HUMAN POWER

TECHNICAL JOURNAL OF THE IHPVA

NUMBER 53, SPRING 2002

Number 53
Spring 2002

$5.50

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Number 53 **Spring 2002** **$5.50/IHPVA members, $4.50**

HUMAN POWER
is the technical journal of the
International Human Powered
Vehicle Association
Number 53, Spring 2002

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Human Power (ISSN 0898-6908) is published irregularly for the International Human Powered Vehicle Association, a non-profit organization dedicated to promoting improvement, innovation and creativity in the use of human power generally, and especially in the design and development of human-powered vehicles.

FROM THE EDITOR

This issue of *Human Power* is a bit different. David Gordon Wilson has asked me to take over as editor at least for a while, as he is involved in starting a company building small gas turbines and in completing the third edition of *Bicycling Science.* Dave Wilson has made *Human Power* into the world's premier technical journal on HPVs, (including HPBs, HPAs) and also some stationary applications of human power. If there were a knighthood for human power, he would deserve it!

I would like to broaden our scope to include articles to do with the philosophy of human power. There are two reasons for this. Firstly, we are getting less material than before as HPV physics become more and more specialised; and secondly, the status of human power in society is a precarious one and we need to give it all the support we can in order to improve the quality of life in present and future societies. Please send your articles and letters.

Human Power continues to be produced by Jean Anderson and John (Elrey) Stephens of the HPVA. It is sent to HPVA members together with *HPV News* (now edited and produced by Peter Eland of *VeloVision*) and is available for subscription to all other IHPVA members at reduced rates.

A brief introduction

I am 48 and live with my wife in an old house in the foothills of the Bernese Alps near Lake Thun. It's full of parts from human- and solar-powered vehicle and boat projects. I grew up near Mount Tamalpais in California, where mountain biking started, and studied in Basel and in hilly Wales and England, where I was introduced to HPVs.

Jason Patient

My own projects have mostly been human-solar hybrid vehicles and boats and formerly racing these in the Tour de Sol. These have always been either easily transportable or semi-amphibious in order to tour without being car-dependent. I'm vice president of Future Bike Switzerland, where one of our specialties is organising races for HP rail vehicles.

—Theo Schmidt
Steffisburg, Switzerland

Contributions to Human Power

The editor and associate editors (you may choose with whom to correspond) welcome contributions to *Human Power*. They should be of long-term technical interest. News and similar items should go to *HPV News* or to your local equivalent. Contributions should be understandable by any English-speaker in any part of the world: units should be in S.I. (with local units optional), and the use of local expressions such as "two-by-fours" should be either avoided or explained. Ask the editor for the contributor's guide (available in paper, e-mail and pdf formats). Many contributions are sent out for review by specialists. We cannot pay for contributions. Contributions include papers, articles, technical notes, reviews and letters. We welcome all types of contributions from IHPVA members as well as from nonmembers.

Comparison of measurements of bicycle spoke tension using a mechanical tensiometer and musical pitch

by John S. Allen

Abstract

The tension of 140 spokes in four bicycle wheels was measured using a tensiometer—a mechanical device designed to measure spoke tension—and by plucking the spokes like harp strings and determining their tension using the standard formula for the fundamental frequency of vibration of stretched wires. The measurements by the two methods were compared. When spokes were laced such that they touched each other, the musical measurement was of the average tension of a laced pair, and so there were 93 rather than 140 musical measurements. Tensiometer measurements of laced spokes were averaged for comparison with the musical measurements.

Both types of measurements proved accurate enough to use in establishing the correct tension of spokes when building bicycle wheels. The function relating the measurements conducted using the two methods is linear and consistent, though there was some discrepancy between the results. Each method proved to have strengths and weaknesses related to convenience, which will be discussed.

The wheels used in the investigation

The tension of the 140 spokes of four bicycle wheels was measured. The wheels were:

- A 622 mm, 40-spoke dished rear wheel with 14 gauge (~2.0 mm diameter) plain gauge spokes on the right side and 14/16 gauge butted spokes on the left side (~1.6 mm diameter over most of the length, ~2.0 mm near both ends); both sides quadruple-crossed, spoke length 296 mm.
- A 630 mm, 36-spoke wheel with 14/15 gauge (~1.8 mm diameter) butted spokes on both sides. One side is laced triple-crossed and the other is laced radially. Spokes on both sides are 296 mm long. (Same length despite the difference in pattern because the hub flanges are of different sizes).
- A 451 mm, 28-spoke wheel with 14-gauge (~2.0 mm diameter) spokes, double-crossed, not laced, 215 mm. This wheel had a steel rim and a very wide range of spoke tensions.
- A 406 mm 36-spoke wheel with 14/15 gauge (~1.8 mm diameter) spokes, triple-crossed, 183 mm.

Using wheels with different spoke lengths, patterns and tensions made it possible to determine how these factors affected the relationship between the tensiometer measurements and musical measurements.

The musical method

The fundamental frequency of vibration of a stretched string or wire varies according to the following equation, assuming small amplitudes [1]:
where

F^1 = the fundamental frequency [Hz]

$$F_1 = \frac{1}{2L}\sqrt{\frac{T}{m}}$$

L = the length of the string

T = tension of the string

m = mass per unit of length

This resolves to $T = 4\,F_1^2\,L^2\,m$ which is used to calculate the tension from the measured frequency.

The cross-sectional area of the spoke and the mass per unit length m are exactly proportional to each other. Therefore, for two different strings or wires of equal length, one thick and another thin, the frequency is the same if the tension per unit of cross-sectional area is the same. One way to think of this is to imagine two identical spokes side by side, both of the same gauge and at the same tension. They vibrate at the same frequency. Now imagine lightly connecting them together all along their length. They still vibrate at the same frequency. Finally, imagine merging them into one, thicker spoke. It still vibrates at the same frequency.

These facts greatly simplify the measuring of spoke tension for wheel builders. To determine whether a spoke is optimally tensioned, we don't have to measure the thickness or, what is more difficult, the tension, since the musical pitch translates directly into the tension per unit of cross-sectional area.

Note that the fundamental frequency of a spoke increases only as the square root of tension. Therefore, every doubling of frequency—one musical octave—raises the tension by a factor of 4. A spoke whose fundamental frequency is only 1.2 times as high as the value given in the table—a musical minor third higher—is already under more than 1.4 times as much tension, and is likely to fail quickly.

Bicycle spokes rarely break due to excessive tension; but the rim may not withstand it, and when the rim relaxes around the spoke holes, the wheel fails. Weight loading on a wheel decreases tension of the few spokes at the bottom of the wheel greatly, and raises tension of the remaining spokes only very slightly, but lateral loading while pedaling out of the saddle causes significant increases in spoke tension and can lead to rapid failure of an over-tensioned wheel. On the other hand a common error in wheel building is to leave the spoke tension too low, resulting in a weak wheel, since spokes go slack under smaller loads, and fail to hold the rim steady. The excess motion in a slack wheel is what breaks the spokes and allows the nipples to unscrew.

As the thickness of a wire increases, our equation for musical pitch becomes slightly inaccurate because the greater bending stiffness adds its contribution to the stiffness generated by the wire's tension. The discrepancy is not large and only amounts to a few percent. Table 1 includes a correction which I

Table 1.

Length (mm), plain	Length (mm), butted	Musical pitch
308		F#
292		G
276	308	G#
262	292	A, 440 Hz
248	276	A#
236	262	B
224	248	C
212	236	C#
201	224	D
191	212	D#
181	201	E
172	191	F
163	181	F#
156	172	G
147	163	G#
	156	A

determined empirically by measuring the musical pitch of tensioned spokes clamped off at different lengths.

Part of a spoke at the outer end is inside the spoke nipple, and part at the inner end is in contact with the hub. These parts do not contribute to the vibrating length. The table also accounts for this. The ends of a butted spoke are sufficiently thicker than the shaft of the spoke so that the ends contribute only slightly to its effective vibrating length. This, and the greater strength at the threads and head of a butted spoke, account for the higher musical pitch recommended for butted spokes.

The yield strength of good steel is about 150 000 pounds per square inch or 1 040 N/mm^2, and the tension recommended in the table is $^1/_3$ this—about as high as you can take the tension and still leave an adequate margin of safety.

In the following comparison with the tensiometer measurements, I used a length adjustment of 3 cm for all spokes in this investigation (reduced vibrating length to account for the effects of bending stiffness), and used the musical method to measure existing spoke tensions rather than to adjust a wheel for optimum working tension.

The tensiometer method

The tensiometer (fig. 1, 2) is a mechanical device which contacts the spoke at three points. The middle one of these points is the tip of a probe which is pressed against the spoke by a spring. The higher the tension of the spoke, the less it is flexed out of line by the probe. A reading of the probe position is taken from a dial gauge which registers the probe position.

Figure 1. The Hozan Tool Industry, Inc. spoke tension meter C-737 used in this investigation

The response of the tensiometer differs with spoke thickness, because the increased thickness displaces the tensiometer probe more, and because thicker spokes also have greater bending stiffness. The tensiometer used for this investigation was supplied with a calibration chart, with a different set of readings for different spoke gauges. No information was provided as to how the chart was developed, but apparently one or more readings were taken from spokes whose tension had been premeasured, at each of several tensions.

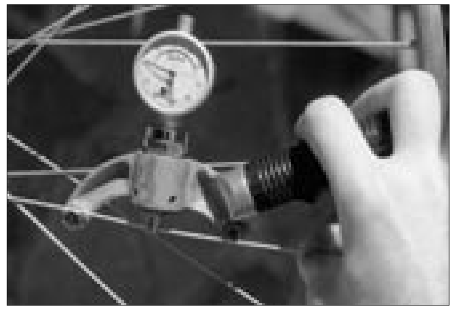

Figure 2. In use, one arm of the tensiometer is hooked under the spoke and the other is pressed down until it just touches the spoke, depressing the central plunger against spring restoring force and producing a dial reading. The tension must be read from a calibration table, as the reading is a nonlinear function of tension, spoke thickness and spoke bending stiffness.

Because of the effect of bending stiffness and the geometry of the tensiometer mechanism, it is clear that the tensiometer readings should form a nonlinear function of spoke tension, and in fact, they do. But a graph of the calibration readings shows clearly that the calibration measurements are also somewhat "noisy"—they do not form a smooth curve. The inconsistencies in measurement might be due to friction in the tensiometer's mechanism, friction between the spoke and the tensiometer probe; inconsistencies in thickness of spokes that are nominally of the same gauge; variation the position of the tensiometer along the spoke; nonlinearity in the tensiometer's response, or perhaps other factors.

Comparing the methods

In order to compare the tensiometer reading of spoke tension with the value calculated using the musical method, it is necessary to interpolate between the points in the tensiometer calibration chart. If it is assumed that the "noise" in the tensiometer calibration results from measurement error, then the best interpolation is a smooth curve whose form reflects on the tensiometer's geometry.

Both the musical method and the tensiometer method as used in building wheels tend inherently to have a quantization error. In the musical method, it is the tendency to assign a musical pitch to the nearest musical semi-tone. With the tensiometer, it is the tendency to assign the tension to the nearest calibration table entry. Interpolation is possible, but requires higher musical skill with the musical method, and mathematical calculation when using the tensiometer.

When curve fits are used in deriving a tension measurement from the tensiometer reading, quantization error is no longer an issue, and the "noise" of the calibration tables is smoothed out, though errors in curve fit may occur.

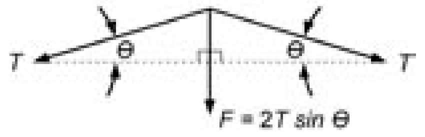

Figure 3. Geometric model of the tensiometer

In order to generate the curve fits, a geometric model of the tensiometer was developed (fig. 3).

As apparent from figure 3, the tension on the spoke relates to the force on the probe as

$$F = 2T \sin \Theta$$

or

$$F = \frac{2Ty}{\sqrt{y^2 + a^2}}$$

where T is the tension, y is the position of the tensiometer probe, F is the force on the probe and a represents the length of the spoke between the probe and the support at each side of the tensiometer's arch.

The force on the tensiometer probe varies as

$$F = b(y + c)$$

where b is a constant which represents the spring rate of the tensiometer probe and c is a constant representing the position of the probe when the spring is at rest.

Now, equating the force, F in the equations above, and solving for T, we obtain:

$$T = \frac{b(y + c)\sqrt{y^2 + a^2}}{2y}$$

The geometric model accounts for spoke tension and thickness, but not for bending stiffness. However, tension and bending stiffness affect the reading of the tensiometer similarly, and so adjustments in the parameters of the formula should be able to compensate for differences in bending stiffness quite well. It is to be expected that the values of b and c will vary with spoke gauge, reflecting the differences in spoke thickness and bending stiffness.

The parameters a, b and c of the equation above were adjusted by eye to produce smoothed curves for 14-, 15- and 16-gauge (~2.0, ~1.8, and ~1.6 mm diameter) spoke shafts, which conformed as well as possible to the tensiometer calibration readings. The comparison between the calibration readings and the smoothed curves are shown in the calibration graph (fig. 4). The vertical scale of the graph is logarithmic, reflecting the fact that the ratio rather than the difference between the calibration reading and the height of the smoothed curve is to be kept as small as possible.

As can be seen, the fit of the smoothed curves for all three spoke gauges is quite good. It does appear that the smoothed curves for the lighter gauge spokes may be a bit low near the low end of the tension range, and high near the high end. However, given the noisiness of the calibration readings, no firm conclusion can be reached on this issue. There is, however, a wide variation in the constant a between the different spoke gauges.

