LINE-GO
A Linear Driven HPV Design Family

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Summary

I present my view of how **the linear drive train adapts to the human motor.** comprising: • Linearly and near-linearly moving pedals • A linear chainless highly efficient drive train • Continuous step-less gear-ratios. The LINE-GO family of bikes was developed with the user in focus. To prevent bike theft and to facilitate using means of collective transportation together with bikes, the designs include examples of: • Foldable frames • A Self-supporting foldable canopy. Including • Seat developments • A minimal slip differential • Suspension • Alternative steering wheel bearing and support • An all mechanical servo assisted minimal disk-brake system, the versatility of the project land with • Bike lay-outs and • Scooter lay-outs. • Recumbent trike lay-out with • Height-adjustable seats. To keep up the value of the folded bike: • Small diameter wheel phenomena were looked upon. • Producer, Retailer and User-friendliness, depend on • Reliability, potentially designed into, by a high degree of simplification. **A short chronological list of my bike project** couples the past to the present, as do some **ancient and modern linear drive configurations**

A couple of hardware prototypes will be presented with pictures and drawings and comments to the above, with outlines to further development to suite challenged athletes as well as ordinary athletes.

The linear drive train adapted to the human motor

The two different types of drives, LINEAR and CIRCULAR, are appointed names in regard of the way the feet move. The traditional circular drive with cranks, forces the foot to follow a circle, in a cadence set by the speed and gearing.

The linear drive-train principle is really simple. A rope unwinds with the pedal force from a line wheel, which transmit the torque over a freewheel clutch to the drive axle. When the pedal is retracted by will, the rope winds up back on the line wheel by a rubber band, in a winding direction opposite to the rope.

With a linear drive, it’s possible to have a left and right foot cadence, as well as the preferred step length, independent of the speed.

With a linear drive, the entire working step length, is equally efficient, in opposition to the circular drive case, where efficiency is angular and co-ordination dependant.

With a linear drive, it is feasible to have a continuously and step-less change of the gear ratio during the working step, with a low gear ratio at the beginning, and a high gear ratio at the end.

The high angular momentum of the leg, as it reaches its stretched position, is a problem encountered on ordinary bikes, and possibly even more so, on linear driven bikes (1). This is usually come around on a circular drive, by either lowering the cadence or decreasing the distance from the seat to the crank (2).

Co-ordination of the force direction is a great efficiency factor (3). On a circular drive, this is left to the leg apparatus, developed by nature through walking and running, to adjust its force vector to the rotating trajectory of the crank.

On a linear drive, there is a need for either a dead stop, adjusted to the length of the leg, or a steep increase in gear ratio. The second opens up for a better use of the output from the motor, as the force direction remains and the momentum energy is put to use. I have found that a final Ggear ratio, at the end of the working step, of about 14 does that.

With a linear drive there are fewer constraints to the human motor.

The phantom of the linear drive

There is the possibility of extreme gear-ratios, efficiently put to use in a linear drive train. Why isn't the world full of them?

Gearing consists of three principles.

One being the diameter change on the line wheel, as the rope unwinds (4). This is a action close to the cam-roll or eccentric rolls, making the diameter change faster.

The other I would like to call the bow-line gear: A straight rope will give very high loads at its ends, when a force perpendicular to the rope acts on the middle (5).

The third gearing element is the ordinary built in ratio: The diameter of the wheel, divided by the diameter the rope acts on.

Together these three gearing element make up the total gear ratio by multiplying. I prefer to call it the generic gear ratio, Ggear. This is free from cog-inches.

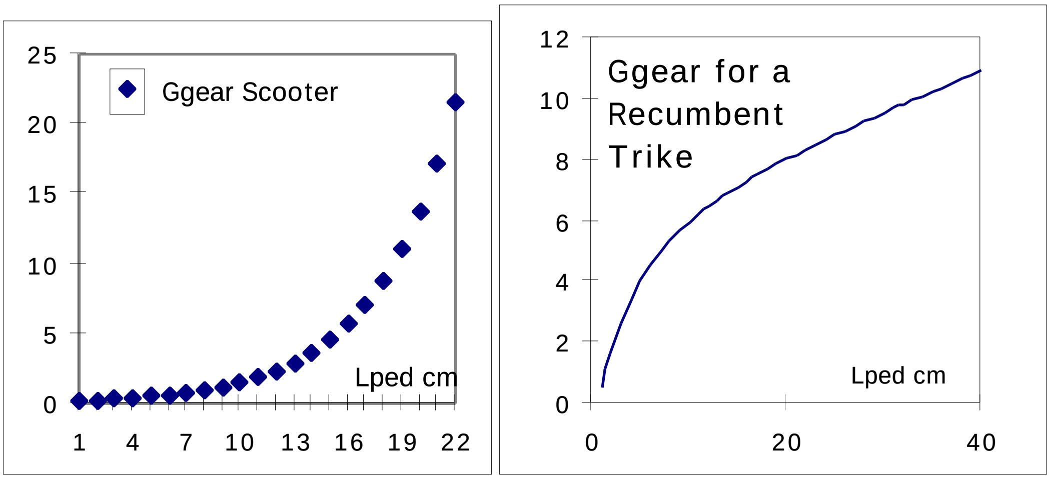
It needs a generic gear ratio (Ggear), to be able to compare linear and circular drives. Ggear is the rolled out length of the wheel (Lroll) over the length the pedal has moved (Lped).

