Bicycling Magazine's Newsletter for the Technical Enthusiast

BIKE • TECH

Aerodynamics • Mechanics • Physiology • Materials • Engineering

IN THE LAB

Volume 1 1982

The Ultimate Titanium Frame?

As Stiff as Steel at Half the Weight

Fred DeLong and Crispin Miller

An accident in a brazing furnace and the two strange-looking bicycle frames that emerged have led Cecil Behringer and Pino Morroni to develop a promising new treatment for titanium bicycle frames. From the "victim" frames it appears that the treatment can approximately double the stiffness of a titanium frame. If the controlled version of the treatment works, it should create frames with the same stiffness as steel, at barely over half the weight. Moreover, since Behringer and Morroni's frames are lugged and brazed, they have no welds prone to soft or brittle spots. In short, these bikes may avoid both of the major problems of other titanium frames.

Behringer is now building a chamber to apply the controlled treatment, which hardens the inside and outside tubing surfaces by electrically implanting nitrogen atoms into the titanium. He is also building two frames to treat in it. These frames will be exhibited at the 1982 International Cycle Show in New York in February and the American Welding Society meeting in Kansas City in April.

Behringer is a metallurgical engineer from Edina, Minnesota, well-known for his expertise in metal-joining techniques for aircraft and spacecraft. He has also been active in bicycling for most of his life; he rode in six-day races in prewar days and learned framebuilding from "Pop" Brennan in 1936. A self-professed fanatic, he also builds portable steel velodrome tracks. Morroni, now of Rome, is known by many cyclists as the developer of wheels with spokes screwed straight into the hub flanges, avoiding the bend where fatigue causes breakage. He also makes special saddle frames, bottom brackets, and headsets, and is noted for his uncanny mastery of machining techniques. In their collaboration on bicycle frames, Morroni machines the titanium parts and Behringer joins and treats them.

The collaboration began in 1971 when Morroni, then living in Detroit, approached Behringer at a show there and suggested that they could build titanium bicycles. Behringer agreed, and they developed a system of lugs and brazing techniques to join high-strength titanium alloy tubing.

Other titanium frames had been made by inert gas welding, either of pure titanium or high-strength alloys, but the welding had detrimental effects. If this process was applied to high-strength alloys, it overheated them, necessitating heat treatment afterward that could distort the frame's alignment; and even with pure titanium, welding carried the risk of chemical embrittlement. Heated titanium is extremely reactive, and even if the welding region is shielded by streams of inert gas, any deflection of the gas stream by air currents allows atmospheric moisture, oxygen, and nitrogen to reduce the strength of the weld and make it brittle in spots.

Behringer took inert-atmosphere brazing techniques which were in standard industrial use for reactive metals and applied them to titanium bicycle construction. He heated the joints electrically or by quartz lamps in a furnace evacuated or filled with argon. The airtight furnace prevented any atmospheric contamination of the heated titanium.

But it did not protect the titanium from the furnace operator's mistakes. In 1973, when four of the frames were being brazed in a large furnace made available by a local factory, the process reached a stage at which the furnace was to be cooled by introducing cool argon. The operator used nitrogen instead.

When the furnace was opened, Behringer was horrified to find the frames covered with a gold and purple layer of nitrides. Two of them were so heavily encrusted with other reaction products as well that he considered them unusable (and still does). But two frames seemed to have possibilities, so he and Morroni assembled them as bicycles.

They happened to be not just all right, but the stiffest titanium frames Behringer and Morroni had ever seen. A scrap of tubing that had hung in the furnace along with them was tested and turned out to have approximately

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doubled in stiffness. The frames were made from tubing of standard diameters and .025-inch thickness for comparison to (straight-gauge) Reynolds 531 of that thickness; they weighed 3.6 pounds with fork and headset installed and 10 pounds assembled as track bikes.

Why Stiffer Frames?

Why the frames were stiffer is not completely clear. It is generally agreed that yield strength of metals can be increased by alloying substances, such as nitride, whose atoms occupy the occasional gaps or "dislocations" between atoms in the metal's crystalline matrix. When metal "yields" to a stress and deforms, it does so by slippage between layers of atoms in its crystals. Dislocations can facilitate this slippage by allowing the atoms on a slippage plane to shift one at a time; as each atom moves into the gap, it leaves a new gap behind it for the next atom, and so the gap moves up the line in a sort of musical chairs game. If the gaps are clogged with nitride ions (atoms), then deformation cannot occur unless whole planes slip at once. This requires a greater force, and therefore the yield strength is greater.