The goal of the modeling is in any case only to derive a formula whose form reasonably well reflects the tensiometer's response to spoke tension, so that the parameters of the smoothed curves may be used to calculate a spoke tension that corresponds to any tensiometer reading. The tension is calculated by inserting the values of a, b and c for the appropriate spoke gauge into the equation for tension, along with the tensiometer reading y. This results in a calculated tension for each spoke examined.

Using the musical method, the tension can be calculated for individual spokes in a wheel with radial or unlaced spokes, but in a wheel with laced and touching spokes, it can be calculated only for each laced pair, which resonates as a unit.

Though a tensiometer measurement is available for each spoke, a tension reading for each laced pair of spokes must be derived in order to make a comparison against the musical readings. The combined tension reading is the average of the tensions of the two spokes.

The values of tension using the musical and tensiometer methods may now be compared. The results of the comparison are shown in figure 5.

Conclusions

1. As can be seen in the graph, there are a few outliers, which most likely result from recording errors rather than measurement errors, considering their extreme values and small number. Aside from these, the correlation between the musical and tensiometer readings is tightly grouped and nicely linear over a 10 to 1 range of spoke tension, for spokes of differing lengths of all three spoke gauges, laced or unlaced.

2. A perfect correspondence between the musical and tensiometer readings would produce the function

$$y = x$$

where y is the tensiometer measurement and x is the musical tension measurement.

The actual function (in Newtons) is approximately

$$y = 1.2x - 200$$

The causes of this difference in measurements could be in either the tensiometer or the musical method, or both, and can not be determined without measuring the tension of accurately tensioned spokes, for example, spokes supporting a hub from which weights are suspended. It is, however, most likely that the offset in the crossing of the y axis is due to an error in the zero setting of the tensiometer calibration, because frequencies of vibration inherently correspond accurately to tension ratios.

3. Both the musical method and the tensiometer are accurate enough for use in establishing the correct tension level of spokes in wheel building. However, the accuracy of both measurement means could be improved by accurate calibration. In the case of the musical method, calibration would serve to establish accurately the length compensation which is necessary to account for bending stiffness for the different spoke gauges.

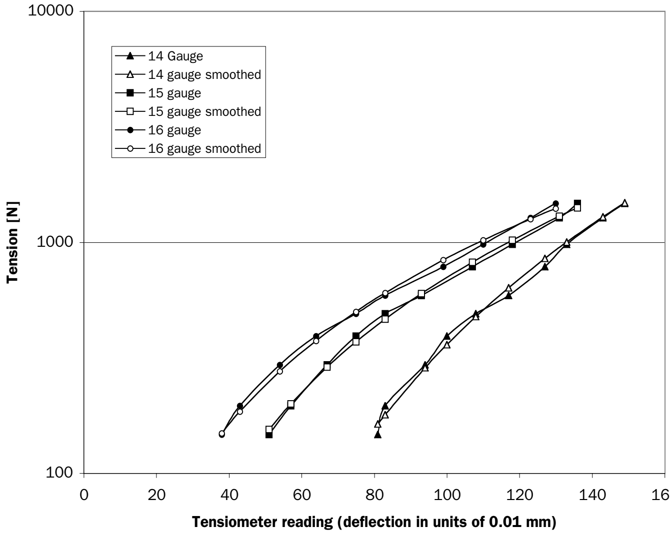

Figure 4. Tensiometer readings vs. tension [N]

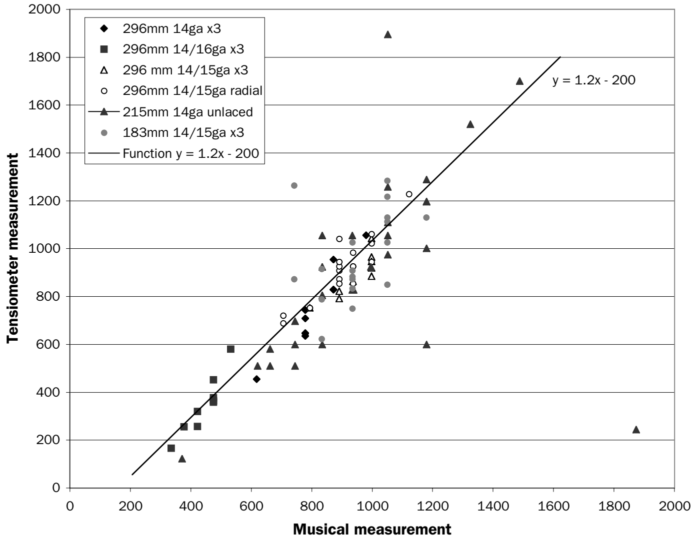

Figure 5. Musical vs. tensiometer measure [N]

4. There are strengths and weaknesses to both methods. The musical method is much faster than using the tensiometer, and the musical pitch relates directly to the optimum working tension of spokes based on their stress per unit of cross-sectional area, regardless of the spoke gauge. However, the musical method requires musical training. When spokes are laced and touching, the musical method as used in this investigation does not measure the tension of individual spokes, but rather, gives an average tension reading for each pair of laced spokes—sufficient to measure the tension level of a wheel as a whole, but not as useful for identifying individual spokes which are too tight or loose. (It is possible, though more difficult, to measure the tension of individual spokes by listening for the musical note produced by the part between the lacing and the rim).

Suggestions for further research

1. Check the calibration of the tensiometer used in this investigation, so that the causes of the discrepancies between the tensiometer and musical measurements might be identified.

2. Providing a more sophisticated modeling based on a larger sample of calibration readings, accounting for bending stiffness, and using a curve-fitting algorithm rather than an eyeball comparison would certainly produce a more accurate correspondence between the readings and the smoothed curves.

3. Perform musical measurements on accurately measured spokes (for example, using a hub from which weights are suspended) so as to identify an accurate function of musical pitch as it relates to tension and spoke length.

4. Provide a statistical analysis of results.

5. Measure a number of different tensiometers, to determine the level of accuracy which can be expected of them.

Acknowledgements

Thanks to Calvin Jones of Park Tool Company [http://www.parktool.com/] for motivating me to conduct this investigation, and for the loan of a tensiometer; David Gordon Wilson and Sheldon Brown for their encouragement, and Jobst Brandt for the background information in his book *The Bicycle Wheel* [2] and for his doubts about the musical method, which further motivated me to investigate it.

References

[1] The derivation of this formula is given, for example, in Alonso and Finn, *Fundamental university physics*, vol. 2, "Fields and waves" (1967, Addison Wesley), section 18-7.

[2] Brandt, Jobst. 1993. *The bicycle wheel, 3rd ed.* Menlo Park, CA: Avocet. (ISBN #0-9607236-6-8)

About the author

John S. Allen <jsallen@bikexprt.com>, [http://www.bikexprt.com] has had a long career as a writer about bicycling, and is author or co-author of a number of publications, including Sutherland's *Handbook for bicycle mechanics* and *Bicycling street smarts*. He lives near Boston, Massachusetts, USA.

LETTER

Human-powered trackway systems continue to fascinate. A new variation is described in the excerpt of two letters by John Barber, whose company has developed a magnetic suspension unit needing no energy input or electronic control system (but requiring separate mechanical guiding and drive systems). It is interesting that he sees his system as a low-cost solution for "third world" problems, with the lifting units being part of individual vehicles free to join and leave an overhead track at stations. So far the company has built several models of the maglev unit, but not of the overhead track. John Barber writes: "In many areas small vehicles, either human powered or propelled by internal combustion or electric motors, are well suited for providing a significant portion of local transport needs. However, their effectiveness is frequently compromised by problems of local roadway conditions, terrain, inability to travel longer distances and limited endurance…. It is true, for highly efficient bicycles on good roads, that the running friction is not high. But that is often not the case. Balloon tires on primitive roads are pretty common in large areas of the world. Resistance here is sizable. I have read commentaries on the problems faced by rickshaw drivers, of a similar nature.


Segment of an elevated trackway with magnetic suspension unit supporting a vehicle.

"MTSC, of Westlake Village, CA, USA, has developed and patented a particular magnetic support technology for transport systems that uses permanent magnets mounted on the vehicle for generating lift. The configuration we use is such that no vehicle motion, nor input of energy, is required for the lift. The lift is inherently stable, although the vehicles do need to be steered. Additional information on the technology may be found in our web site: http://www.magsupport.com. The patent is # 5'825'105 (US).

"The concept envisions the construction of a network of independent elevated guideway segments, on which the vehicles, levitated by the MTSC magnetic support system, would operate. This could provide, with modest expenditure, a grade-separated, high-quality travel way, generally immune to weather, offering a smooth ride, and requiring relatively little energy input for propulsion.

"The cost of a lifting unit: in mass production where the magnets are being purchased in quantity, and the lift unit parts are likewise being fabricated in quantity, we estimate a cost on the order of [US]$1.00–$1.50 per kg of mass lifted."

John Barber
President, MTSC

Adding arm power to a recumbent

by Daniel Kirshner


Figure 1. Dan Kirschner on his custom recumbent bicycle

A disadvantage of recumbents—the rider can't rise out of the saddle in a sprint—can be turned to advantage. The recumbent riding position allows use of the arms to add power to the bike… if a practical way to do so can be found. I have developed a working prototype that allows this.

The most surprising aspect of the design is how easy it is to both steer and power the bike at the at same time. The arrangement however also appears to be surprisingly effective in allowing me to put more of my human power to use.

Here is a description of the arm power mechanism, its development, and its effects. I also describe my plan to make the mechanism a simple add-on to just about any recumbent.

How the arm power mechanism works

Figure 1 shows the arm power mechanism on my custom recumbent bike. A professional frame builder built the bike to my design (without arm power!) about 17 years ago. Two vertical handles on either side of the seat are part of a single handlebar unit. Power is supplied through a "rowing," back-and-forth motion of the handlebar unit, which pivots about a horizontal axle, transverse to the bike, under the seat. Power can be applied both on the forward (push) stroke, and on the rear (pull) stroke.

Steering is accomplished by differential motion of the two vertical handles, which also pivot about a generally vertical axle that itself rotates about the transverse, horizontal axle. Figure 2 provides a close-up of the rowing/steering mechanism. The "floating" chainring serves as a chain tensioner as there is no mechanism to tension the primary chain.

Figure 3 illustrates the main features of the mechanism.

Rowing and steering axles

The "rowing axle" is a transverse horizontal axle. A short "tongue" extends rearward from the center of the axle. A vertical hole through the tongue is used to attach the vertical steering axle (although, of course, this axle tilts backwards and forwards from vertical during the rowing stroke). The handlebar clamp holds bearings mounted on the steering axle.

Power take-off

Arm power is transmitted through the horizontal axle to a short "crank arm" attached to the end of the axle on the left side of the bike. From the end of the crank arm a short spindle-axle holds a bearing attached to the "connecting rod" that transmits the back-and-forth motion of the crank arm to the rotary motion of another bearing/spindle-axle on the intermediate/crossover drive.

An important feature of the power mechanism is that the handlebars have a "fixed" connection to the intermediate/crossover drive, and thus to the pedals. Because there is no freewheel mechanism between the pedals and the handlebars, when your feet move, the handlebars move. This lets your feet carry the arm levers through the "dead spot" at the end of each stroke.


Figure 2. Close-up of the arm powered rowing/steering mechanism

Steering take-off

Steering motion is transmitted by a link with rod-end bearings at each end. At the front of the link, a short "crank arm" is attached to the "steerer" tube of the forks (where the handlebars would go on an upright bike). At the rear of the link, a short arm attached to the horizontal portion of the handlebars positions the rear rod-end bearing a couple of inches in front of the handlebars.

This positioning of the rear rod-end bearing is important: it is located on the axis of the horizontal axle. The back-and-forth power stroke of the handlebars thus has no effect on the steering (or a negligible effect when the steering motion moves the bearing position slightly off the axis).

You might be able to see in the photographs that the prototype handlebars are constructed from modified aero-bars clamped to a horizontal tube.

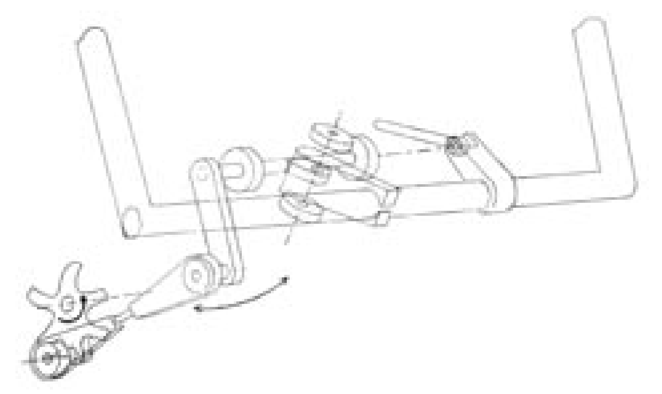
Figure 3. Diagram showing the main feaures of the mechanism

Weight

In its current form the arm-power mechanism adds approximately 1.4 kg (3 lb) to the bike, not counting the intermediate/crossover drive, which itself adds about 0.5 kg (1 lb). A refined design (eliminating the aero-bar clamps, for example), could probably save 0.5 kg, and under “Future developments,” below, I discuss plans to eliminate the crossover drive. In this case the net weight addition should be about 1 kg (2.2 lb).

