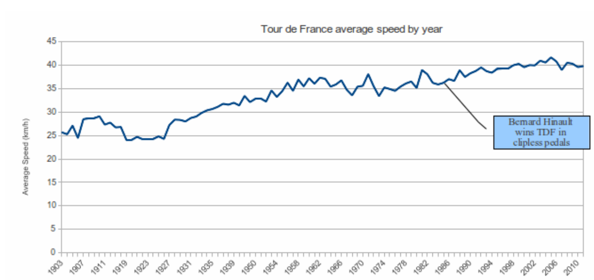

Figure-1. Tour de France average speed by year [1].

Through the years manufacturers introduced many incremental improvements including new materials, new components and many types of accessories. From 1930, there were bicycles to suit different market segments, ranging from the reliable working cycles through to high-performance racing and sports bikes made of advanced lightweight materials with advanced gears and new braking technology. This phase was oriented by the market segmentation. The innovation was suited to the needs of different user groups. The post-WWI period in Europe, led to an expansion in the demand for cycles as a cheap mode of transport and this put emphasis on mass production decrease costs and improve quality. For a long period innovation focused on the production technology to achieve these goals. In this period the product and the market remained stable. This is typical of the mature phase in the "product" life cycle. Innovation took place in specialist niches, for example, in racing bike technology with new advanced materials. Then, in the 1960s, Alex Moulton introduced his small wheel collapsible bike. His bicycle could be folded up and carried on the tram in for commuters to use between the office and the station. Such models were not huge commercial successes, but the market where it really had an impact was in bikes for children where the small wheels were particularly advantageous. After this initial success some manufacturers borrowed from the cross-country motorcycle to build the BMX - Bicycle Motor Cross market. This opened up a new business area and tapped into the new affluent markets of the 1970s. Important product innovation followed this development, especially around accessories, new lightweight fashionable materials, and cycle "smarter" clothing (helmets, etc.). This leisure bike industry expanded further as the aging generation of former BMX kids. This people grew up and began demanding the "mountain bike". This process led to the birth of interest in cycling as a leisure activity rather than as an economical mode of transport. For manufacturers this came at a good time since the car market was slowing down. The manufacturers opened up a phase of product differentiation. Some companies have a catalog of up to 10,000,000 variants of bicycles. Advertisement of the type that follows are common “If your last bicycle was a 3-speed butcher's bike or a 10-speed 'racer', you are in for a pleasant surprise. Advances in materials and technologies mean that bicycles are generally lighter weight and work much better than they did 10, 20 or 30 years ago. Here are some of the features of modern bikes that make cycling comfortable and fun! There is a vast range of styles and sizes of bikes on the market. Bikes are now built for every purpose you could imagine, from competing in the Tour de France to going to the shops. So whether you want a bike for commuting or one for climbing up Ben Nevis, or even a bike that will do both, we'll have a bike for you be it a road bike, a mountain bike or anything in between (i.e. a hybrid). Light Weight and Safety: advances in material technology mean that you can now get a lightweight aluminum-framed bike at a fraction of the cost you would have paid twenty years ago. In more recent years, carbon fiber bikes have become more affordable too. That's a good thing because a lighter bike is easier to pedal up hills. The use of better materials can also improve safety. Witness the 4-fold improvement in wet weather braking performance that came about when aluminum alloy rims superseded chromed steel wheels. Bicycle brakes have evolved dramatically over the past few decades. If you bought an everyday bike up till the late 1980s, it would have probably come with long-arm caliper brakes (remember using your feet to stop the bike on wet roads?) When pioneer mountain bikers twinned tandem bike technology (cantilever brakes) with motorcycle levers, they set a new standard in stopping power. The cantilever brake evolved into the more powerful V-brake in the 1990s. A properly adjusted V-brake remains a cool, lightweight design, but for consistent all-weather performance and longer pad life, they have been superseded by mechanical (cable operated) disc brakes which, in turn, have been usurped by hydraulics. Originally designed to work consistently in extreme MTB downhill racing, hydraulic disc braking has now trickled down to mid-range MTBs and hybrids with the result that the ideal of fingertip brake lever control is more accessible than ever before. Suspension is now ubiquitous on mountain bikes (and some hybrids) because it smoothes the bumps, thus enabling you to ride further and/or longer and/or faster over rough terrain. It's a misconception that suspension is just for expert mountain bikers. Quite the opposite suspension helps to keep the tires 'planted' while the wheels roll over obstacles that might have otherwise pitched you off the bike. Suspension therefore helps compensate for lack of skills when you start out, and helps build confidence as you climb the MTB learning curve. Saddles now come in a huge range of shapes and sizes from traditional Brooks leather to women's specific to clinically tested Body Geometry. Choose a saddle that's optimized for your style of riding. If you like to stretch out to the bars, you'll probably be most comfortable on a saddle so skinny, you're barely aware it's there. If you prefer to sit upright, a wider cushioned gel saddle can offer armchair-like comfort. Handlebar height is crucial for comfort. It's also down to personal preference so it's difficult to advise on. Athletic riders usually prefer to ride stretched out and aero with handlebars below saddle height. For others, comfort means riding upright so the bars are above saddle height. We find most riders are 'in the middle' and like their handlebars to be around the same height as the saddle. Transforming an ill-fitting bike to one you enjoy can therefore simply be a matter of swapping the original handlebar stem for a taller or shorter one. Pedals - again you have a massive range to choose from because getting the best support for your feet is important. Some say the first rule for improving trail skills is to get yourself a pair of flat AKA platform pedals. Others, including roadies, mountain bikers, tourers and commuters, prefer to ride 'clipped in', with the shoes literally connected to the pedals. This isn't as scary as it sounds. Swinging the heel out 20 degrees to disconnect the foot swiftly becomes second nature. Riding clipped in, truly engaged to the pedals, enhances the feeling of being at one with the bike. Index gears are another major development of the past few decades. Instead of crunching the chain between cogs, modern shifters make it easy to precisely change gear in 'indexed' steps. Indexed gears have made slipped gears history: bum shifts a thing of the past. Precise reliable indexed gearing has also made multi-geared 24, 27 and 30-speed gearing not only possible, but amazingly easy to master and use. And the first time you reach for the lowest gear to help ease yourself up the steepest hill; you will agree that having a gear for every occasion is definitely not overkill. This case is based on work by the Open University/UMIST Design and Innovation Group. Case Studies ©2005 Joe Tidd, John Bessant, Keith Pavitt [2].