Hence,

$$\frac{\text{Lrolled}}{\text{Lped}} = \text{Ggear} . \qquad \text{equ 1}$$

Here the Lped is either along the curved line of a circular drive, or the travelled length of a linearly moving pedal. For comparison, the Ggear of a 21 geared bike with 26" wheels, range from 1.75 in the lowest gear to 7.5 in the highest gear.

On an ordinary upright bike with a linear drive, the automatic Ggear ranges available, easily become impressively high, with Ggear from 0.5 to 16.



Computed generic gear ratios, Ggear, with widely different characteristics.

A one-size-fits-all dream-design is closer with a linear drive without a dead stop.

With a linear drive, there is less support than with a circular drive, for a situation where the rider wants to make a jump standing on the pedals.

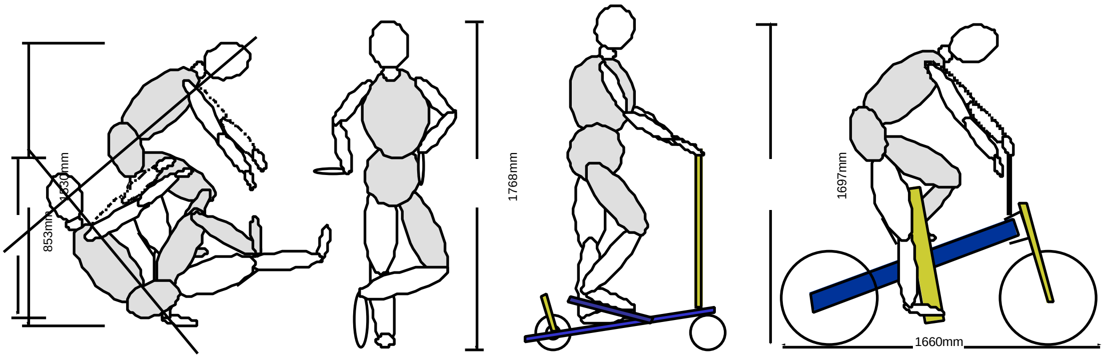
The linear drive was invented more than 100 years ago, and has a great history (5) (6). A design, comprising all three gearing principles, was granted a patent to B. Ljungström in 1897 (8). The story has it, it became the SVEA bike. There were built about 3000 of them. It was technically more complicated than other bikes, and maybe it priced itself out of the market. The project was sponsored by Alfred Nobel. The SVEA bike is today exposed at the Stockholm Technical Museum. It was of a third type, basically a linear drive train, but with pedals moving reciprocally along a circle line. This kind of drive train design, can be made for ordinary upright bikes and for a standing driver operated, scooter look-alike two wheeler design (7), as well as for a velomobile (9). I have no record of what became of them. I would like to see them work.

I have adopted different drive trains of my own invention, to different bike and trike designs, and I did not find any major restrictions to the linear drive philosophy. The research in the patent literature, was made afterwards. Where these to complicated or simply didn't last long enough.

Wear and fatigue are highly designable and will surely find several solutions. Modern materials may be the difference. For example are polymer fibre ropes better suited for linear drives than steel wires are.

Some weight is saved by replacing cranks, chains and sprocket wheels, with rope, rubber cord, delrin line wheels and rail bound, low weight pedals.