Arm power background

I was intrigued by the notion of adding arm power to bicycles by ergometer test results summarized in *Bicycling Science.* [1] These results showed that with a “forced rowing” mechanism using both arms and legs, “…about 12.5 percent more power than with normal pedaling was obtained throughout the time period for all subjects.” Forced rowing is a mechanism that defines the end of the stroke and thus conserves the kinetic energy of the moving masses. This is unlike typical rowing in a boat, where the rowers must decelerate and reverse their motions without help from the mechanism. [2]

While the result showing additional power available from the arm and leg power mechanism is indeed intriguing, it should be noted that the test period extended only as long as five minutes.

With respect to creating arm and leg power mechanisms for human powered vehicles, references on the internet indicate that there has been quite a bit of activity. (See, for example, www.geocities.com/rcgilmore3/land_rowers.htm.) I’m aware of only two bikes currently in production: the Thys “Rowingbike” is built in the Netherlands (see www.rowingbike.com); Scott Olson’s “Rowbike” is built in the USA (see www.rowbike.com). These bikes use a “free rowing” motion (as opposed to the “forced rowing” mechanism discussed above). The linear rowing motion is transmitted directly to the hub, with a ratcheting/freewheel mechanism for the return stroke. Such a mechanism does not decelerate the rower’s feet or arms at the end of the stroke. I have not seen information that compares the performance of these bikes with other legs-only machines.

Gardner Martin has built several modified Easy Racers [Tour Easys] that put hand cranks in place of the handlebars. The hand cranks are connected via chain, idlers and freewheel to the bottom bracket chainrings. The chain twists a bit during steering. Gardner says that the rider does have to learn to counter some of the torques introduced by arm power, and indicates that the arm-powered bike lets a rider produce more power, and use higher gears on hills, for example. Gardner’s ergometer tests showed a higher heart rate as soon as the rider starts using his/her-arms, so it may be that the arm-and-leg-power combination is less efficient than a legs-only machine. My tests, however, do not show this result, as I describe below.

Development

I gave active thought to adding arm power to my recumbent for at least five years, and ran through many possibilities in my mind. First, however, I needed someone who could help with prototype work. A short search of local bike shops turned up Stephan Long. He built a stationary bike/trainer that included handlebars much like those on the bike described in this article, linked to the crank chainwheels in much the same way. I didn’t do any scientific tests, but it was clear that the mechanism was comfortable to operate, and appeared to allow me to increase my power output.

I knew that I would want to experiment with different ratios between the arm “rowing” speed and the leg rotation speed. The stationary trainer convinced me that I wanted my arms going “half as fast” as my feet. I also thought that any faster movement of my arms would make it that much harder to steer. Of course, the stationary bike told me nothing about whether it would be possible to both power and steer a bike at the same time.

Designs

The first design I chose to build was similar to the mechanism described above, except that the handlebar unit did not have a vertical axle. Instead, both vertical handles could twist about their own axes. A steering linkage much like a car’s — with link rods to each side — transmitted the twisting motion through an “idler” to a fore-aft link to the front of the bike.

This prototype proved to be unrideable — even though it did not have arm power motion at all. I could not produce enough torque to control the bike merely by gripping the vertical handles. The quick addition of horizontal extension handles (bar ends) to each vertical handle produced an easily-controlled bike — but it was now much wider than I desired.

The next (and present) prototype involved modification of my bike’s existing handlebar clamp/bearing unit (see fig. 3) and the addition of the horizontal axle, held by bearings placed in modified handlebar clamps. I first tried the bike without the arm-power connecting link — the handlebars worked fine for steering — and then hooked up the arm power link. As I said, it was surprisingly easy to ride.

Over the next several months nearly all the components were replaced as they either broke or proved too flexible. Also, I did not feel that my arms were making an adequate contribution to powering the bike — my legs would feel fatigued while my arms didn’t seem to be doing much work. So I experimented with different ratios between the arms and legs. The original ratio was 2:1 — the arms going half the speed of the legs. I then tried a 1.5:1 ratio. While this sounds odd, it was still comfortable to power. Nevertheless, I still didn’t feel that my arms were contributing enough. I have kept a 1:1 ratio since then.

How well does it work?

The bike seems to work very well: you definitely feel like you are adding power with your arms, and I can use higher gears on hills. But is there an advantage? How big is the effect, if any? Finally, over the long run, you would expect to be limited by your aerobic capabilities, so you might not expect any advantage except in short-term sprints.

I’ve been the only rider so far, so the tests are limited. I have three different results to report: (1) comparisons among my recumbent with arm power, without arm power, and upright bicycles on a half-hour uphill ride;
(2) similar comparisons on a very brief uphill sprint; and (3) heart rate comparisons between using and not using arm power on a trainer.

Table 1 shows comparisons among my recumbent with arm power, without arm power, and an upright bicycle on a half hour uphill ride. It’s a challenging ride; the one time I rode with a heart-rate monitor it showed a maximum of 186 beats per minute. My wife tells me the charts show that at my age (47) that should have killed me! Table 1 shows the times for three parts of the ride — in certain cases I did not complete the ride, or did not get a time for the final part (stopwatch error!).

The comparisons are only rough. As table 1 indicates, I used a Brompton folding bicycle as the upright. The Brompton has 16-inch wheels and a five-speed hub, so may be less efficient than the recumbent. Then again, the Brompton has high-pressure (85 lbs) tires, and has a weight advantage over my recumbent — 12.3 kg (27 lbs) versus 15.5 kg (34 lbs).

While I came close on the upright in one case (trial 4 compared to trial 1) nevertheless, the best times went to the arm-powered recumbent. Without arm power the recumbent was 3.5 minutes or so behind the same bike with arm power.

Table 1. Times for uphill ride (min:sec)

Trial Bike	Part 1	Part 2	Part 3	1+2	1+2+3
1. Recumbent - with arms	05:06	14:07	11:17	19:13	30:30
2. Recumbent - no arms	05:37	15:43	12:41	21:20	34:01
3. Recumbent - with arms	05:15	13:45	11:12	19:00	30:12
4. Upright - Brompton	04:58	14:16	—	19:14	—
5. Upright - Brompton	05:23	14:42	12:15	20:05	32:20
6. Upright - Brompton	05:24	14:23	—	19:47	—

Table 2. Comparisons: short uphill sprint

	seconds	kg bike	kg total	sec. slower	% slower	kg heavier	% heavier
Best Schwinn upright	21.34	19.5	83.4	0.66	3.2%	7.3	10%
Best Brompton upright	20.68	12.2	76.2	—	—	—	—
Best recumbent arm & legs	22.28	15.4	79.4	1.60	7.7%	3.2	4%
Best recumbent legs only	23.21	15.4	79.4	2.53	12.2%	3.2	4%

Table 2 shows comparisons for a brief, approximately 20-second, uphill sprint. I did the sprint about three or four times on each bike/configuration. Table 2 reports the best times, and also some statistics on the percentage comparisons of the times and weights of the bikes and rider (who was approximately 63.9 kg (141 lbs) in each case).

In this case, the upright bicycles are definitely ahead of the recumbent. The percentage comparisons support the advantage of uprights in the short sprint. While my heavy old Schwinn makes that configuration 10% heavier than the lightest, fastest bike — the Brompton — it’s only 3.2% slower, while the recumbent configuration, which is only 4% heavier, is 7.7% slower (with arms) and fully 12.2% slower without arms.

I should note that the times shown in table 2 were taken early in the development of the arm power recumbent. Perhaps additional conditioning would make a difference.

Finally, I also compared my heart rate with and without arm power on a trainer. I used my old Houdaille “Road Machine” trainer: this trainer uses a flywheel/fan to provide both wind resistance and realistic simulation of the momentum of the bike and rider. I established a steady speed (as measured by a typical cycle-computer) and noticed that my heart rate was stable at that speed (within about plus or minus 1 beat per minute). I then stopped using my arms, and used my legs alone to maintain that speed. At every speed-heart rate combination that I tried — from a sedate 12 miles per hour at about 130 beats per minute, to a difficult to maintain 29 miles per hour at about 182 beats per minute — the use or non-use of arm power made no difference. I conclude that my heart rate, at least, closely reflects the power requirement, however it is achieved.

Combining these results with my subjective impressions, the arm power appears to allow me to exercise at a higher aerobic level, less limited by the capability of my leg muscles over longer periods. Certainly, when I made the half-hour hill climbing comparisons, my legs ached a great deal more without the arm power. It remains to be seen whether this will be true for other riders, and under different conditions (for example, a longer exercise period). Nevertheless, in short sprints, the ability to move around on the bike seems to generate more power for at least a short period.

General observations

How does it feel to ride? Good. Even when you are using a great deal of force to push and pull — you can use both strokes for power — you are still able to make fine steering adjustments. Apparently your body is well attuned to controlling small differences in the motion of your arms, even when they are moving quite a bit.

One thing you cannot do is ride one handed — or, you can, but only if you stop pedaling. If you stop pedaling, you can use your feet to hold the power mechanism steady. Then pushing or pulling on one handlebar gives you conventional steering. But steering with one hand while the handlebar also moves back and forth with the pedals is nearly impossible. This is a serious drawback that I shall try to fix, as I describe in “Future developments,” below.

As I mentioned earlier, there is no freewheel between the pedals and the arms, so that your foot motion carries your arms through the dead spots at the end of each stroke. In fact, it is almost impossible to use arm power only — you tend to get stuck at one end of the stroke or the other, or else you push or pull a moment too soon—and end up freewheeling backwards.

I worried about play in the mechanism between the arms and the pedals. I worried about wrist strain, since the pivoting handlebars would appear to move your wrists in a way that nature did not intend. So far, however, that has not been a problem.

Future developments

I am working in two areas. Firstly, a long connecting rod can be used to transmit arm power to the pedal crankset. This would eliminate the need for an intermediate/crossover drive, and make the mechanism simple to add to just about any recumbent. Secondly, the arm power mechanism needs the ability to disengage from the pedals, so that you can continue pedaling while riding one-handed.

Finally, I have not yet decided whether to patent the arm power mechanism. My understanding is that U.S. law allows me to file within one year of the disclosure marked by this publication (while I have now forfeited European rights). No one that I have consulted who has expertise in this area, however, has recommended pursuing a patent—the recumbent market is small, and the number of potential arm power converts smaller still. One is unlikely to get one's money back, which might be better invested in developing the product. I will be interested to hear if this publication's readers support this advice!

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[2] The ergometer tests were conducted by J.Y. Harrison, and reported in "Maximizing human power output by suitable selection of motion cycle and load," *Human Factors* 12:3, 1970, pp. 315–329.

The author

Dan Kirschner <dank@ed.org> lives in Berkeley, California, with his wife and two daughters. Most days he rides the bicycle described in this article 5 miles (8 km) each way to and from his work as an economic analyst in the regional office of Environmental Defense. He also enjoys rides in the Berkeley and Oakland hills. He previously contributed an article, "Aerodynamics vs. weight," to the Second International Human Powered Vehicle Scientific Symposium in 1983 (reprinted in *Human Powered Vehicles*, Abbott and Wilson, eds., Human Kinetics, 1995).

Bicycle design, safety, and product-liability litigation*

(with case studies of wire-ropes, brakes, rims, and tire-fit)

by David Gordon Wilson

Abstract

The United States is a litigious society, and product-liability litigation is of considerable concern to companies that export to the U.S. Much publicity is given to "horror stories" of seemingly excessive judgments against apparently ethical manufacturers after they have been sued by unscrupulous people pretending to be victims of what is claimed to be deficient design. However, these reports are far from representative of the actual situation. The other side of this story is that product-liability litigation is decreasing quite markedly in the U.S.; that this form of litigation brings about major improvements in product design and in the safety of the public; and that it is possible to avoid most negative impacts of such litigation by striving for, and documenting, excellence in the design and manufacturing of products, by clearly warning users of dangerous situations, and by putting trust in insurance that is standard for the industry. Some areas in which improvements in design and manufacture of bicycles are needed are discussed as examples.

Introduction

Background

Product-liability litigation in the U.S. has been governed by state laws, despite frequent attempts by business-friendly legislators to get unified federal laws passed. Business people must therefore be concerned about their products being used in states where requirements may be particularly onerous. In practice, state legislators are quick to copy laws that have worked well elsewhere, so that the differences among regulations in different states are not as large as might be imagined. However, in many areas of modern life we are driven by what we know of extreme cases: only these are reported by news organizations. Here is a recent example (disguised so that your author does not get sued, because I was an "expert witness" for one of the manufacturers involved) of what seems to me to be an unfortunate extreme situation.

An extreme case?

"Bill", a young and energetic U.S. physician, bought a regular "road" bicycle for recreation. He found that he liked biking, and hearing that sew-up tires are used by racing cyclists and would enable him to go faster, bought new wheels and "tubular" tires and had them installed on his bike. One day he went with a group of fellow physicians on a ride that included the summit of a small mountain. While pausing at the top he joked to his friends that he had bad brakes, showing that with the brake levers fully squeezed against the handlebars he could move his bike easily back and forth. He then said "Last man down the mountain buys the beers!" and rode off down the steep, rough, bumpy, asphalt road with the others in hot pursuit. The road had signs showing a speed limit of 35 km/h, and, after about a kilometer, a warning of a sharp S-bend. The person who was closest behind Bill said that as he approached the bend his cycle computer was registering about 75 km/h and that Bill was out of sight ahead of him. He braked to get around the bend and saw that Bill had hit a stone wall and was lying on his back some distance from his bicycle.