Even if these commercial messages seem to underline a very large improvement in bike technology, the average speed of the Tour De France demonstrates that it is untrue. Even if modern bikers enjoy better training and food, their speed didn't improve in a very significant way. It should also be also taken into account the presence of a steady increase of individual time trial from the 1960s. The time trials have a conspicuous influence on in the average speeds of Figure-1. In individual time trials a highly specialized bike is used along with an aerodynamic driver-bike outfit. This bike and this outfit cannot be used on ordinary roads.

Technology has not lead to the improvement level declared by the manufacturers. A different more modern approach is introduced in this paper. An up-to-date electronic CVT system is introduced in this paper. This system uses commercial off-the-shelf components to implement continuous variations of gear ratio. Both the pedal and the wheel pulley diameters can be varied independently. This variation is computer controlled. In this way it is possible to take into account the load on pedals and the speed. Also the pulley geometry can be continuously varied to accommodate more convenient oval shapes. The V-belt tensioning is also controlled in the same way, increasing the tensioning with the transmission load. In this way power transmission efficiency is optimized [3-6].

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Drive efficiency

When pedaling rider’s feet move in circles about the centre of the bottom bracket. In “standard” bikes, the torque of that motion is transferred to the rear wheel via pedals, crank arms, chain ring, chain, rear sprocket and rear derailleur. Rider’s work is transferred on pedals.

Depending on the efficiency, a large part of that energy would be transferred to the rear wheel as motive force for the bike-rider system. The main losses of the system are [7]:

- Friction in the pedal assembly
- Hysteresis in the pedal axles
- Hysteresis in the crank arms
- Friction in the bottom-bracket assembly
- Hysteresis in the frame
- Efficiency of the transmission system
- Hysteresis in the chain/belt/gears
- Hysteresis in the rear hub
- Hysteresis in the spokes
- Hysteresis in the rim
- Friction between the rim and tire
- Friction between the tire and road
- Hysteresis of the tire

And what obviously doesn’t work?