The effect of the posture

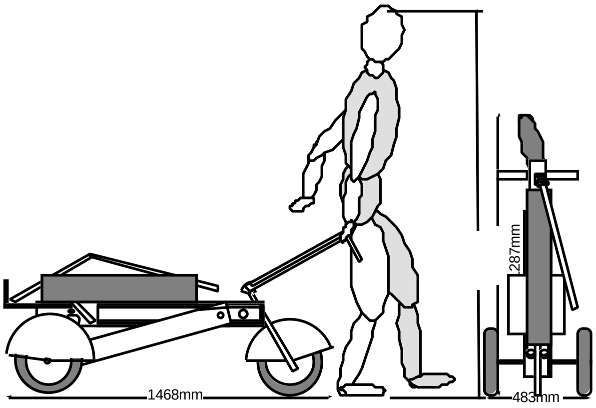


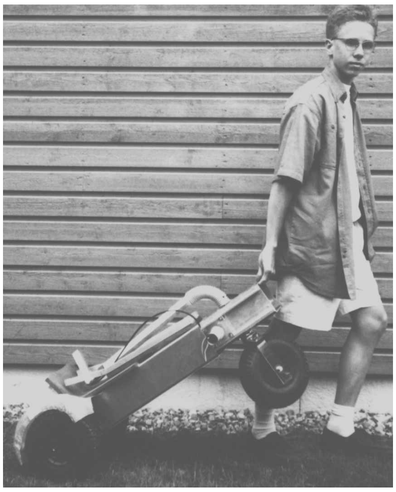
The body posture has a profound effect on the design of a bike. It affects the aerodynamic drag, the speed, the comfort, the balance of the vehicle, how injuries develop during an accident, the first impression starting social interaction with other people and road users. To satisfy the user, the variety of factors result in different designs for different user preferences.

When attempting to fit my linear drive train to different kinds of working postures, I end up with designs for : A traditional up-right linear-drive bike, a pedal driven scooter and recumbent two- or three- or four-wheelers of different heights, driven by the front or rear wheel(s). Some easier to use, and other easier to make. Not all presented here. Some designs may be driven either by foot or by hand.

I find it necessary to test in real life these designs, to feel the difference of the new designs in comparison to existing ones. Technical assessment can only be a first start.

The foldability difference

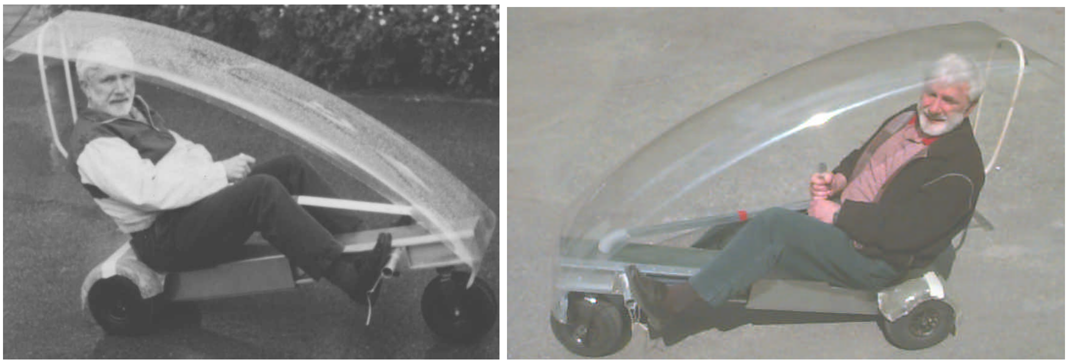




I have tried to find out what the user value of a bike that can be folded really is. To guarantee the accessibility of a bike, in my opinion, one has to bring it along. To do so, it has to be light, small and fast folding. It has to be very safe against ”auto-folding”. The luggage should best be left on the folded bike, to avoid the item multiplicity problem to the ordinarily limited number of hands. Awkward lifting postures are to be avoided, and rather rolling the whole thing should be quite easy, even up the stairs. Drive lube and dirt encapsulation needs designer attendance. The preferred method to fold, is in my opinion, to slide a tube into an other, and lock them with two bolts. A joint of this type is simple to make and its strength is easy to calculate.

The Swedish MicroBike and the British Strida, both have toothed belt drives, and very fast ways of folding and unfolding. That makes them suitable for bringing them on a bus or a commuter train. They are both very unsuitable to lock outside a building, but rather handy to bring inside, hopefully out of reach for bike theft. They can both be stowed away or hung up inside a coat. I can see the limited applicability of this, but until some critical mass is acquired it’ll probably work.

A come-rain-come-shine-canopy



Tailwinds are very rare for bikers, depending on the fact that the bike speed vector adds to all winds. Instead the most common wind direction to a biker, is an apparent head wind. Only a bent bikers will be meaningful to protect with a windshield, and it had better be foldable. Here bent could mean both forward over a triathlon tiller bar and recumbent. Friedrich Gauss (1777-1855) described a sphere in a fruitful way as two perpendicular bending radii in a constant relationship with each other, the Gaussian curvature K.