Bill had severed his spinal cord and was, tragically, a quadriplegic from then on. He gave his bike to a family member, who, after having the front wheel and fork replaced, used it regularly. Bill confessed at some point that the accident was his fault. However, after over a year he (or possibly his insurance company) decided to try to get some money through the courts, and his lawyer sued the bicycle shop that sold him the bike, the bicycle manufacturers, and all possible manufacturers of the rims and the tires (the actual front wheel and tire had been disposed of). One would have thought that these companies would have had a very strong case. Yet one by one they, or rather their insurance companies, all "settled out of court," meaning that they agreed to pay large sums to the plaintiff to avoid the far-larger costs of going to trial. They also may have felt that, however strong their case, the sight of this young man sitting paralyzed in a wheelchair, with his wife and child, would be enough to make an American jury decide that these insurance companies were rich and Bill and his family had already been punished terribly. To award him a large settlement even though he was at fault could be possibly some form of jury-administered social justice.

The present status of product-liability litigation in the U.S.

Cases like this seem to be typically American. In what is considered to be a free-enterprise system (but is in fact increasingly regulated) the absence of a national health-care and welfare system seems to give credence to reports of juries leaning to the "left". They are drawn largely from the lower end of the economic spectrum because professional people try to find reasons to be excused from jury service. However, contrary to popular belief, jurors do not overwhelmingly sympathize with individual plaintiffs at the expense of companies. According to "Jury verdict research" reported in *Business Week* on November 8, 1993, defendants (usually manufacturers) won 57 percent of the products-liability suits in 1992. This proportion had been 45% in 1989. Popular opinion also paints a picture of a flood of products-liability litigation. In fact, products-liability lawsuits were less than 1 percent of the total state and federal caseload in 1994 [1] and less than 0.4% of the civil cases in state courts. (There is a huge backlog of lawsuits awaiting trial in most U.S. jurisdictions, but most cases are suits between businesses and between family members, particularly divorce cases.) The number of product-liability lawsuits is also in sharp decline, having dropped 40 percent between 1985 and 1991. Insurance premiums covering product liability dropped 45 percent between 1987 and 1993. [2]

There is also concern regarding so-called "punitive damages" awarded by some courts. These are imposed for particularly egregious cases in some states (punitive damages are not allowed in many states, including Massachusetts) and are derived from ancient Roman and English law. In fact, apart from the special and shocking case of asbestos liability, the awarding of punitive damages is very rare in the U.S. Michael Rustad, of the Suffolk Law School faculty, performed a study showing that between 1965 and 1990, only 355 product-liability cases resulted in punitive-damage awards in state and federal courts, an average of fourteen per year for the whole U.S. [3] A manufacturer of bicycles or components would have to be very delinquent, or exceedingly unlucky, to be included in this number.

The remaining fear of liability lawsuits

So far I have given some details of the type of case that strikes fear in the heart of small manufacturers who are concerned that one such lawsuit could put them out of business; and I have also tried to show that much of the concern is exaggerated. However, I should describe how lawsuits come about and are adjudicated or settled in order to give bicycle manufacturers, particularly those outside the U.S., an understanding of the risks and rewards of exporting to the United States.

The U.S. is a country where even a poor person can sue the world's largest corporation. To do so she/he needs to persuade a lawyer who specializes in this type of case that her/his injuries or other harms are sufficiently serious to justify taking action. The lawyer will generally do this on a "contingent-fee" basis: that is, she/he will charge the client nothing for his/her services, but will take 25–33% of any monetary award. This has the socially desirable consequence that people of limited wealth are given full access to the courts in cases where they have been harmed. Although occasional large awards receive a great deal of publicity, juries are generally hard-headed and reasonable in awarding damages.

Most cases, however, do not go to trial. The early stages of a lawsuit are taken with "discovery", a process in which each side is required to make available all relevant written records and all relevant people to give depositions. So-called expert witnesses are hired by both sides to add weight to the testimony and to act as engineering/scientific detectives. The discovery process can be a time-consuming, disruptive and costly period for a manufacturer, although the attorneys' and experts' costs are usually handled by the insurance company. The opposing lawyers can demand, however, all drawings, sketches, notes and other records that have any possible connection with the injury to the plaintiff. Each item considered actually relevant is labeled as "Exhibit A, B," etc. During this period the attorneys for each side are assessing their situations and their likelihood of winning or losing in the trial. At some point the lead attorney on one side will contact the lead attorney on the other side and say something like the following. "As a result of discovery and depositions we have an overwhelming case, and your side is likely to have to pay large sums if we go to trial. My client has expressed a willingness to settle out of court for a payment of *X* dollars." Sometimes the other attorney accepts the offer with alacrity. More often there is a period of negotiation, as in a market anywhere. In under ten percent of cases agreement is not reached, and a trial date is set. This may be several years after the suit is filed.

I believe that this procedure is fair (with the exception of the effects of the inordinate delay between the complaint and any eventual resolution) and leads to social justice in the large majority of cases. It is difficult to be fair in cases where a life has been lost or serious permanent injury has resulted from a product defect. Suppose, for instance, a promising young person, just married

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* This is an adaptation of a paper given at the sixth annual bicycle-design competition in the Taiwan Bicycle Industry R&D Center, 29 August 2001, which is a considerably updated and expanded version of a paper first given on 5 August 1998, under the title "The design of advanced human-powered vehicles/velomobiles and product-liability litigation: can they co-exist in the light of apparently outrageous U.S. cases?" *Proceedings of the Third European Seminar on Velomobile Design*, Roskilde, Denmark.

and just launched on a promising career, is permanently confined to a wheelchair because the fork of a new bicycle snapped in normal use. No amount of money could compensate this person and her/his spouse and family for the terrible change in the quality of their lives for perhaps the next fifty years. The medical-care costs alone could amount to a huge sum. Such cases could be regarded as the norm in malpractice lawsuits against the U.S. medical profession, which takes extraordinary steps to prove that every decision and procedure taken has been for the best. A whole battery of very expensive tests will often be specified for a minor ailment, purely to ward off a suit against supposed malpractice in the event that a patient's recovery is not all that might be expected. A bicycle manufacturer does not need to go to these extremes. However, she/he must likewise take very conscientiously, and document in some way, the design and manufacture of any component the failure of which could cause, with reasonable probability, serious injury or death.

Manufacturers in countries where liability litigation is rare might well react with some alarm at having to take major precautions to avoid being sued, and to face unwelcome prying into their design, manufacturing and business practices if they are sued. These risks seem to be the price we pay to have markedly safer products in the U.S. (and increasingly the safety advances achieved in the U.S. have been adopted in Europe and elsewhere. The European Commission has in fact recently published "The Green Paper" recommending changes substantially in the direction of U.S. practice. [4])

I believe that the quality of design and manufacture is enhanced by the possibility of liability litigation. There is, however, some question about the benefits that occur if a case is settled out of court, because of the secrecy that is more marked in the U.S. than in, at least, Britain. (My professional field is turbine design, and the catastrophic failure of a turbine in Britain is followed by a full exposure of the causes, and the steps taken to cure the problem, in papers presented to the Institution of Mechanical Engineers.) This public airing seldom occurs in the U.S., except in the case of airline crashes. However, I believe that the message does get broadcast.

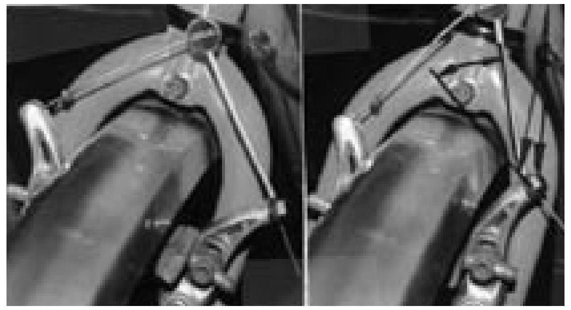


Figure 1. Cantilever brake showing cable clamped to the top of left cantilever, and typical angle through which the cable bends at each operation of the brake.

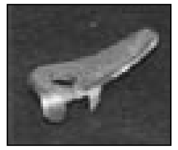


Figure 2. Curved washer (above) made to fit under the clamp bolt on the cantilever arm, providing a large-radius bend for the cable.

Figure 3. Cantilever brake with curved washer installed, showing gentle curve through which the cable is now bent.

A sample case: fatigue in wire ropes

An example is a case in which I served as an expert witness. A lineman working on overhead wires while on a truck-mounted aerial ladder was severely injured when the ladder suddenly collapsed, dropping him to the pavement. The cause was relevant to safety in bicycles: the ladder was operated by wire ropes that passed around several sheaves (pulleys).

The sheave diameter was only seven times the wire diameter. The standards set by the wire-rope manufacturers are that the sheave/rope diameter ratio should be 72 for long life, with 42 being an absolute minimum. At a ratio of 7, the rope was bound to have a very short life before metal fatigue caused it to fail without warning. When the lawyers for the two sides agreed on an out-of-court settlement, I became very disturbed that workers would be killed or injured because, it seemed, the information about the extreme hazard that these ladders and booms posed would not be made public. The attorneys agreed with me that my professional-engineering ethics outweighed my expert-witness responsibilities, and allowed me to send warnings of the extreme danger of these ladders to unions and other places. However, I believe that the manufacturer recalled the trucks faster than did any actions resulting from my warnings: the company did not want to face the rash of lawsuits that it now knew would be certain to come. Liability litigation had worked!

Does it work for bicycle design and manufacture, or do we need more-stringent government standards? Below I discuss three areas in which I believe that bicycle manufacturers have not been as diligent as is required by the need to protect the public.

Three examples of avoidable defects in bicycles

Fatigue failures in cables

The parallel for our industry to the wire-rope failures in the aerial-ladder case is that bicycle brake and gear-shift cables are taken around pulleys and bends with a diameter ratio of far less than 42, and also fail periodically without, usually, any warning. I have had many cables (and handlebars and cranks) break suddenly, but fortuitously never at a critical time. If I had, there would have been a strong probability of a fatal accident, and, because bicycle accidents are usually not investigated with any degree of seriousness, the cause would not have become known. A recent example illustrates the problem: I normally ride recumbent bicycles. However, when snow or ice covers the roads I switch to an "upright" bicycle, and on such a day recently I borrowed my wife's town bike to go to work. We live on a steep hill, and I needed to ride up it. I applied the brakes gently to get ready to mount the bike. The front "straddle" cable broke. When I examined the rear brake I found that it, too, had a frayed "straddle" cable and that it, too, was about to break. This horrified me, because the next trip taken by my wife would almost certainly have been downhill with our small daughter in a child seat, and the cable would have certainly failed when she tried to stop at the major intersection at the bottom of the hill.

On examination, I found that the straddle cable was attached to the right cantilever-brake arm by a pivoting joint, where there was no sign of incipient failure, but it was bolted to the top of the left arm (fig. 1). The angle through which the average cantilever brake rotates guarantees that the cable will fail in fatigue, just as surely as will a paper clip that is bent back and forth. I put on a website an account of this failure, something about the design of the brake, and details of a very-low-cost addition that would give virtually infinite life to the cable (fig. 2, 3), and I also sent it to the manufacturers. This account is given here as appendix I.

Brake and wheel-rim failures

When I started bicycling most brakes acted on the wheel rims, and most rims were steel. Braking was adequate in dry conditions, but appallingly inadequate when wet. When we studied the problem, we found that the then-available brake-pad materials suffered a drop of well over 90% of their friction coefficient when wet. [5] We also found an aircraft-brake-pad material that had almost the same coefficient of friction wet and dry. However, the level was too low for direct substitution in the caliper brakes of the time. A simple increase of leverage to give a greater braking force was also impracticable, because such a brake would not give the clearance needed for free-running of naturally "wobbling" rims. We then devised and patented a brake mechanism that had two sequential leverages: a low leverage that would bring the pads up to the wheel rims with little movement of the hand-brake lever, and then a high leverage that produced the required braking force. We demonstrated the brake's outstanding performance to many U.S., Japanese and European companies, and lent them prototypes. A description is included in appendix II, derived from an article published in *Velo Vision* [6].

To our consternation and disappointment, no company was interested in the brake. After a long period there was a fairly sudden switch to aluminum rims. These do give much-better wet-braking performance than do steel rims. Unfortunately, they also wear very rapidly and are then liable to explode without warning under the high forces produced by tire pressures. When the front-wheel rim explodes, the wheel is likely to lock up suddenly, and very serious injuries can result to the rider [7].

This defect is similar to the first, above, in that the failures do not occur until the bicycle has been ridden for some time. Most bicycles sold in the U.S. nowadays are ridden relatively little. Serious adult bicyclists (I am one!) are the people who bear the brunt of these fatigue failures in cables, handlebars and cranks, and in the wear of aluminum rims. We are, alas, of little concern to most bicycle manufacturers, or to government regulators.

Dangerous run-flat performance of bicycle tires

When a bicycle tire/tube deflates, the tire either provides directional stability or, more likely, produces such instability (through "flopping" from one side to the other, fig. 4) that the bicycle rider is thrown off. This is particularly the case if the tire is on the front wheel. Many injuries and some deaths have undoubtedly resulted.

Figure 4. Tire with beads having slipped off the bead set flops over first on one side, and then on the other.

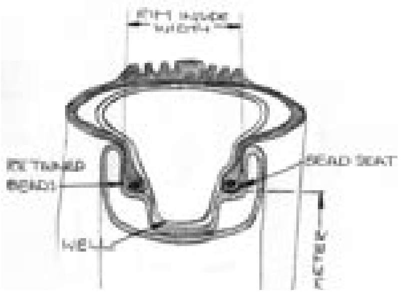


Figure 5. Tire with beads retained on the rim bead seats runs symmetrically, giving good controllability.