Chain drive

The chain drive solution is the most adopted for bike. The advantages of this solution are several. Maintenance is very limited. A few times in a year the chain should be tensioned and lubricated. Even if tension is not ideal the chain will work. If the chain exits out of the teeth it is sufficient to engage the chain and tension it to restart. Chain breakage is rare, since over dimensioning of the chain is unavoidable with bike loads. Chain can be mass produced at very low price. However, chain is a critical issue. Efficiency can be reduced from the highest 98% to a mere 80% just by tensioning. 98% efficiency is limited to very expensive chains with ceramic treatments like DLC (Diamond like Carbon) and proper lubrication. Also a perfect condition is required, since wear should be very limited and run-in should have been performed accurately. This type of chain may cost two order of magnitude more than a good quality commercial one.
Of course also the sprockets should be appropriate. Most popular are the aluminum alloy sprocket with "Sanford" treatment and solid lubricant deposition.

To enhance efficiency course pitch should be chosen, with the relative variation of chain transmission ratio. In fact chains approximate the primitive circle with a polygon of chain pitch side.

The big chainring over the small one will reduce losses in the chain. This has been confirmed by testing. Each chain link will rotate through a much smaller angle as it transitions to/from the chainring. Further, bigger chainring also implies bigger sprocket with a reduction in the transition angle at the rear of the bicycle as well. There are also some non-linear effects in the chain-tooth interaction causing increasing greater energy friction loss when a chain-tooth pair is more heavily loaded, as it is when smaller chainrings and rear sprockets are used.

Also good chain lubrication will enhance wear resistance and efficiency. Lubrication influences significantly chain life.

The viscosity should range between 50 and max. 300 cStmm^2/s at 40°C. Again the lower Figure guarantees the higher efficiency.

Some years ago Aachen Technical University (RWTH) published comprehensive studies for determining the influence of lubrication on service life. The results are summarized in Figure-2.

In comparative tests, a commercial-quality roller chain that is adequately lubricated will suffer an elongation of only 0.5 mm. The same chain in the same load condition, when non-lubricated, reaches its wear-out limits of 3% (30 mm, Figure-2).

With temporary dry-running, however, wear elongation will amount to 12 times the best value of 0.5 mm.

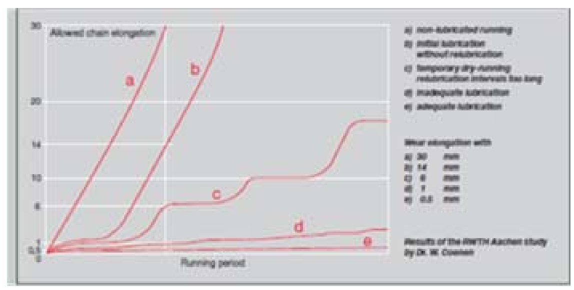

Figure-2. Wear elongation depending on lubrication and running period [8].

The service life and efficiency of chain drives largely depends on maintenance. It remains with user's attitude to lubrication whether a chain drive life will be reduced sixtyfold. In bikes the chain drive runs usually unprotected from dirt. For this reason plastic roller chains cannot be used. The pre-lubricated chains with sealed roller have efficiency slightly lower than traditional hardened roller at the bike loads.

Another shortcoming of chain is that trousers, sockets and shoes may be soiled by chain lubricant.
Another advantage of the chain drive is the tolerance to misalignment.

Roller chain manufacturers estimate that most (90 to 95 percent) of all installed drives are either improperly lubricated or not lubricated at all. The most obvious solution is oil retaining chain housing. Besides obvious weight considerations, oil-retaining chain housing can easily represent up to 75 percent of total chain drive system cost.