Hence,

$$\frac{1}{R1} * \frac{1}{R2} = K\,. \qquad \text{equ 2}$$

This formula also describes the best approximation of the shape, that a double bent sheet of plastic elasticly will conform to when forced to bend. This means that a half sphere can be rolled together to a near cylindrical shape, and as long as the deformation is within the linearity limits of the material, it will spring back to its original shape whenever left to do so. The preferred shape will be the one a thermoplastic sheet was cooled into after heating. This could be either of the to shapes rolled in or rolled out, so to speak. This is the philosophy behind the folding canopy, which was cooled into the rolled in shape.

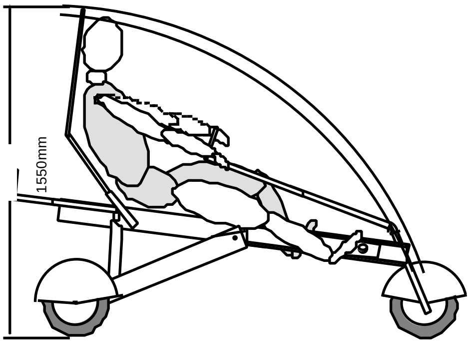
When stretched out in its rolled out shape, it stabilises itself and can work as a canopy. The surface treatment needed to have enough visibility when rained upon is yet to be applied.

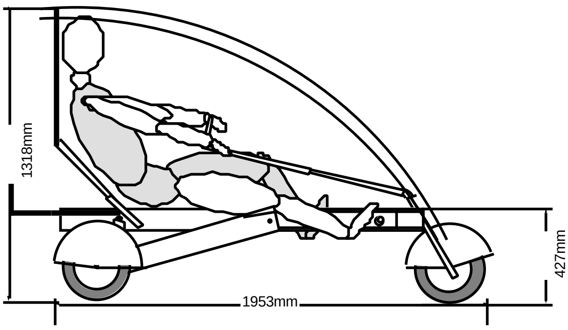
Brakes

A braking apparatus has to be compact, especially when built into a weather protected part of a compact foldable trike, with the driving wheels mounted on a driven axle, as on go-carts. That makes up for the choice of a disc brake. Unamplified hand power, as transmitted through a braking wire, is far from enough to act directly onto a tiny disc of 90 mm diameter. I designed ”self energised” brake pads, with the extra clamping force coming from the mechanical servo, consisting of one slightly moveable brake pad, with a parallelogram type of swing, caused by the rotating disc. The moveable brake pad is held by a pivoting pair of bolts, clamping the pads together. If contact between pads and disc is established before the pivoting bolts have come to a certain angle, here called A, the brake will come to a dead stop, due to the clamping forces do grow more rapidly than do the dragging forces braking the disc. Above a certain angle, called B the servo effect is almost negligible. With pads being of sole leather and the disc of aluminium, A is 10 ° and B is 30°. There has to be a strong spring to retract the sliding pad, and the wire and handle.

To avoid a pronounced fade of these tiny braking surfaces, they have to be ventilated and cooled by holes. They also have to be thermally isolated from heat sensitive parts like bonded surfaces and plastics.

Ups and downs, a magic spell





When sitting in a recumbent position, a low seat is, to some potential riders, uncomfortable coming in and out of, and by others regarded as unhealthy and unsafe in traffic interaction. Some people may even regard a low supine posture as a bodily language sign of social inferiority. To women in particular, legs above the seat is a non preferred posture. If it is possible to heighten the seat, it also may leave room for an ample storage underneath. I hope a feature like this may be regarded as a valuable option by different people with changing needs. Therefore I made different designs, that are possible to change, from a supine position in a head wind, to a high upright position for carrying goods.

Suspensions for comfort and hardware protection

Bumps in the road may cause overload on structural elements. Sitting down in a recumbent position gives the rider no way of avoiding the vertical accelerations of a bump. Sitting directly above a wheel axle is far worse than in between two axles, which reduces the centre of gravity movement to half the bump height.

A pair if blade springs has been tested with very good results, designed for giving a parallelogram type of action, sustaining three times the static load. They are fairly strait forward to calculate from a cantilever beam formula, but strain concentrations from combined loads are not simple to estimate or to come around. In polycarbonate, stress concentrations superimposed on the stress level at 90 % of a calculated rupture stress, repeatedly led to failure. Fibre composite materials are better suited for designing around a strain concentration problem. Composites need tooling and processing care to avoid resin rich areas with a low fibre content. A rubber cushion type of spring under the seat, in conjunction with the blade suspension, gave a remarkable feed back by the resonant phenomena of a wash board between the two suspension systems. I conclude that they are very similar in action and can be interchanged. For simplicity the rubber type of suspension is highly preferred.