This problem, and an investigation into it, are described in appendix III. It was found that a seriously unstable tire (when flat) could be converted to one that gave stable, controllable conditions simply by improving the fit between the tire and the wheel bead-seat (fig. 5). Further, we found that in the U.S., Japanese, and International standards (ISO) there were standards for rim diameters but there was none for tire beads.

In my editorial for *Human Power* 51 under the heading "Tiresome" [8], I contrasted the public concern over the tire failure that caused the fatal crash of the Concorde airliner and over the tire failures on Ford sports-utility vehicles with the total lack of concern over the performance of bicycle tires, causing, possibly, a similar loss of life. "Remedies for bicyclists have the same status as so-called 'orphan drugs'. These drugs are not developed for fatal but relatively rare diseases because drug companies see insufficient profit. Is the bicycle-tire-rim case a situation where industry is not being sued enough? The much-maligned product-liability lawyers can correct serious deficiencies in industry responses, or lack of responses, to shoddy practice."

My sad conclusion from these three areas is that bicycle and component manufacturers do not exercise the highest engineering capabilities in bicycle design, and that improvements are needed.

Impact of liability laws on bicycle design

The perceived impact of liability laws in the late 1970s on the design of the Avatar 2000 which we believed to be the first recumbent bicycle to be produced for general sale since the 1930s, was the following. The initial impetus for the design was my concern for safety, [9] because I had seen many reports of riders of regular "road" bicycles being severely injured or killed after going head-first over the handlebars on applying the front brakes too hard, or riding into a grating or hole in the pavement, or having baggage or a stick get caught in the front wheel, for examples. It seemed to me to be safer to go feet first. It was easy to list, in addition, other virtues that would improve safety: the near-impossibility of catching one's pedals on the road; the great improvement in the ability of the rider to see forward and to the side; the improved braking capability on both wheels; the shorter reaction time resulting from the hands being on or close to the brake levers at all times; and the lessening of injuries because riders are closer to the ground than when on road bikes. There were, and are, a few negative aspects to recumbents: the view to the rear is more circumscribed unless one uses a rearview mirror; and it is difficult to recover from a skid because of the low center of gravity and the attendant rapidity with which one is “dumped” on the ground. The “safety balance” is clearly in favor of the recumbent. However, we knew that we would not receive large cheques from grateful riders who felt that our bicycles had saved them from serious injury. We would be more likely to be sued for larger amounts in those few areas in which our design might be worse than that of upright bicycles.

We responded to this dilemma in three ways:

1. We made the bicycle as safe as practicable;
2. We gave prolific warnings about possibilities of danger; and
3. We took out an insurance policy that was standard for (small?) bicycle manufacturers.

We discussed the positive and negative features of the bicycle design with the insurance representative, who felt comfortable in giving Fomac, manufacturers of the *Avatar*, a policy that would apply to manufacturers of regular bicycles. There was an indication that, if the *Avatar* turned out to be as much of an improvement in safety as we claimed, our rates might even be reduced. This gave an added incentive, if one was needed, to increase safety in our design wherever possible. As mentioned above, insurance rates for liability have in fact dropped markedly since that time.

The insurance industry

Insurers are therefore major players in liability litigation, frequently almost taking the place of the defendants in pretrial organization of the defense and in the trial itself. Their role is that of insuring against risks to businesses, and of doing it in a way that is least costly to manufacturers (otherwise they would go to other insurers) while making a profit themselves. Insurers have a major stake in litigation, and have an obligation to ensure that any settlement is not greater than the limits of the insurance that has been purchased by the manufacturer. An insurer (meaning an individual agent or the firm she or he represents) may decide to settle out of court even though many may believe the case to be defensible, as in the example quoted above, simply to avoid the continuing high costs of attorneys and expert witnesses and the large amount of time that its own personnel will be spending on defending the suit.

Education and litigation

Design education has been helped by liability litigation. At M.I.T., and I’m sure at most universities, concern about the impact of litigation on engineering has led to an much-increased emphasis on engineering ethics and on our responsibilities to society. The disaster to the Challenger space shuttle was a shock that brought about changes, particularly after it was found that engineers who had been fighting to have the launch put off because of what seemed to them obvious flaws in the low-temperature performance of some seals had been overruled by policy-makers, some of whom were also engineers. Our students are shown a videotape of a talk by one of the “whistle-blowing” engineers involved in the Challenger case, and many are moved to tears. We examine other case-studies for lessons to be learned. For instance, one of the first skyscraper fires in history occurred in a New York building on the 37th floor, far too high to be reached by ladders. The first group of firemen decided to take the elevator to the 38th floor, break through the ceiling and spray water on the fire. However, the elevator stopped on the 37th floor, the doors opened automatically, and all were killed. The elevator was one of the first to be operated by heat-sensitive buttons, and these naturally stopped it where the fire was blazing. We ask our students how it was that in the several years required to invent, develop and manufacture this elevator-control system, no one in the company making them, nor in the architectural engineering offices specifying the use of the buttons, ever considered what would happen in the case of a fire. It seems likely that one or more people did think of this possibility, but were overruled. One obvious conclusion is that no one was concerned about being sued for malpractice. Yet it is surely malpractice to design and install a device that, although it works wonderfully for every expected use, will kill or injure in an unexpected, but not unlikely, situation.

Can concern for safety go too far?

Designs analogous to heat-sensitive buttons for elevators can be found in many areas. Only a few years ago we drove cars that had rigid steering columns ready to pierce drivers’ chests even in a low-speed collision. Now we have cars in which the driver and occupants are surrounded by air bags and restrained by belts and protected by a passenger compartment that will allow people to walk away from a frontal collision at 60 km/h and higher. Some research has found that some drivers like to operate their vehicles at an exciting level, a level at which they perceive a certain degree of danger. Give them seat belts and airbags and their average speed increases so that they feel the same degree of safety or danger. On the other hand, there is in the U.S. at present an enthusiasm for huge sports-utility vehicles, partly because they are much more likely to survive, along with their drivers and passengers, in collisions with regular automobiles. The safety of others, including pedestrians and riders of bicycles, has thereby decreased. There is, therefore, an optimum level of safety engineering. This level should be found by estimating the benefit-cost ratio of any proposed change, evaluated over the whole affected population, not just the users of the new system.[10] The “benefit” side of such analyses require the invidious decision on what value to put on human lives saved. Perhaps it is justifiable to avoid this thorny question by using, instead, the expenditures that could be predicted as having been avoided in litigation lawsuits. In either case, benefit-cost analyses would indicate that some proposed safety measures had gone too far. It is also certain that safety aspects of bicycles, regular and recumbent, would be found to have not received enough attention. We cheerfully ride bicycles with brakes that wear fast and don’t stop us safely, on rims and tires that can explode at at least a thousand times the frequency of those on motor vehicles, and so forth. There are several ways (research and development, industry standards and government regulation being three) whereby improvements in bicycles can be attained. We may have to depend on a fourth way: liability litigation.

Acknowledgments

Attorneys Neil Sugarman and Phillip M. Davis and my spouse Ellen Wilson were kind enough to read early drafts of this paper and to give valuable advice and documents that I have incorporated in the final version.

Appendix I: Serious, inevitable failure on Shimano cantilever brakes

The brake cable on several types (e.g., BR-CT20) of Shimano cantilever bicycle brakes (and possibly those of some other manufacturers) will inevitably fail after a period of use. Brakes of this type have at least one of the stranded brake cables bolted to the ends of the brake arms (fig. 1).

Therefore, when the brake is operated, the cable is bent sharply at the point of attachment and then bent back as the brake is released. This process is absolutely certain to fail the brake cable after a certain number of brake applications, just as the wire of a paper clip will fail after a small number of times being bent back and forth. This is a very serious danger.

Widespread standards for stranded-steel-wire cables (e.g., as given in Marks’ *Standard Handbook for Mechanical Engineers*, 7th. edition, McGraw-Hill, 1958, p. 8–114) give the minimum diameter of drums or “treads” around which a cable should be bent as 72 times that of the cable diameter, with 42 as an absolute minimum “in certain cases.” A bicycle brake cable is typically about 1.8 mm (0.07") diameter. Therefore the radius of a curve through which the cable should be forced to bend should be at least 38 mm (1.5"). The incorporation of a sharp bend for the cable in these designs of brakes, relied upon by bicyclists to save their lives at intersections and down hills, betrays a shocking ignorance of standard practice.

Steps that need to be taken

These brakes and cables should be recalled and replaced on an emergency basis, either voluntarily by the manufacturers or by government mandate. As a low-cost alternative, curved extension washers (fig. 2) could be supplied by the manufacturers to individuals and to bicycle-repair shops, who should be paid for getting in touch with owners and for installing the washers and replacement cables. (I donate the design for this purpose.) That a washer of this type (a slightly different design would be required for each type of brake) completely solves the cable-bending problem can be seen from figure 7, showing the modified brake (in the “brake-on” position) on a Specialized bicycle.

Appendix II: The Positech Brake

(Excerpt from: “The Brake That Got Away: The Positech mechanism was all set to revolutionise cycle braking—but it never happened”).[6]

In the 1960s…brake blocks were of black or red rubber, sometimes incorporating fibres. Braking in dry weather was superb, but in wet weather it was abysmal and extremely dangerous. This seemed to me, a mechanical engineer, a crazy state of affairs. I put the topic of wet-weather braking on my project list for students at MIT in around 1968, and that year the first of three excellent students chose to work on the problem. David Asbell measured the coefficients of friction of commercial brake blocks on chromed-steel bicycle rims in wet and dry conditions, and found that the standard black-rubber block suffered a loss of well over 90% of its friction capability when wet—clearly unacceptable for a road vehicle’s main braking system. He also tested some automotive friction materials, and found one that had only one-quarter of the dry friction that rubber could generate—but about three times the wet friction. We later found a material used in aircraft brake pads that also had about a quarter of the black-rubber dry friction, but virtually identical friction performance wet or dry. The following year, two students enlisted to work on the topic, and we discussed how we could use the ‘new’ material. We could not simply increase the leverage of the brake operating mechanism, because then the pads would move only a quarter as far. Bicycle wheels cannot be produced and maintained ‘true’ enough to have a pad such a short distance from the rim without it rubbing. We then hit on the breakthrough concept: a mechanism that would bring the pads rapidly up to the rim, moving with little force, and then when they hit the rim, automatically switch over to a high mechanical advantage. In other words, once the pads hit the rim, instead of a hand movement on the brake lever moving the brake pads rapidly and with little force, further hand movement would move them just a small distance, but with massively more force. This system would produce a sufficiently forceful squeeze to take advantage of the new material, but still give plenty of clearance between pads and rim when the brakes were “off”. John Malarkey worked on a nice design to do this using hydraulic brakes. However, we found that it had previously been patented for automobiles. Brian Hanson, for his bachelor’s thesis, measured more precisely the friction behaviour of the new material, and subsequently, for his master’s thesis, worked with me on a mechanical braking system. He achieved his objective: the innovative brake worked, although appearing, as one would expect from an academic project, rather ‘clunky’. MIT wasn’t interested in patenting it, and we did so ourselves….

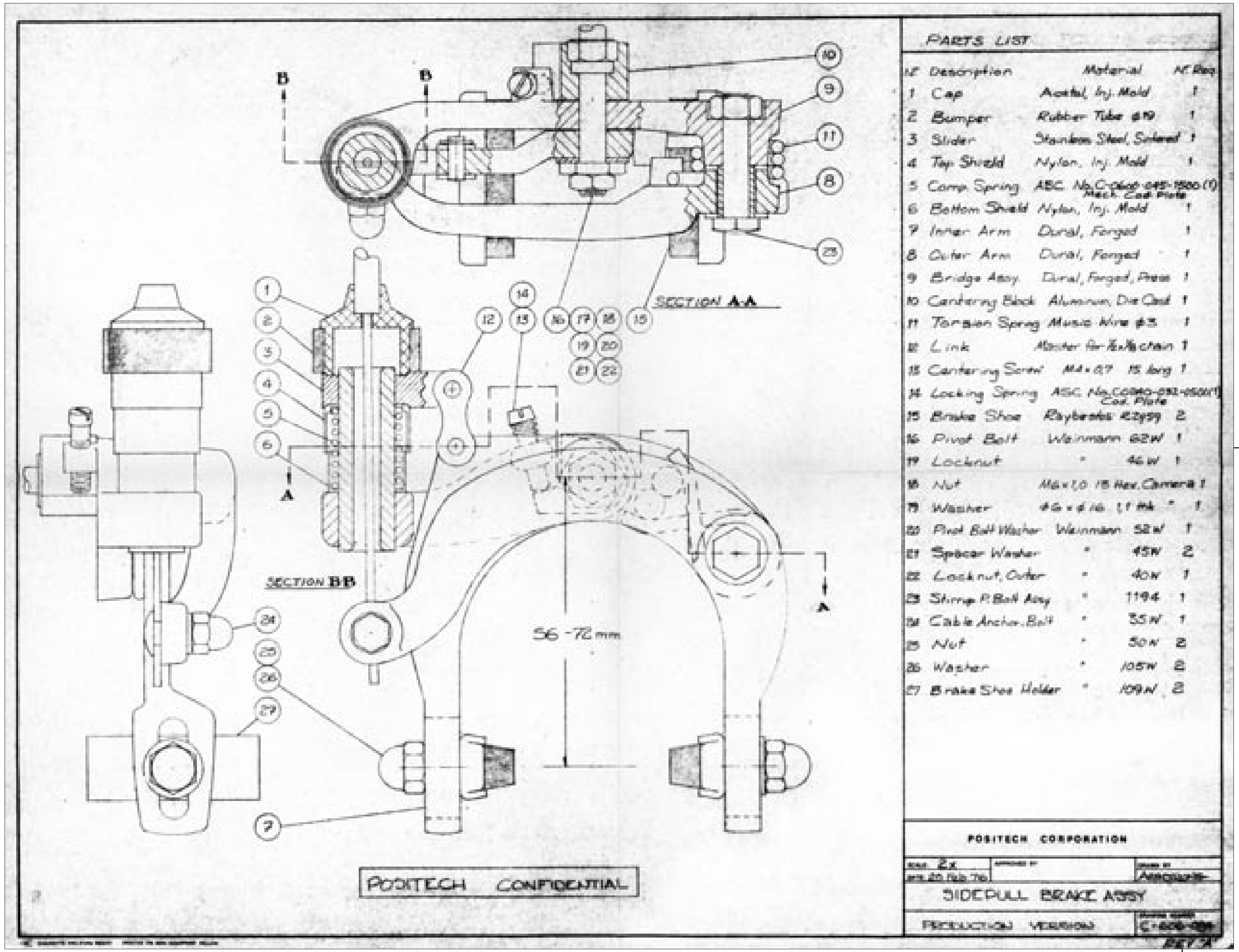
Allen Armstrong of Positech produced a beautiful new design of our double-leverage brake (fig. 6). He kept the same locking-slider system for changing to the higher leverage, but he added a feature to decrease the leverage during the pad-approach stage of the braking action....