Another maintenance cost is drive component replacement. Chain wear is a major weakness of a chain wear. The result is chain stretching or elongation. Chain should be replaced when an elongation of approximately 3 percent occurs. Also the sprockets should be replaced with

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each new roller chain because the metal-to-metal contact generates severe sprocket wear.

Power rating tables published within the roller chain industry are based on a theoretical design life of 15,000 hours. This value is calculated by assuming proper drive design, alignment, lubrication, maintenance, etc. However, actual drive life rarely approaches the ideal. Unlubricated roller chain drives operating under harsh conditions will last only 100 hours.

Maintenance and energy costs notwithstanding, roller chain drives offer designers and users some advantages over V-belt or synchronous belt drive systems:

a) Versatility (possibility of derailleurs)
b) The ability to have any length of chain with connecting links
c) The availability of a large selection of chains and sprockets

Chain drive efficiency evaluation

The Full Load Test Method (FLT) uses a variable speed drive motor that simulates a rider pedaling a front chain ring. A DC generator applies a torque load to the rear axle to simulate the load at the rear wheel. A torque transducer is installed on the front drive shaft and another on the rear load shaft. Efficiency can be then measured. It is assumed that the equipment's ceramic bearings holding the shaft and the derailleur pulleys consume a negligible fractional wattage [9]. Tests of efficiency for the derailleur type chain drive indicate that the overall efficiencies for the transfer of power from the front drive sprocket to the rear sprocket range from 80.9% to 98.6% depending on the conditions of drive operation. Primary factors affecting the efficiency include the sizes of the sprockets in the drive and the tension in the chain. [10-13]

Timing belt drives (Synchronous belt drives)

These specialized belts are typically made by the same manufacturing companies that produce timing belts for automobiles, machinery, and other synchronous belt drive applications. The main advantage of this solution is that lubrication is not required. With the modern carbon fiber reinforced belts also tensioning is seldom required, since the belt is largely over dimensioned. For these reasons the average life is also longer than chain drive metal bicycle chains [14] Jump up to:a b "Cycle Drive Systems: FAQ" (Retrieved 2009-08-05). However, Derailleurs cannot be used, so an internal-CVT is used if multiple gear ratios are required.

The belt cannot be opened as a chain can, so the bicycle frame must designed to accommodate the belt by having a proper opening in the rear triangle or an elevated chain stay.

Sprockets misalignment should be limited to avoid excessive friction and wear. This also means a stiffer frame. A chain is more tolerant in this respect.
Standard pulleys with dual guides had problems with the dirt trapped in the pulley. The problem was solved with center guide belt drives. However this latter are more prone to climb over than traditional industrial solution.

Belt teeth mesh with grooves on sprockets provides positive power transmission. With modern carbon fiber technology, synchronous belt drive systems have an equivalent capacity to roller chain drives in the same width.

A synchronous belt drive system typically costs more initially than those of a comparable standard roller chain or V-belt drive. By contrast, synchronous belt drives are virtually maintenance free. No lubrication is needed. Roller chain requires frequent retensioning and V-belts require periodic retensioning. By contrast a synchronous belt typically requires no retensioning for the life of the belt.

A typical roller chain will elongate approximately 3 percent over its life, requiring about 1.5% of center distance take-up.

A V-belt requires 1.5 to 2.5% of center distance take-up over its life, depending on the cross section, the belt manufacturer and the load level.

A synchronous belt typically requires less than 0.04% of center distance take-up over its life.

Chain and sprocket wear are significant costs in a roller chain drive. In a clean environment, a synchronous belt outlasts a comparable roller chain on the order of 3 to 1, and the sprockets outlast roller chain sprockets 10 to 1.

Like roller chain drives, synchronous belt drives are sensitive to misalignment and derailleurs cannot be used [15].

V-belt drive

V-belt drives are not common in bicycles. In fact for a correct operation they need a proper tensioning and maintenance. Also the friction mechanism of power transmission is critical, since rain severely reduces the friction coefficient. More, dirt may impair the transmission. However, V-belt has several advantages. They are simple and efficient and it is possible to implement a CVT. This later fact is the reason of the solution introduced in this paper.

With efficiencies ranging from 95 to 98 percent at installation, these drives are more efficient than roller chain drives. V-belt drives offer a wide range of sizes at low cost, along with ease of installation and quiet operation.