Sitting is a noble art for noble parts

I have had a profound personal interest, from an acing back point of view, to try to understand, how a seat interacts with a human body. A major experiment, became moulding a fibreglass polyester sandwich seat, with an integral carbon fibre weave facing on one side and a polyethylene foam on the other, to the shape of my body as positioned in a selected armchair. I drew several conclusions from that experiment.

- First, a functional shape does indeed replace, the suspended action of the cushioned fillings of an armchair, with second to none comfort.

- Second, the vertical centreline of the mould, from below my shoulders to just above the seat, is indeed a straight line.

- Third, the 13 mm thick polyethylene foam, with a Shore A indention value of 25, which equals the value of all persons buts I have measured. It does indeed prevent a soar but when sitting hole days on a flat wooden chair.

- Fourth, the angle of comfort, between a flat, hard, horizontal seat and a flat, hard back support is very close to the small span of 120° to 130°.

Fifth, the spine and hip bone need support from a harder cushion filling than available in a cushioned seat, and the support is not to be transferred through the soft tissues of the waist. The polyethylene foam give enough support.

This all adds up to understand why sometimes a hard seat with an appropriate shape gives better relief to an acing back than does even a bed. The but tissue is best of when calandered no harder from the outside than from the inside.

Where does energy go in small wheels?

Small diameter wheels are prone to stumble over obstacles. On soft ground, like a lawn or a gravel faced pedestrian path, they dig steeper holes to come out of than larger wheels do. I think this is the main reason for big wheels. A folded bike with big wheels however is to bulky. Bike wheels have for long been preferably large, until sir Alec Moulton combined a small wheel diameter with a suspension. The Dunlop invention of the pneumatic tyre gave rise to a new type of rolling resistance that is to day fairly often misinterpreted, though the Michelin brothers did invent a good solution to one part of the problem with their radial carcass tyre.

A plea for good bicycle tyres have been heard before and is still to be emphasised for small diameters. One major problem is said to be the low priced import giving developers no margin between the cost for materials and ready available tyres on the market. I think there is a technical approach with patents and profits awaiting for a truly dedicated developer.

The rolling resistance when no power is transmitted, as measured by Ian Sims Australia, give to faint a difference between tyres, to make up for the sensation of power drain when going uphill, changing from a racing bicycle to a mountain bike or a small diameter wheel bike. Does size really matter this much? I think not, because the sensation is the same if only tyre pressure is lowered.

The missing link may be the power transmitted from the drivetrain through the pneumatic tyre to the ground. It has to be transformed into stresses in the tyre carcass, and in my opinion, these stresses tend to return the deformed cross-section to the toriodal shape. Meaning, the tyre cross-section flattened towards the ground, is deformed back to a round shape by the stressfields in a diagonal carcass, producing a redundant work-out equal to squeezing a tennis ball. This can be designed away in three ways.

- One being a radial orientation of the filaments together with circomferential filaments building up the carcass, whereby the tractional filaments are separated from the filaments deformed by the ground.

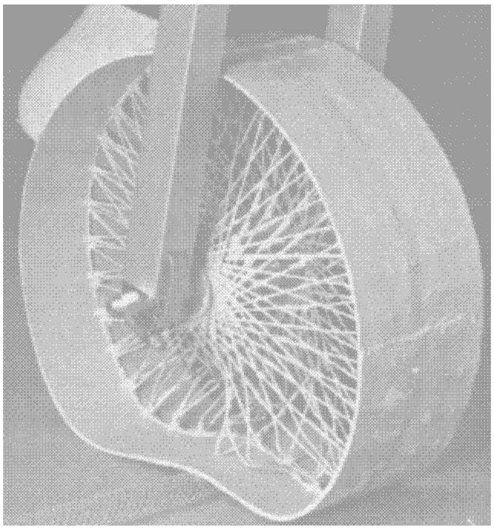
- The other, being a more wide shape of the tyre cross-section, seen on modern racing motor bikes, with a rim width to tyre height ratio slightly above one.

- Hence $$\frac{\text{Wrim}}{\text{Htyre}} \geq 1. \qquad \text{equ 3}$$

This could also be accomplished by simply putting an ordinary tyre on to a wider rim, which however is hard to find. This ratio has a value close to one for very thin racing push bike tyres and less than 0.4 for mountain bike tyres. I think proportion matters more than size uphill. I have not been able to test this hypothesis.

- Third, the rubber compound, inherited from the car tyre industry, where damping is favoured, could be switched to a blend with a greater bouncing factor, leaving more of the deformation energy to be elasticly recoverable.