I also demonstrated the brake fitted to the front wheel of a Raleigh Gran Sport with steel rims (standard at the time) to Raleigh management at their US headquarters in Boston. I could show exactly the same emergency stopping distance with the wheel wet as when it was dry.

The brake had additional advantages: it was self-adjusting, and the pads seemed to last for ever: over two years for me—at a time when I was bicycling over 15,000km per year. It required no modifications to the bike or the brake lever. It could be made much lighter than was our prototype. We thought that the brake would be irresistible. All the companies that carried out tests obtained the same or better results.

...but not a single company wanted to take out a license to manufacture them....

I even visited the Raleigh headquarters in Nottingham, UK, and was entertained to an impressive lunch in the panelled boardroom with the senior



Nº	Description	Material	Nº Req.
1	Cap	Acetal, Inj. Mold	1
2	Bumper	Rubber Tube #19	1
3	Slider	Stainless Steel, Sintered	1
4	Top Shield	Nylon, Inj. Mold	1
5	Comp. Spring	ABC No. C-0600-045-1500 Mech. Cad. Plate	(1)
6	Bottom Shield	Nylon, Inj. Mold	1
7	Inner Arm	Dural, Forged	1
8	Outer Arm	Dural, Forged	1
9	Bridge Assy.	Dural, Forged, Press	1
10	Centering Block	Aluminum, Die Cast	1
11	Torsion Spring	Music Wire #3	1
12	Link	Master for ½×⅛ chain	1
13	Centering Screw	M4×0.7 15 long	1
14	Locking Spring	ASC No. C0080-032-0500 Cad. Plate	(1)
15	Brake Shoe	Raybestos R2959	2
16	Pivot Bolt	Weinmann 62W	1
17	Locknut	" 46W	1
18	Nut	M6×1.0 15 Hex. Camera	1
19	Washer	#6 × ø16 1.1 thk "	1
20	Pivot Bolt Washer	Weinmann 52W	1
21	Spacer Washer	" 45W	2
22	Locknut, Outer	" 40W	1
23	Stirrup & Bolt Assy	" 1194	1
24	Cable Anchor. Bolt	" 35W	1
25	Nut	" 50W	2
26	Washer	" 105W	2
27	Brake Shoe Holder	" 109W	2

people in the company. None still rode a bicycle, and no one wanted to discuss our brake. Someone stated that they were working on another solution to the wet-braking problem....

Within a few months the new solution was revealed: the whole bicycle industry switched to using aluminium-alloy rims. They are much better than steel rims in wet weather. They provide a reasonable solution for people who will travel less than 2000 km on their bicycles. Those of us who use a bicycle for everyday use are less well served by aluminium rims. The braking surface wears very fast. Also, the pads pick up pieces of grit, which cut grooves around the rims. The rider has no indication of how much wear has taken place until the rim explodes under the huge sideways force of the tyre pressure. A rim exploding on the rear wheel just stops the bike unexpectedly. When it happens on the front wheel it can be fatal. How can this be a good solution?...

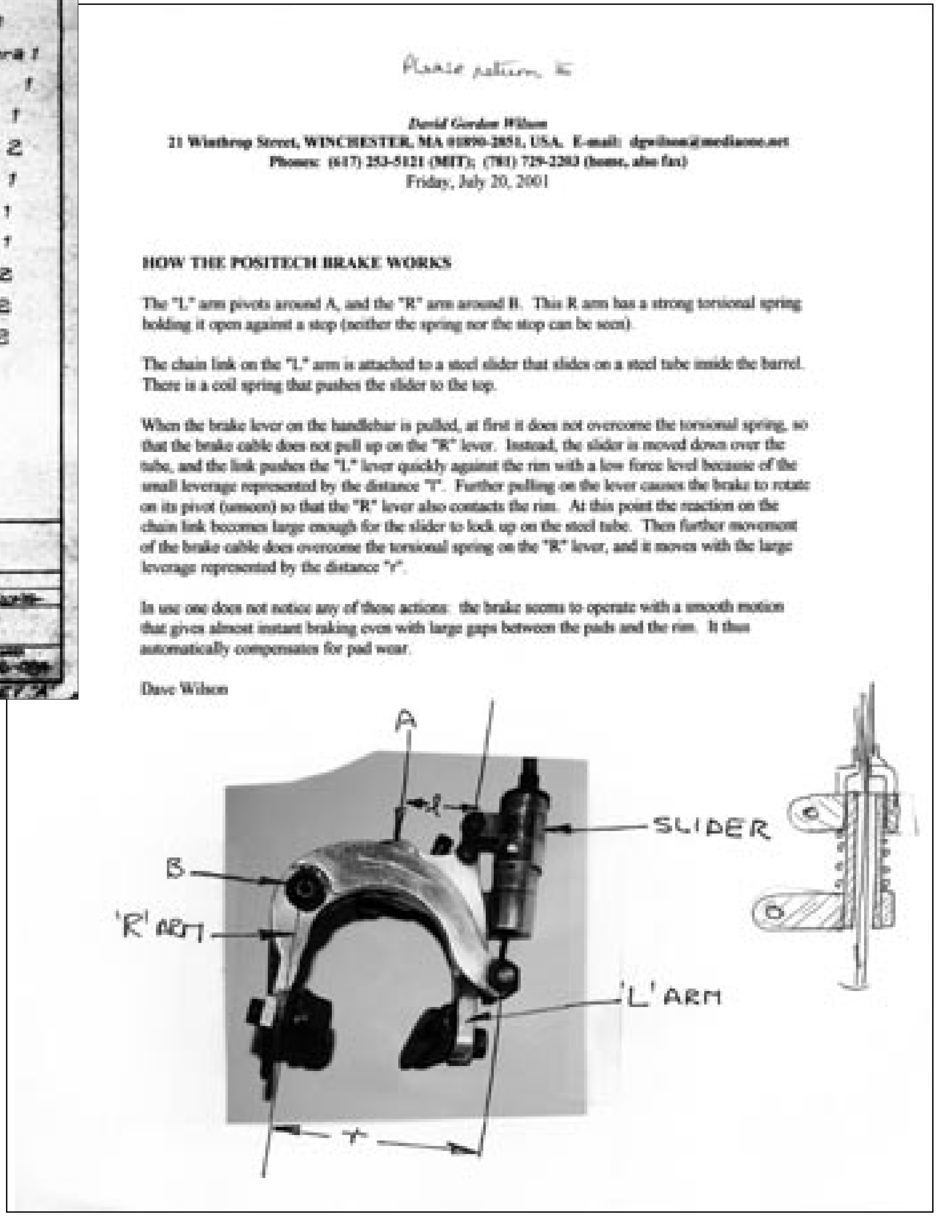
While I sometimes yearn for the days when I used a steel rim and a Positech brake on the front wheel with almost no concern about any aspect of stopping ability, wet or dry, I must confess that there was always one worry. All rim brakes heat the rims in long high-speed descents, and the heat can burst or deflate tyres, which, on the front wheel, can lead to nasty injuries. There is a brake now that avoids tyre bursts, rim explosions, and lost wet-weather braking: the disk brake.

How the Positech brake works

The left-hand arm 'L' pivots around A, and the right-hand arm 'R' around B. This 'R' arm has a strong torsional spring holding it open against a stop (fig. 7; neither the spring nor the stop can be seen). The chain link on the 'L' arm is attached to a slider which moves up and down a steel tube inside the protective barrel. A relatively weak coil spring pushes the slider to the top of this tube. When the brake lever on the handlebar is pulled, at first it does not overcome the torsional spring, so that the brake cable does not pull up on the 'R' arm. Instead, the slider is moved down over the tube, and the link pushes the 'L' arm quickly against the rim with a low force level, because of the small lever-age represented by the distance 'l'. Further pulling on the lever causes the brake to rotate on its pivot (unseen) so that the 'R' arm also contacts the rim. Further pulling of the brake cable can't move the slider further, so it now overcomes the torsional spring on the 'R' arm, and presses the blocks to the rim with the large force represented by the distance 'r'. In use one does not notice any of these actions: the brake seems to operate with a smooth motion that gives almost instant braking even with large gaps between the pads and rim. It thus automatically compensates for pad wear.

Figure 6. (Left) Allen Amstrong's "Positech" brake.

Figure 7. (Below) How the Positech brake works.



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Friday, July 20, 2001

HOW THE POSITECH BRAKE WORKS

The "L" arm pivots around A, and the "R" arm around B. This R arm has a strong torsional spring holding it open against a stop (neither the spring nor the stop can be seen).

The chain link on the "L" arm is attached to a steel slider that slides on a steel tube inside the barrel. There is a coil spring that pushes the slider to the top.

When the brake lever on the handlebar is pulled, at first it does not overcome the torsional spring, so that the brake cable does not pull up on the "R" lever. Instead, the slider is moved down over the tube, and the link pushes the "L" lever quickly against the rim with a low force level because of the small leverage represented by the distance "l". Further pulling on the lever causes the brake to rotate on its pivot (unseen) so that the "R" lever also contacts the rim. At this point the reaction on the chain link becomes large enough for the slider to lock up on the steel tube. Then further movement of the brake cable does overcome the torsional spring on the "R" lever, and it moves with the large leverage represented by the distance "r".

In use one does not notice any of these actions: the brake seems to operate with a smooth motion that gives almost instant braking even with large gaps between the pads and the rim. It thus automatically compensates for pad wear.

Dave Wilson

APPENDIX III: BICYCLE STABILITY AFTER FRONT-TIRE DEFLATION

The problem

On three occasions I have had front-tire blowouts, or at least rapid loss of pressure, that have resulted in my having been thrown off my bicycle with some violence. One was when riding a *Moulton* road bike as a bus was about to pass; one was on an *Avatar 2000* recumbent; and one on a new German *Viento* recumbent, when I narrowly avoided being hit by a large truck. A friend told me about someone who was, in fact, killed after his front tire burst, causing him to be propelled into the path of a car.

The reporting from dead bicyclists is zero, and the reporting of and examination of bicycle accidents are so perfunctory that it is highly probable that a considerable number of deaths and serious injuries are the result of instability following front-tire deflation. Therefore this has to be regarded as a serious problem.

Our study of the problem

In the summer of 1998 I wrote about flat-tire instability to an e-mail list then called HBS, for "Hardcore bicycle science". No one reported previous studies of this problem apart from one described by Doug Milliken, who wrote a letter "Flat-tire directional performance" to *Human Power* in spring 1991 (9:1, p. 17). He tested a motorcycle fitted with proprietary run-flat tires on the rear wheel. The tires had a flap of rubber on the outside of the tire that fitted tightly over the rim and acted as a bead-retention system. One with a small flap did not in fact hold the bead when the tire was flat, and the bead fell into the "well" in the rim. The tire flopped around, causing the motorbike to go unstable, even though the tire was on the rear wheel. The second tire with a wider flap held the beads in place. With this tire, Milliken found that he could run the bike at high speed (80 km/h) and could perform various maneuvers without problem. He thought that good run-flat bicycle tires would probably be tubeless.

I also wrote to other e-mail lists, and several writers contributed valuable experiences and suggestions. Some reported similar occurrences to mine, including Dave Larrington of the British Human Power Club, who had had "***instant*** crashes" from front-tire flats on regular bikes and on recumbents, and Joshua Putnam, who considered the problem serious enough to institute the practice of letting the air completely out of the front tire when trying out a new bike. Bill Volk wrote, "I too find the situation to be unacceptable. I run heavy, inefficient thorn tubes because of my fear that a blow out at high speed would be a disaster. Why can't we have rims that retain the tires even at no inflation? And perhaps a rubber strip that is placed around the rim, under the tube, that supports the bike on loss of air pressure…. I had Performance semi-slick 26" tires that fit so snugly that you could safely ride no-inflation. That should be the standard."