V-belts are manufactured in a variety of materials, cross-sections and reinforcement materials. They also allow flexibility in the positioning of the motor and the load.

V-belt drive is relatively inexpensive to purchase, install and replace. They should be installed properly and tensioned to the belt manufacturer's recommended values. These drives require very little service, except for retensioning. Due to belt slippage, they can lose up to 5 percent of their efficiency if not properly maintained.

Timing vs Vbelt

Tension is the most important operational and maintenance issue in a V-belt drive. If belts are too loose, they vibrate, wear rapidly, and waste energy through slippage.

If belts are overtightened, they will show excessive wear. The proper tension of a V-belt is the lowest tension at which the belt will not slip at peak-load conditions.

Synchronous belts (also called cogged, timing, positive-drive, or high-torque drive belts) are toothed and require the installation of mating grooved sprockets. These belts operate with a consistent efficiency of 98% and maintain their efficiency over a wide load range. Synchronous belts require minimal maintenance and retensioning, operate in wet and oily environments, and run slip-free. However, synchronous belts are noisier than V-belts, less suited for use on shock-loaded applications, and transfer more vibration due to their stiffness.

For V belts, torque losses are due to hysteresis losses incurred from bending stresses imposed as the V-belt goes around the sheave or pulley. There are also frictional losses at the belt/pulley interface, and windage losses as the belt moves through the air. Slip and belt creep will result in speed losses.

V-belts are quiet, clean, versatile, inexpensive, non-lubricated, and require low maintenance. For this reason their cost-effectiveness may surpass many other forms of power transmission (gears, chain).

V-Belts vs. Synchronous belt efficiency

Many efficiency questions deal specifically with the relationship between V-belts and synchronous belts.

Synchronous belts can offer a slight improvement in efficiency over the standard V-belts. This is due to lack of slip/creep component Ps in the efficiency equation (1). Another very small improvement is that they exhibit some reduced bending stresses Ph on small diameter pulleys (1) (2). Efficiency however, may be eliminated by mis-alignement (2). This term is indicated with Pm (Pmesh) that increases with misalignment along with wear. This fact equalizes the efficiency of V-belt and timing belts in practical "lightweight" applications.

$$\eta_{Vbelt} = \frac{P_{out}}{P_{in}} = \frac{P_{out} - (P_h + P_s + P_e)}{P_{in}} \quad (1)$$

$$\eta_{timing} = \frac{P_{out}}{P_{in}} = \frac{P_{out} - (P_h + P_m)}{P_{in}} \quad (2)$$

While synchronous belts offer positive engagement between belt teeth and pulley teeth, there exists a frictional when component as belt enters and exits pulley. This friction, although minimal, generates the energy losses Pm. Same is true of V-belts, however this term does not grow as fast as in timing belts with misalignment.

Additionally, slack side tension is present also on a synchronous belt drive. When transmitting a load, synchronous belts, like V-belts, operate at approximately a 5 to 1 tension ratio. Consequently, operating tensions and bearing loads are similar to those for V-belts. Another consideration is the added reliability of multiple V-belt drives.

All belt drives exhibit very high efficiencies when operating correctly. The quantification of efficiency ratings between different belt drive systems should be done with caution. One of the most difficult problems is the method by which efficiency is quantified in the field. Care must be taken to minimize the affect of drive variables. These include load, speeds, temperature of drive components, humidity, air density, wind velocity and others. Quantifying efficiencies is not easily done in a laboratory and is an even a more arduous task when done in field conditions [16]

NuVinci CVT (Figure-3)

An example of a commercially available system capable of Continuous Variation of the Transmission ratio (CVT) is the Nuvinci N360. This transmission has a mass of about 2.5 kg. This type of CVT is particularly interesting because the range of variation of the transmission ratio sufficiently large (360%). In this way the pedal is never too soft or too hard, so too abrupt steps in pedal loads can be avoided.

Figure-3. A hub-CVT based on the NuVinci idea.

Geared hubs

This system is somehow derived from automatic gearbox with epicycling gear. They doe not offer a continuous variation of the trasmission ratio.