A possible all composite wheel has been made, to show the that it could be done. Soft spokes from Kevlar in Polyurethane matrix broke, after that they had been repeatedly bent at the rim.



The picture shows a prototype all composite filament wound wheel, when loaded across a cable in a softened state, by closing the hubs to each other. Climbing capability enhanced by the elastic deformability and an inherent suspension.

Friendliness to all users

- Users are manufacturers emphasising simplicity and reliability of parts and assemblies and a high through put on a production line and an expected high revenue on the investment.

- Users are also the transportation team of the gods and they have to give a high yield of sellable merchandise.

- Users are retailers, who don’t want to keep voluminous goods in store, or spend to much time on a final assembly, or getting customers complaints for broken or bad parts. But a high price they want.

- The buyer and final user will settle for nothing less than the highest value and joy for their money. And that’s final!

- Whether a design meets all these demands remains to be worked out. A small package with a ready-to-fold-out-and-go-bike, with a design added value of usable and easily maintained features and looks, may prove to be a major ingredient to a wider use of human powered vehicles.

Reliability in design with simplicity in mind

The drivetrain pulley can be a chain, a wire, a belt or a rope. The free-wheel clutch is needed for each line wheel. All bearings can be sealed. I have chosen a reciprocating way of action which need a rewind. The rewinding mechanism can be a clockwork spring, but I have chosen a rubber cord. The whole design would become simple to maintain, if standard elements are simple to change.

The framework is chosen to be in anodised aluminium for the prototypes, but the original design concept was in composite materials. An over-all low weight is contributed to by the choice of materials and greater cross-sections, whereby the stress levels are held down. This contributes to better security margins against mechanical failure, at the penalty of a slightly higher weight. The uncertainty of what the actual loads are in use, have been scrutinised by calculating backwards on existing bikes, which seem to converge to a safety margin for steel parts of only 1.25 over the ultimate load bearing capacity.

The steering system design for a foldable trike can be utilised having different approaches. Better than the steering wheel with a telescopic square tube and a universal joint, are the double pulley ropes, that seems to give a better feel. Direct steering certainly is preferable, but it is harder to combine with the foldability. I wanted however to test other solutions.

A steering wheel king pin made up by a couple of threaded nuts and a threaded bolt works fine when graphite grease lubricated. Almost as good as the traditional bike steer ball bearing unit. For trikes the threaded bolt and nut is quite adequate.

A possibly major draw-back from a life-time expectancy point of view, are the linearly moving pedals. The linear pedals are delicate components, heavily loaded and prone to wear and fatigue, and so is the rail they run in. The pedals have some similarity to in-line roller skates. After some 13 generations of trial and error in design, they now seem to work satisfactory, but they can be further improved.

A plurality of ball bearings are inevitable in a linear recumbent design, but they are readily available and reliable.

All plastic line wheels though have to be manufactured with close tolerances to press fit appropriately on to the bearings. They have all been laced from delrin and nylon for the prototypes.

Joints between load carrying members in aluminium, have preferably been made with bolts and nuts to avoid the uncertainty a prototype welded joint. Some joints have been epoxy bonded, for example the box beam with the special profile for the pedal rail.

A short chronological list of my bike project

My interest in velomobiles started about 1983, as an intellectual hobby. I became interested, because a friend of mine was devoted to biking. He did not buy my suggestions for technical improvements, for example to spare the wrists by transferring the upper body weight to the tiller bar with the elbows.

In 1987 I grasped one universal part of the complex, the wheel. I designed and made a filament wound, all composite, no flat tyre, with adjustable hardness, and was granted a patent for the patent application (10).

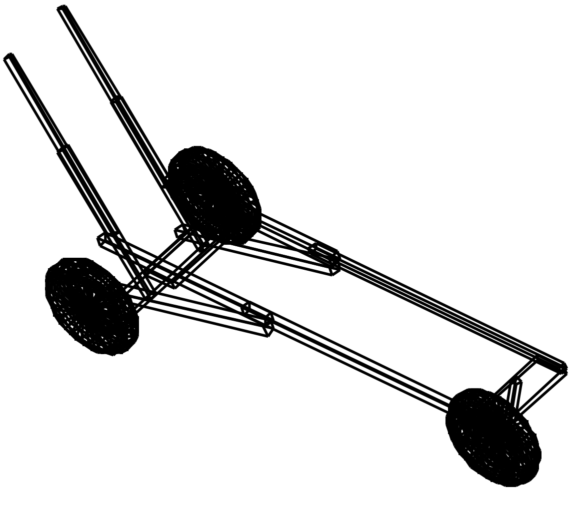
In 1992 I went on with the drive train, by studying the human motor capacity, and how it was geared up on bikes, and I was hooked on the linear drive idea, as a technical challenge.

