Adding arm power to a recumbent

by Daniel Kirshner

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.

Figure 1. Dan Kirschner on his custom recumbent bicycle

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.

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

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

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.

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).

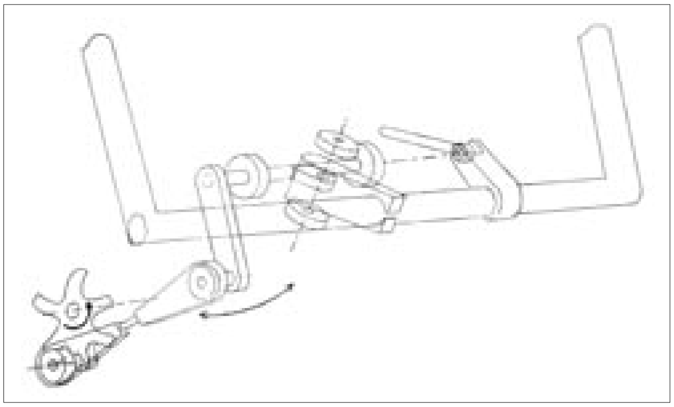

Figure 3. Diagram showing the main feaures of the mechanism

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 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.

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	—

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!

References

[1] Whitt, F. R. & Wilson, D. G. 1982. *Bicycling Science*, 2nd ed. Cambridge, MA: Massachusetts Institute of Technology.

[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.

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