Presumably because of a tight-fitting tire, Ed Deaton of Fools Crow Cycles, faced with difficult choices, rode 8 km on a flat front tire: he had IRC "Road-lites" with Sun M14 rims. Similarly Andy Milstein of Princeton had no trouble riding with a flat front tire. It was a Tioga Comp Pool, measured by Mark B. of Wheel Life Cycles to be 46 mm wide, on a Sun CR-18 20×1.75" rim of about 27-mm width. (That was significant because one of my early suspicions, and a concern of Larry Black, was that a wide tire on a narrow rim might have a greater tendency to "flop" alternately left and right. This suspicion was thus shown to be unfounded.)

Bill Volk mentioned that Sutherland's *Handbook for Bicycle Mechanics* had a good section on fits between different brands of rims and tires, but my edition did not have this section, and I could not get an answer to my letter to Sutherland asking about standards of fit. John Allen, prominent bicycle expert and author, sent me a copy of his *Japanese Industrial Standards* D 9421, "Rims for bicycles", giving a tolerance of ±3 mm for rim circumference, and of standard K 6302 "Rubber pneumatic tires for bicycles", which, he pointed out, gave neither tolerances nor dimensions of tire beads. (Later, Andy Oury found that the International Standards Organization ISO 5775/1 "Standards for bicycle tires and rims" also had tolerances for rim diameters but not, as far as he could determine, for tire beads).

My instinct tells me that the old inch sizes had some specified or customary standards because my old 27×1¼" and other "inch" tires were all at-least "good" fits on the rims. Now, it seems from our experience and that of many people who wrote to me, it is entirely by chance that one gets a tire that is a tight fit on a rim and that will therefore provide a substantial degree of safety in the event of a front-tire blowout. However, Doug Milliken, a long-time consultant to Alex Moulton, wrote that Moulton controls both the rim diameter and the bead size of his 17" tires.

In September 1998 I added the problem statement on flat-tire stability to my list of undergraduate-thesis topics at MIT. Andy Oury, then a senior, responded enthusiastically, carried out several valuable experiments, and has allowed me to report some of his results here. We drew up a too-ambitious program in which we wanted to look not only at bead retention but also at the effect of the ratio of tire width to rim width (ATB tires in particular are usually bulbous, having a pear-shaped cross-section on what seems like a small rim) and of tire-sidewall stiffness. Andy Oury worked on what the correspondents just quoted thought was the most important factor, bead retention.

The experiments

We first thought that we could do a highly controlled experiment by having my troublesome bicycle wheel and tire, held in a frame, running on the surface of an inverted portable belt sander. However, the tire did not display the extraordinary alternating flops, left and right (fig. 4), that had thrown me off my bike, and that had prevented me even from pushing the bike subsequently (fig. 5). Oury found that, for the flopping behavior to occur, he had to rig up a bike to run along a simulated roadway with a similar number of degrees of freedom as has a bicycle when it is being ridden (or pushed).

The simplest way of producing bead retention on the shoulders of the wheel rim after deflation seemed indeed for them to be a tight fit. I have had tires that could be stretched over the wheel rims only with great difficulty. When these were inflated, the tire beads remained in the rim "well" until the tube inflation pressure reached around 80% of normal full pressure. They then "snapped" over the rim shoulders with a satisfying crack. My experience follows that of Doug Milliken and Bill Volk: I have never found tire instability with tires that were a tight fit on the rims, and which, therefore, did not flop loosely around in the rim when they became deflated. I confess that I cannot remember if I have had a front-tire blowout with a good-fitting tire. I would certainly remember something like the instability that made staying on the three bikes mentioned above absolutely impossible.

The tires that caused me the problems were exceedingly loose. This characteristic made puncture repair almost a pleasure, because one could get the tires on and off without tire levers. They were so loose, in fact, that centering them during subsequent inflation became difficult: it was easy to produce an eccentric rolling surface, even to the extent of having the tube pop out between tire and rim where the tire was "high". Oury built up the rim shoulders using standard "masking" tape, and he put on fifteen layers before the tires were retained and the flat-tire flopping was inhibited. His experiments therefore did a great deal to confirm the premise: that a slack fit between tire bead and wheel rim is the prime cause of flat-tire instability and that a tight fit will therefore provide a substantial degree of safety in the event of a front-tire blowout. [11]

His tentative results were borne out by Soohyun Park, who subsequently performed more careful experiments in which the test bicycle was loaded in various ways to simulate the loading on bicycle tires, and in which she (and I) successively built up the rim bead shoulder using fiberglass resin until a tight fit of the tire beads was obtained [12]. The improvement in tire stability and front-wheel tracking was dramatic.

Recommendations

The International Standards Organization (ISO) should form a committee of tire and rim manufacturers to agree on standards of rim diameter and shape and of tire-bead diameters so that a tight fit could be relied upon in all circumstances.

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INTERNET GLEANINGS

Demise of the rickshaws in the orient

From: Bill Telfer, 1 Jan 2002

In the Sunday *Southern China Morning Post* was an interesting article about the demise of the rickshaws in Hong Kong. They haven't been used as a commuter mode of transport for thirty years at least, but have always been good for trapping a few tourists, except that traffic conditions have become so hideous that nobody now even wants to sit in one to have a photo taken. Also the remaining few rickshaw men were becoming so aged and decrepit that even the most crass tourists must have balked at asking the old man to pull them along.

The first random thought is about the often invoked issue of colonial exploitation. The supposed indignity of this type of labour, the 'poor rickshaw man', a martyr to imperialism, etc. Well, yes, I guess so, but of course they were just employees of Chinese businessmen who owned the rickshaws—rickshaw magnates, just as taxi drivers today don't own the cabs they drive. But is it really an undignified job or service for a fit person to perform?

The last four machines are up for sale at about US$1'500!

Across the mouth of the Pearl River in Macau a few pedicabs remain. These vehicles are much more up my street, and in the 20-odd years I have been visiting Macau I've often used them and never felt exploitative at all.

However in the past 5+ years their situation has deteriorated to almost the same level as the rickshaw and I doubt if anyone uses them as everyday transport as was the norm until, as I say quite recently. Last time I went to Macau a few weeks ago I was shocked by the growth not so much of cars, as of scooters. It seems every person between 16 and 30 has one. I was cycling of course, and found them much harder to deal with than cars as they come up on the inside as you're trying to maintain a road position in relation to the cars!

What I want to ask is about pedicabs appearing in the UK in recent years. Has anybody got any information on this?

—bill telfer

Rise of the pedicabs in the occident

From: Andrea Casalotti, 2 Jan 2002

In London there are about 80 pedicabs and three main operators.

One of the vehicles used is made in Bath by Cycles Maximus; I think it is the best pedicab on the market.

The local authority is reviewing the industry with the view of regulating it.

—Andrea Casalotti
ZERO
7c Plympton St
London NW8 8AB

The tender independent feelings of water molecules

George Tatum, 17 Jan 2002

[*Editor's note:* George Tatum started a company manufacturing fast human-powered boats, which he also races himself. He has started an ambitious testing and measuring program and shares his data freely with others and we will eventually share it with you. In the meantime, we offer you George's textual cartoon on boundary layer theory and hull design:]

First of all, water will not compress. Also, it will not expand. If forced into a vacuum situation, water will get angry and boil.

Water is made up of molecules that readily attach themselves to a hull shape. These molecules will build up a film which lubricates the hull of a boat. This is very helpful.

At the same time, water hates to be forced into a change of direction unless it is moving on its own in rhythm or waves, kind of like dancing with a fat girl.

The reason water behaves like this is molecular. Water molecules love to help hull shapes move along, but hate to share or be crowded. When a hull meets a water molecule, the best thing it can do is, as subtly as possible, suggest to the water molecule to gently move back, like a dance step. The molecule wants to cooperate. But the water molecule cannot fit in between her girlfriends which are under her, in front of her, or beside her. The only thing she can do is jump or push. Jump is bad. Push hard is bad. But push back ever so lightly is good. If she pushes gently behind her, the girls in the rear, rise a little, giving her ample room to slide out and in as she rubs herself along the hull shape.

Now, I have moved a lot of water molecules in my life and I have grown from each. Firstly, if you suggest to a molecule that she move a direction with a certain force, keep the force exactly consistent in the movement. ***Do not violently increase or decrease the force, ever!***

Optimum reward comes with exact consistency. Slight changes in pressure are okay, though they too come at cost. For example, if you are pressuring a molecule away from the hull shape quickly, and then suddenly slow her down, she will have to suddenly suck on her friends who are still pushing her, and they are apt to trip all over themselves. On the surface, this looks like a wave. The same applies to the withdrawal, but the key is to never let the molecule know you have changed direction. The withdrawal part of the hull shape should optimally suggest the same type of movement with the same force as the intrusive entry part. In fact, it is best if the molecule doesn't even realize you've come and gone. The more she does, the more wave you make, the slower your progress.

If you change the radius of your hull shape's curve, you will cause the water molecule that meets this change to have to push back harder, or pull back harder on those around her. This easily could cause molecules to pile up and fall over, which, as I mentioned before, is a wave. If you run a curve hull shape into a sharp point, or a void, you will bludgeon molecules you meet, and not only do you get a wave, you could get angry, boiling, cycling water, working against you in a collective. If you have a flat surface that transitions to another flat surface, you will face an angry mob of girlfriends. It takes millions of these girlfriends to cost you a knot of speed. But why make war in a sea of love? (Hydrofoils float by doing violence to a few. This method may be unbeatable in short, hard efforts—but love is measured in distance)

The main hull wave is different from the hull skin transition waves. The hull wave is a happy love memory that you must figure out how to mount as high as possible. Hull shape transition waves are independent angry girlfriends dragging in their heels as you pass them by.

The prismatic coefficient states that if you slap a molecule when you meet her and slap her again when you break up with her, you will get the most from her in-between. This works until you are really looking for the big cooperative hull wave, something bigger than your hull form itself.

Don't even consider building a diamond shape. A diamond will slap water molecules, in the middle of locomotion, and they will all hate you.

Think subtle, smooth, long, but firm. Go gentle, but [with] consistent pressure, and go as light as you can.

Despite the lack of math in my head, I sure have fun. As long as the sea keeps treating me as well as she does, I will remain hard consistently to beat in the human-powered circle. Someday I will be more sea than human.

—Geo

Arm-and-leg-powered tricycle

The picture shows Robert Barnett of Choctaw, Oklahoma and his amazing arm-and-leg powered *X4*.

Arm-and-leg powered recumbents, both two- and three-wheel, aren't new—and one, the Angletech *Quadraped*, is available commercially, but they all have required the rider to pivot the hand-cranking mechanism in order to steer.

What makes the *X4* unique is that instead of attaching the arm-cranking mechanism to the steering fork, Barnett developed a twisting mechanism to steer it. That is, the plane in which the hand cranks revolve doesn't change, but while pedaling with your hands, all you have to do is twist your wrists to the right or left to steer.

Since the brake levers also have to be attached to the hand cranks, it makes the mechanism rather complicated. All the linkages are done via conventional bicycle cables and pulleys.

Barnett said that it took him four years and a lot of prototypes to develop the *X4*. "This is the 14th model," he said, referring to the machine depicted here.

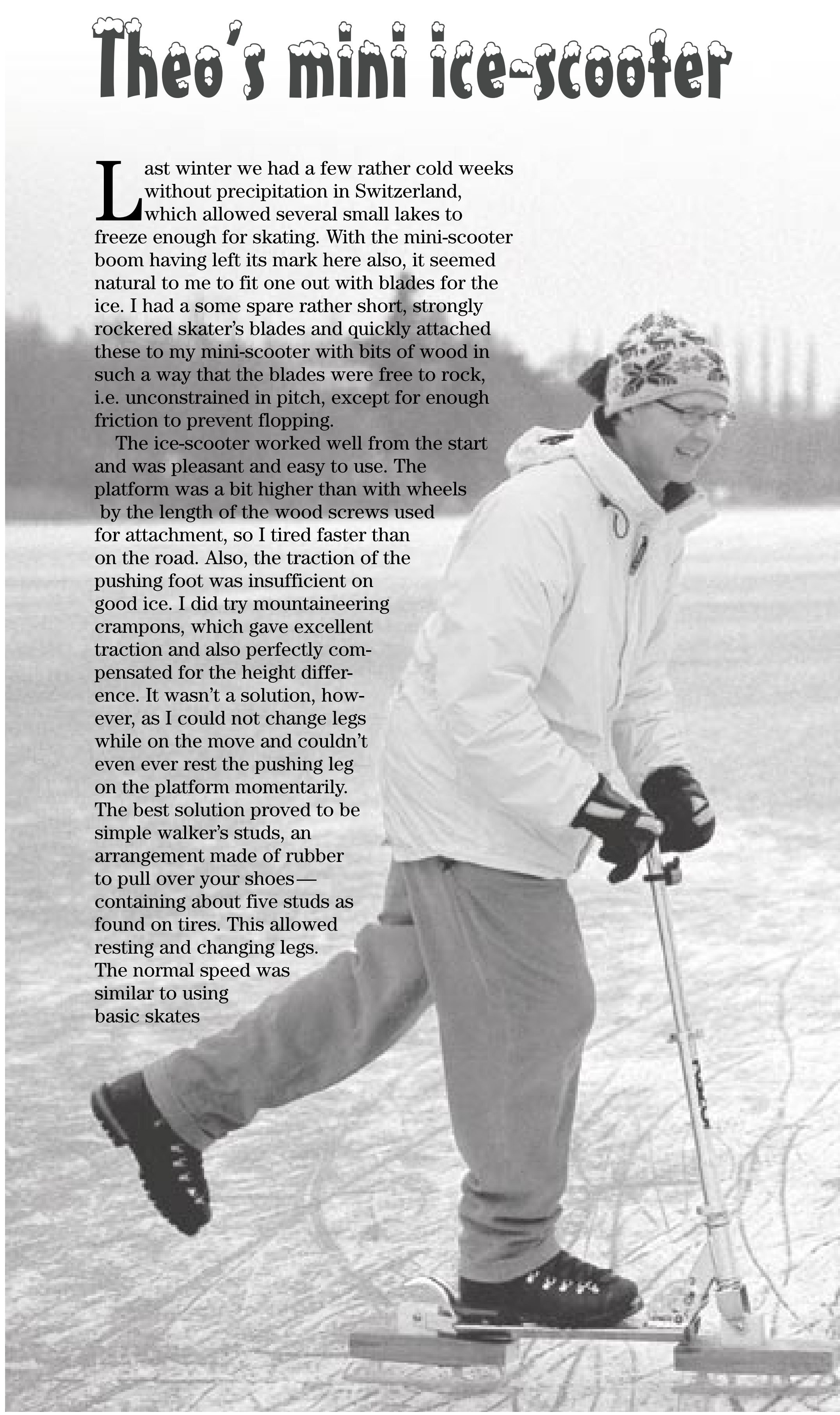
The basic trike frame and seat are an S&B Speedster (made in California), but Barnett carried out significant modifications to the basic trike, including making a titanium rear axle, in addtion to the hand-cranking mechanism.