In 1993 I built my first recumbent, linear driven, all composite bike with the seat moulded to the shape of my back. With a constant Ggear of about 6. It became a test bench for so many technical solutions, that it did not also work as a bike. So I bought a foldable Micro Bike with a toothed belt from crank to wheel.

In 1994 I built my first linear drive, recumbent, all aluminium, box beam, foldable, delta trike with suspension, 206 mm barrow wheels and joy stick steer. It barley worked for test rounds. Pedal and rail wear was tested with different materials.

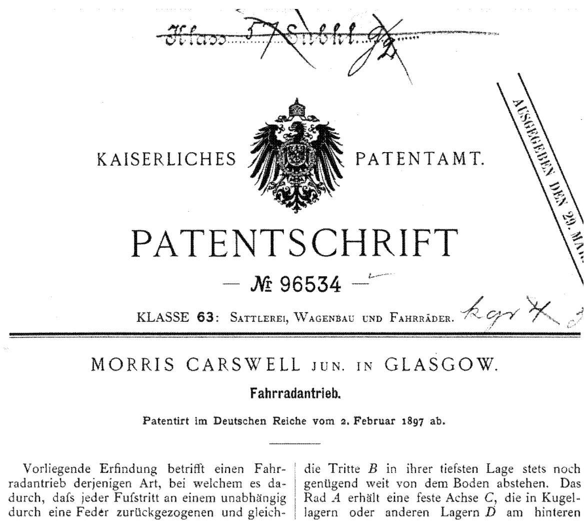
Since 1995 I have been busy improving things, trying to make the hardware as durable as bikes are. I have made computational modelling, tensile, bending and rupture testing on details and joints, establishing a feel for what will work, and taken the different prototypes on test rides commuting 7 km. I entered three contributions to the Danish Design Contest, one being a trike, with only some faint feed back.

I attended the IHPVA events in Holland 1996 and Cologne 1997 and was further encouraged on my perception of the HPV idea.



One of my CAD sketched Trikes

Ancient and modern linear drive configurations



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AUSGEGEBEN DEN 29. MAI

KAISERLICHES PATENTAMT.

PATENTSCHRIFT

— № 96534 —

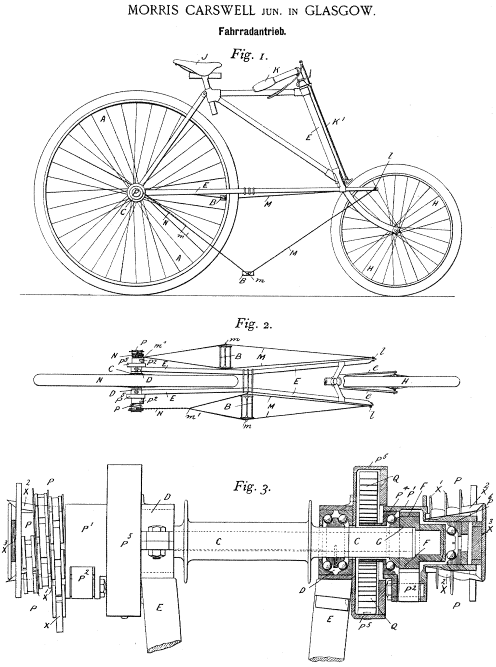
KLASSE 63: Sattlerei, Wagenbau und Fahrräder. kgr 4

MORRIS CARSWELL jun. in GLASGOW.

Fahrradantrieb.

Patentirt im Deutschen Reiche vom 2. Februar 1897 ab.

Vorliegende Erfindung betrifft einen Fahrradantrieb derjenigen Art, bei welchem es dadurch, dafs jeder Fufstritt an einem unabhängig durch eine Feder zurückgezogenen und gleichdie Tritte B in ihrer tiefsten Lage stets noch genügend weit von dem Boden abstehen. Das Rad A erhält eine feste Achse C, die in Kugellagern oder anderen Lagern D am hinteren



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PATENT № 8392.

BESKRIFNING

OFFENTLIGGJORD AF

KUNGL. PATENT- OCH REGISTRERINGSVERKET.