Their efficiency is lower than the Nuvinci, since several gears pairs are used to obtain a single gear ratio.

The shimano alfine (Figure-4)

The Shimano Alfine series is an epicyclic hub gear. The internal mechanical design of the gear hub has two stepped planetary series, offering from 8 speeds up to 11 speeds. It integrates a ratcheting trigger shifter similar to the high-end Shimano classic derailleur, and a hub shell with splines for mounting a disc brake rotor. The mechanisms are grease-lubricated.

The maximum resulting overall gear range is 409%.

Electronic shifting is being also offered.

The weight of the hub is about 1.6 kg.

Figure-4. The Shimano Alfine 700 [17].

The Sturmey-Archer rotary-shifting 5-speed hub (Figure-5)

This new series of rotary-shifting 5-speed hubs has an overall range of 242%. The hub weight is about 1.5 kg. This geared hub is the oldest still on the market and has reached a good level of reliability.

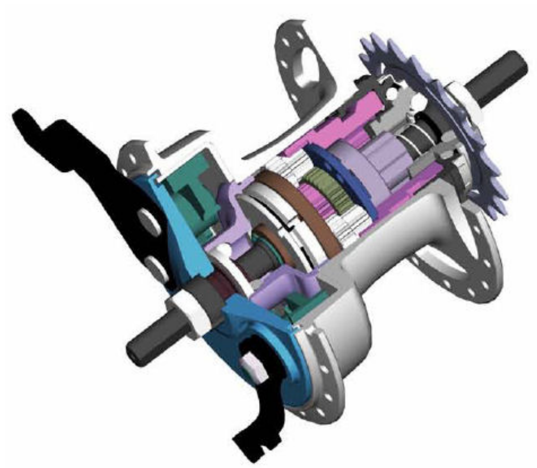

Figure-5. Cross-section of wide-ratio Sturmey-Archer five-speed hub [18].

The Rohloff hub (Figure-6)

Rohloff manufactures this 14-speed gear hub with a mass of 1700 grams. It has an overall range of 526%.

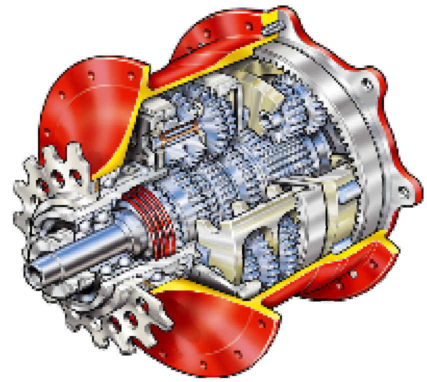

Figure-6. Internal Schematic of a rohloff speedhub 500/14 [19].

This geared hub features the widest transmission ratio available on the market in a single hub.

The new CVT system (see Figure-7)

This new systems is a computer controlled V-Belt CVT. Efficiency can be optimized by automatically adjusting the belt tension.

Two similar pulleys are inserted in the pedal and wheel hubs. This pulley is composed by four protruding arcs (N. 1 in Figure-7). The arcs are controlled by a powerful commercial servo-mechanism (2). This mechanism rotates with the wheel or the pedals. A radio command is continuously outputted from the ECU (Electronic Control Unit) of the commercial programmable remote control. This signal is decoded by the receiver in the hub (3) and rotates the four arms of the servo (4). Each arm of the servo is a cam that operates a roller (5). The roller (5) is linked to the V-shaped pulley arcs that are in contact with the V-belt. By opening the arms it is possible to vary simultaneously the belt tension and the transmission ratio. In this simplified version the oval shape of the pulley cannot be obtained. A more complicated version with two servos can be implemented in order to stretch continuously the wheel shape from a circular to an oval one.