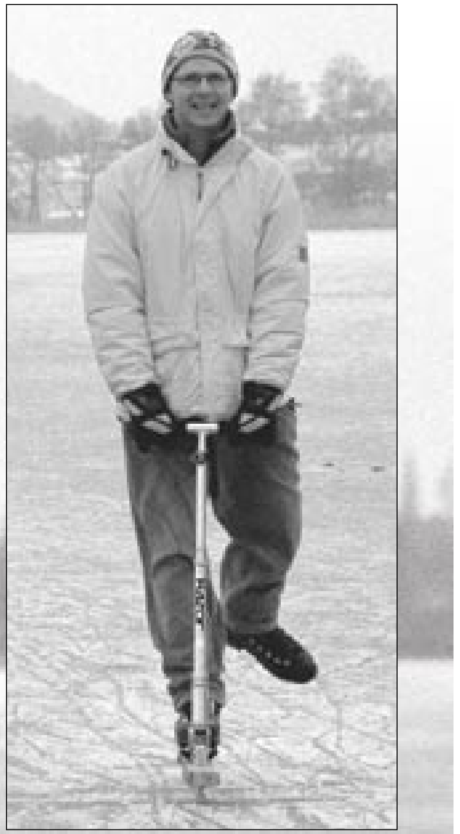
Making it all possible, in addition to Barnett's ingenuity, is his business workshop, Barnett's Tool & Die. The *X4* design is patented and Barnett is hoping to find a manufacturer. He can be contacted at 915 Oak Park Dr., Choctaw OK 73020, USA.

—Submitted by Mike Eliasohn

Robert Barnett provided this photo of his hand-and-foot-crank trike.

Theo's mini ice-scooter





Monika Flückiger

Last winter we had a few rather cold weeks without precipitation in Switzerland, which allowed several small lakes to freeze enough for skating. With the mini-scooter boom having left its mark here also, it seemed natural to me to fit one out with blades for the ice. I had a some spare rather short, strongly rockered skater's blades and quickly attached these to my mini-scooter with bits of wood in such a way that the blades were free to rock, i.e. unconstrained in pitch, except for enough friction to prevent flopping.

The ice-scooter worked well from the start and was pleasant and easy to use. The platform was a bit higher than with wheels by the length of the wood screws used for attachment, so I tired faster than on the road. Also, the traction of the pushing foot was insufficient on good ice. I did try mountaineering crampons, which gave excellent traction and also perfectly compensated for the height difference. It wasn't a solution, however, as I could not change legs while on the move and couldn't even ever rest the pushing leg on the platform momentarily. The best solution proved to be simple walker's studs, an arrangement made of rubber to pull over your shoes—containing about five studs as found on tires. This allowed resting and changing legs. The normal speed was similar to using basic skates (not speed skates).

On ordinary white ice a comfortable long-distance speed was about 15 km/h (almost 10 mph). On bumpy ice it was more comfortable to use the scooter than skates. I never found any really perfect ice except for very brief stretches, where the feeling was then very similar to using the wheels on a perfect surface. The controllability was as good as with the wheels, quite tight curves being easily possible.

Where the ice-scooter really proved ideal was on a frozen creek, where I could go downhill over stretches I wouldn't dare to with skates. Although there was no brake (as for the road), the free foot made a good brake, especially with the walker's studs, yet more controllable than trying to brake this way on the road, where friction and shoe abuse are too high. The mini-ice-scooter still folds and can easily be carried everywhere, but the bit of extra weight is quickly felt. However it takes only a short time to switch back to the wheels, so that this remains a usable transport solution.

—Theo Schmidt

BOOK REVIEWS

Von Null auf 140 mit 93 Zähnen: Aerodynamik von Pedalfahrzeugen

by Andreas Pooch
Liegerad-Datei-Verlag, Troisdorf 2001
www.ligerad.de/aero.htm
ISBN 3-9806385-2-9
€12.65
112 Pages (7 of these are advertising), A5

Reviewed by Theo Schmidt

In spite of it's title (translated *Zero to 140 with 93 teeth: Aerodynamics of pedalled vehicles*), this book is highly readable also by non-aerodynamicists, not containing much in the way of highly technical material. It is rather a copius account of the history of streamlined HPVs to the present day, perhaps the most comprehensive coverage yet available in the German language. It is richly illustrated with over 100 small but clear B&W photos and figures. The vehicles are described chapter by chapter in a vaguely chronological order. Not much is said about competitions or human interest stories, the writing style is factual with no personal commentary, the focus being on technical description and construction. One thing I learned from a description of the SRM power-measuring system, is that corrections must be applied for curves, as two-wheelers lean and the wheels travel further than the path the vehicle's center of mass takes.

Cover illustration: Andreas Pooch

Commercial velomobiles like the Leitra, Go-One, Allweder, and Quest are described and pictured. There is also a description on how to make a fairing from closed-cell polyethelene (sleeping mat material). There are some addresses and references, mainly German-language and European, "Human-Power" is not referenced at all, and the IHPVA only briefly mentioned. In spite of this, American vehicles and record-holders are described fully, drawing on references from *Cycling Science* and *New Cyclist*.

This book is a must for German-speaking HPV enthusiasts and interesting to look at for others as well.

—Theo Schmidt

The recumbent bicycle

by Gunnar Fehlau; translated from the German by Jasmin Fischer
Out Your Backdoor Press,
4686 Meridian Road, Williamston MI 48895, USA US$24.00 postpaid
ISBN NO. 1-892590-55-7

Reviewed by Dave Wilson

We owe thanks to Jeff Potter, well known to IHPVA people, for becoming a publisher and bringing us this excellent book. Gunnar Fehlau is an enthusiast for recumbents, and it shows.

The book starts with a good history, told with a distinctly European perspective. I was thrilled to read about the pioneering efforts of Paul Rinkowski, of whom most of us in North America know too little. He lived in Leipzig, and built a startling array of different recumbents from 1947 until he died in 1986.

The second chapter deals with using recumbents for city use and on tour. Good advice is freely given for all manner of topics and conditions, even some at an extreme at which this reviewer (who rides every day of the year) would balk.

Chapter 3 is on racing and speed records; 4 on aerodynamics. A clutch of good color photos appears at the end of this chapter. (Not all are attributed and described, which would be desirable. I had mixed feelings when I saw, earlier in the book, a very bad sketch of mine, and in this case I was glad not to be acknowledged!)

There follows the longest and best chapter (5), "Basics of recumbent design", in which Gunnar Fehlau applies his wisdom to just about every aspect of different types of recumbents, complete with long lists of advantages and disadvantages of each variation. I have not seen this level of detail and guidance, and it is excellent.

The last, short, chapter is on building your own recumbents and fairings, and is useful without being encyclopedic. At the end is an appendix of recumbent resources (e.g., the addresses of builders and suppliers, clubs, web sites etc.) worldwide, which will be appreciated.

This book should be read by everyone contemplating designing and building a new recumbent. It is very good value.

—Dave Wilson

LETTER

Background

The original letter below was posted to a listserv for a small audience: the North American hpva-board list. Newly-elected board member John Snyder wrote the message in response to a suggestion by another new board member, John W. "Elrey" Stephens, who suggested, "Before we survey the membership, though, how 'bout a survey of the board? What do we want from the HPVA, in return for our effort and our dues?"

—Jean Anderson

In response to Elrey's suggestion for survey of the new board of directors

I continue to be captivated by the ideals expressed in Article III of the HPVA by-laws, especially paragraphs b and d as appear below.

> **ARTICLE III. PURPOSES, OBJECTIVES AND FUNCTIONS SECTION 3.02 SPECIFIC PURPOSES**
>
> (b) Information. The corporation shall serve as a source of information for all human powered land, water and air records and all other records pertinent to the pursuit of human power. The corporation shall act as a source of technological information on human powered transportation.
>
> (d) Stimulate competition and creativity. In all rules, regulations and executive decisions of the corporation, it shall be the overall philosophy and policy of the corporation to stimulate and not stifle competition and creativity. To this end, the fewer and simpler the rules, restrictions and regulations, the better.

Meeting the above objectives is exactly what I want to see happen as a return from effort and dues.

Competition is a very useful public relations tool in that can bring awareness of the HPV concept to the general public in a dynamic and exciting way. Competition also can help motivate, via the promise of a tangible reward and emotion, the creation of new innovation. However, for this type of exploration to have a meaningful purpose competition must be ultimately applicable to pragmatic applications.

I think that the amount of competition is good as is. However, inclusion of records for HP vehicle classes and events that did not exist twenty years ago might now be formally acknowledged, such as: kick scooters, personal achievement on stationary ergometers, roller blading, HP hovercraft, ocean crossings, and other future developments we might not be able to foresee at this time. This may be an IHPVA rather than HPVA matter.

It's as if there is a mini-dark age of stagnation where learning for its own sake is temporarily no longer fashionable, and that the sublimely interesting and infinite subject of human power has become muted in academia. Did you know, as an example, that according to David Rodgers, director of the Office of Technology Utilization, the U.S. Department of Energy currently devotes ***zero*** resources to the study of human powered topics? That is a frightening omission, one that helps clarify the essential need for this association to continue to try filling our unique niche.

Allow a wild daydream for a moment. Imagine that all of the educational materials produced by the HPVA and IHPVA were available in every high school and college campus with an athletic or science department, in North America. And that regular scientific symposiums were once again held that encouraged meaningful basic research to be conducted and made public. These might be ways to keep the dream of widespread application of HPV-related technologies fresh and vital. The knowledge of others' accomplishments can pass along the all-important but nebulous notions of possibility and hope. Fill out the daydream with the HPVA's membership rolls representing at least 3,000 souls within the next three years.

As long as ***hope*** and ***dreams*** exist we human-powered humans have nothing to fear. The altruistic motivations that gave birth to the IHPVA and the HPVA are still 100% valid.

Without visible progress and growth in any endeavor, enthusiasm wanes. Yet, the invisible foundation that supports any entity which enjoys healthy sustainable growth may well be deemed its most important. Our rock-solid foundation is the acquisition and dissemination of knowledge about Human Powered Vehicles.

—John Snyder

HPVA & IHPVA

Because the North American HPVA continues to produce *Human Power*, the technical journal for the IHPVA, the latest election of board members for the North American organization, as well as future dialogs with other IHPVA member organizations, will be very important for the future of this publication.

At the present time, the HPVA continues to pay all costs involved with the technical journal: layout services, envelopes, printing, mailing, storage—and servicing the four or five single subscriptions provided. The latter must be handled separately, causing extra time and costs for airmail postage.

Delayed for two years, the HPVA recently held an election for seven board members (Alan Thwaits resigned during 2001). The newly-elected members, most of whom have not held office with the HPVA, will determine the direction of the North American organization for the next few years.

HPVA board election results

Name	Expires Dec.	E-mail address
Gerry Pease	2002	ger_bar@juno.com
John Snyder	2003	JCSnyder.studio@worldnet.att.net
Jake Free	2003	JFreeEnt@AOL.com
John Cooper	2003	jcooper@stic.net
Paul Pancella	2004	pancella@wmich.edu
John Stephens	2004	lray@ihpva.org
Jean Anderson	2004	slohpver@charter.net
and, incumbents		
Sean Costin	2002	seancostin@aol.com
Danny Too	2002	dtoo@po.brockport.edu

Paul Gracey, former HPVA board member, is the North American representative to the IHPVA.

Human Power

During the past few months, David Gordon Wilson (HPVA), Richard Ballantine (BHPC), and others have been engaged in an e-mail dialog about the future of the technical journal, i.e., how it can reach more people who would like to receive it without being a member of the HPVA, how costs can be shared, how and where production, printing, etc., should take place.

At the present time, some 22 technical libraries around the world are subscribers, and it would be nice to attract more.

—Jean Anderson

International Human Powered Vehicle Association

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