A. F. A:SON ROXENDORFF,

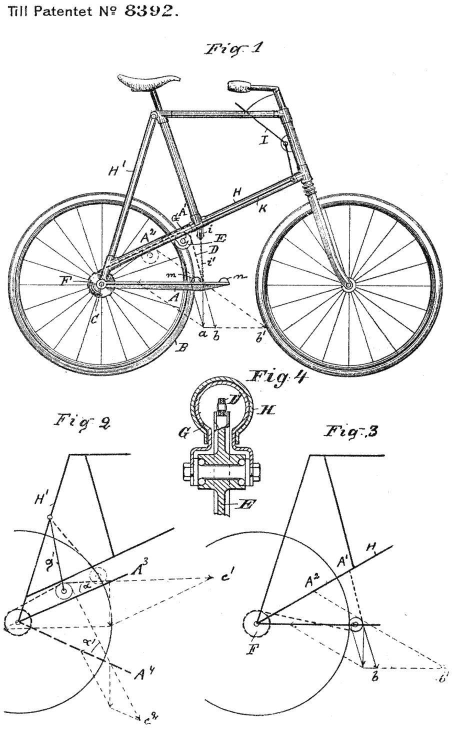
PARIS (FRANKRIKE).

Drifanordning med föränderlig kraftutvexling vid velocipeder och andra åkdon.

Patent i Sverige från den 11 september 1896.

Uppfinningen afser några till kraftutvex-

skjutning kan åstadkommas på olika sätt, t. ex. medelst en häfstång I, som är förenad med



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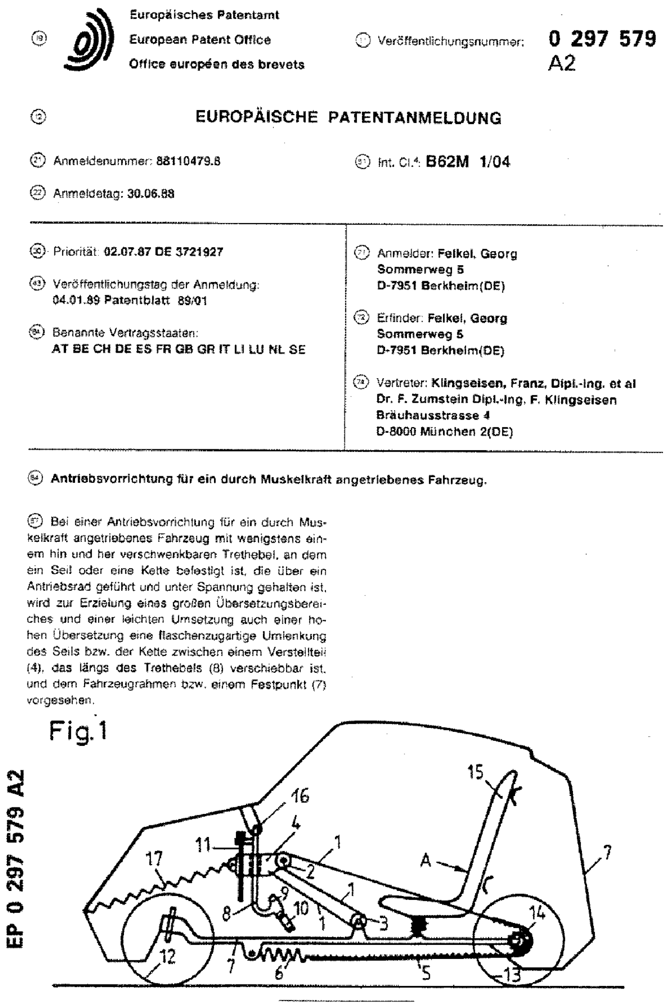

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(54) **Antriebsvorrichtung für ein durch Muskelkraft angetriebenes Fahrzeug.**

(57) Bei einer Antriebsvorrichtung für ein durch Muskelkraft angetriebenes Fahrzeug mit wenigstens einem hin und her verschwenkbaren Trethebel, an dem ein Seil oder eine Kette befestigt ist, die über ein Antriebsrad geführt und unter Spannung gehalten ist, wird zur Erzielung eines großen Übersetzungsbereiches und einer leichten Umsetzung auch einer hohen Übersetzung eine flaschenzugartige Umlenkung des Seils bzw. der Kette zwischen einem Verstellteil (4), das längs des Trethebels (8) verschiebbar ist, und dem Fahrzeugrahmen bzw. einem Festpunkt (7) vorgesehen.

Fig. 1

EP 0 297 579 A2

(9)

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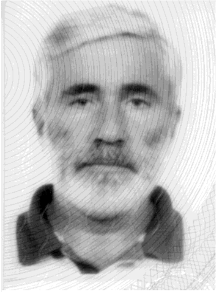
(10)Swedish patent application 8801421-2 from Anders BRAGE Sollentuna Sweden 1988



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