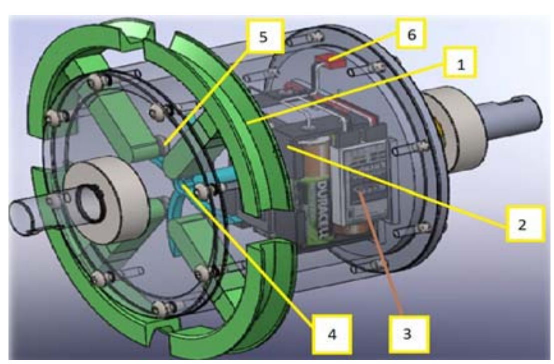

Figure-7. The new concept, this hub is installed both in the front (pedal) and rear (hubs). It is possible to control tension and ratio by moving the arcs (1). The system is controlled by a computerized commercial remote control.

The charging of the servos can be made through the plug (6). Servos autonomy is 8h.

The transmission ratio can be varied continuously from 0.64 to 1.54 (360%).

In alternative to recharging it is possible to install two generators of the type once used for night lights. The power required by the servo is a few Watts.

Advantages of the new CVT system on the classic derailleur

The main advantages are the absence of maintenance and the possibility to vary the transmission ratio continuously. The efficiency of this drive can be optimized if the load on pedals and the bike speed is measured by commercial remote sensors. GPS and internet maps can be used to acquire road vertical geometry. Tension can be controlled by moving outwards simultaneously the pulley arcs (1). It is also possible to measure the effective belt tension with sensors. However the elongation of modern V-belts at bike loads is negligible.

Advantages of the new CVT system

The main advantage is possibility to keep the transmission with the right tension (it is also be controlled by a fuzzy logic system [20-23]. In this way the efficiency can be maximized. Another advantage is the large availability of up-to-date commercial components that reduce drastically the number of custom parts to be manufactured.

Disadvantages of the new CVT system

The main disadvantage of this CVT system is that the V-belt should be protected from dirt and rain. A protection should be then implemented. A single arm arrangement like in scooters can be also implemented.

CONCLUSIONS

Technological advantages seem not to have been so important in bike racing. In fact the average racing speed in Tour De France has not varied significantly. The impression is that marketing has overestimated the true improvement of innovations. For this reason a new solution has been devised.

An innovative drive system for bicycle has been designed and optimized. This solution makes it possible to keep the efficiency to the maximum possible through transmission life. The system is maintenance free. It is also possible to implement more sophisticated solutions as oval pulleys. A major advantage of this solution is the outsourcing. Several commercial components are available on the market. The system is computer controlled and speeds, loads and road-vertical-geometry can be easily inputted through commercial sensors. Optimization strategies can then be easily implemented in the control software. For example it is possible to reduce the workload or to maximize the speed. The drive uses a V-belt CVT that achieves a good level of efficiency. This efficiency is kept constant to the optimum by software controlled active tensioning. The main shortcoming of this system is that this innovative transmission should be protected from dirt and rain. A single arm solution similar to motor scooter can then be implemented.

The overall weight of the system, belt included, is around 1 kg. The bike arm is not included.

Symbols

Symbol	Description	Unit
η_{Vbelt}	Vbelt efficiency	-
P_{out}	Output Power	[kW]
P_{in}	Input Power	[kW]
P_h	Power loss - hysteresis	[kW]
P_h	Power loss - slip	[kW]
P_e	Power loss - engage/disengage	[kW]
η_{Vbelt}	Timing belt efficiency	-
P_e	Power loss - mesh	[kW]

$$\eta_{Vbelt} = \frac{P_{out}}{P_{in}} = \frac{P_{out} - (P_h + P_s + P_e)}{P_{in}} \quad (1)$$

$$\eta_{timing} = \frac{P_{out}}{P_{in}} = \frac{P_{out} - (P_h + P_m)}{P_{in}} \quad (2)$$

REFERENCES

[1] http://bicycles.stackexchange.com/questions/7661/why-arent-tour-de-france-riders-going-any-faster.

[2] www.wileyeurope.com/college/tidd.

[3] L. Piancastelli, L. Frizziero, G. Zanuccoli, N.E. Daidzic and I. Rocchi. 2013. A comparison between CFRP and 2195-FSW for aircraft structural designs. International Journal of Heat and Technology, ISSN 0392-8764. 31(1): 17-24.

[4] L. Piancastelli, L. Frizziero, N.E. Daidzic and I. Rocchi. 2013. Analysis of automotive diesel conversions with KERS for future aerospace applications. International Journal of Heat and Technology, ISSN 0392-8764. 31(1): 143-154.

[5] L. Piancastelli, L. Frizziero and I. Rocchi. 2012. Feasible optimum design of a turbocompound Diesel Brayton cycle for diesel-turbo-fan aircraft propulsion. International Journal of Heat and Technology, ISSN 0392-8764. 30(2): 121-126.

[6] L. Frizziero and I. Rocchi. 2013. New finite element analysis approach. Pushpa Publishing House, Far East Journal of Electronics and Communications, ISSN: 0973-7006, Allahabad, India. 11(2): 85-100.

[7] http://blog.nomzit.com/2013/01/20/the-physics-of-pedalling/.

[8] http://www.rexnord.eu/fileadmin/Rexnord_Kette/PDF/Catalogue_Flyer/Auslegung_Kettentrieb_E.pdf.

[9] http://www.friction-facts.com/equipment/chain-full-load.

[10] James B. Spicer,* Christopher J.K. Richardson, Michael J. Ehrlich and Johanna R. Bernstein. On the efficiency of bicycle chain drives. The Johns Hopkins University, Baltimore, Maryland 21218, Masahiko Fukuda and Masao Terada Shimano Inc., Product Engineering Division, Sakai Osaka 590-77, Human Power Number 50, Spring 2000, Technical Journal of the IHPVA, International Human Powered Vehicle Association, IHPVA, PO Box 1307 San Luis Obispo, CA 93406 USA, http://www.ihpva.org.

[11] L. Piancastelli, L. Frizziero, S. Marcoppido, E. Pezzuti. 2012. Methodology to evaluate aircraft piston engine durability. edizioni ETS International Journal of Heat and Technology, ISSN 0392-8764, 30(1): 89-92.

[12] L. Piancastelli, L. Frizziero and I. Rocchi. 2012. An innovative method to speed up the finite element analysis of critical engine components. International Journal of Heat and Technology, ISSN 0392-8764. 30(2): 127-132.

[13] L. Piancastelli, L. Frizziero, E. Morganti and E. Pezzuti. 2012. Method for evaluating the durability of aircraft piston engines. The Walailak Journal of Science and Technology, Institute of Research and Development, Walailak University, ISSN: 1686-3933, Thasala, Nakhon Si Thammarat 80161, Thailand. 9(4): 425-431.

[14] Gates Carbon Drive Systems. http://www.carbondrivesystems.com/whycds.php?lang=us.

[15] http://www.reliableplant.com/Read/2418/selecting-drive-system.

[16] http://www.gates.com/facts/documents/Gf000188.pdf.

[17] Belt Drive Efficiencies. PA NOTE GatesFacts™ Technical Information Library, Gates Compass™ Power Transmission CD-ROM version 1.2, The Gates Rubber Company Denver, Colorado USA.

[18] http://www.auntiehelen.co.uk/tag/alfine-11/.

[19] http ://www.sheldonbrown.com/sturmey-archer_5-spd.html.

[20] L. Piancastelli, L. Frizziero, E. Morganti, A. Canaparo. 2012. Fuzzy control system for aircraft diesel engines. edizioni ETS, International Journal of Heat and Technology, ISSN 0392-8764, 30(1): 131-135.

[21] L. Piancastelli, L. Frizziero, S. Marcoppido, A. Donnarumma and E. Pezzuti. 2011. Fuzzy control system for recovering direction after spinning. International Journal of Heat and Technology, ISSN 0392-8764. 29(2): 87-93.

[22] L. Piancastelli, L. Frizziero, S. Marcoppido, A. Donnarumma and E. Pezzuti. 2011. Active antiskid system for handling improvement in motorbikes controlled by fuzzy logic, International Journal of Heat and Technology, ISSN 0392-8764. 29 (2): 95-101.

[23] L. Piancastelli, L. Frizziero and E. Pezzuti. 2014. Aircraft diesel engines controlled by fuzzy logic. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608. EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA. 9(1): 30-34.