This increase in yield strength is a widespread phenomenon and is, of course, the motivation for making most structural alloys. But while alloying often increases yield strength, it does not normally affect stiffness (or "modulus of elasticity"), because elastic deformation (change from which the metal springs back on its own) does not involve slippage of crystal planes. Whether alloying can ever stiffen a metal by blocking its dislocations is a debatable question. Behringer thinks that it may. Possible other stiffening effects are a matter of conjecture.

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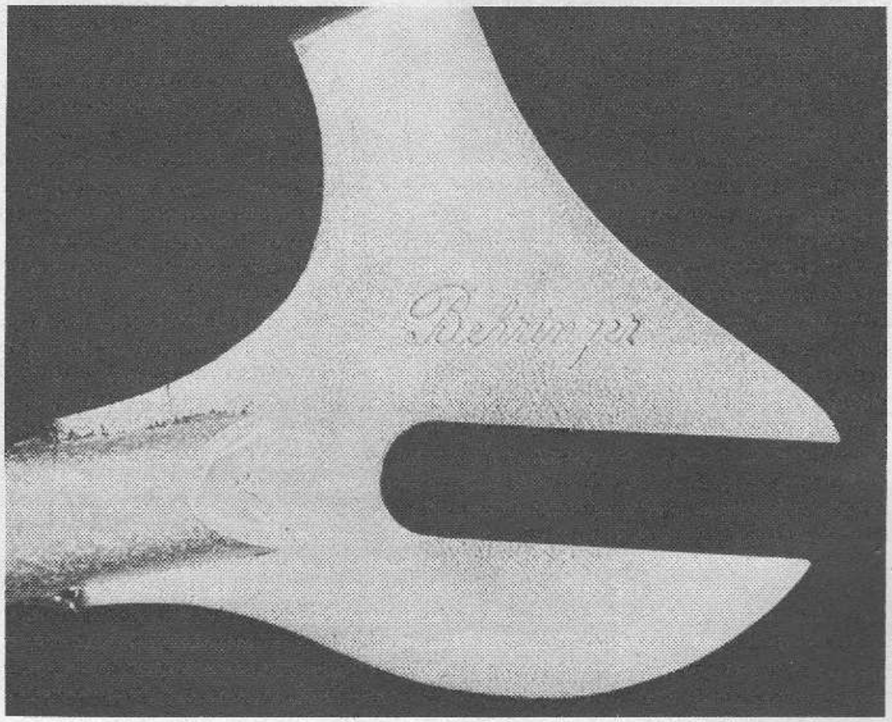

Malone Bradley

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Morroni took the bikes to Italy. People scoffed until he rode one down a stone staircase. Czechoslovakian Olympic sprinter Anton Tach, who had been among the scoffers, then took some time trials on it. He rode six 400-meter track trials, three with the titanium bike and three with his own bike. He consistently broke his own record with Morroni's bike and never met it with his own bike.

Since 1973 the bike has been ridden 22,000 miles, including many races, by a large group of riders. It has been repainted four times; each time, Behringer has stripped it and inspected it for fatigue cracks by the dye-penetration method. So far he has not found any.

(The other frame was retired early because Behringer decided to rebuild it as a smaller size. So far his busy schedule has kept him for finishing it.)

Controlling the Process

In spite of the nitrided frame's success, the haphazard nature of its processing deterred Behringer from making any more, until he found a way to control the process. That technique appeared in 1980, when American industries developed processes for arc-plating or "sputtering" titanium nitride onto other metals to produce very hard surfaces, for such things as cutting tools. (Behringer was bemused later to discover that German industries had been using the process for nearly a decade.) Behringer experimented and learned that nitrogen could also be sputtered into an existing titanium surface to produce the same sort of titanium nitride surface, and then he set out to produce the new nitrided frames.

Behringer and Morroni make their frames (including the lugs) from a titanium alloy containing 3.5% aluminum and 2.5% vanadium, with a yield strength of 140,000 psi (roughly twice that of pure titanium). The lugs are constructed from various sizes of tubing, bored and mitered (by Morroni) and then brazed with a titanium-copper-nickel filler compound by quartz lamps shining into a small argon-filled quartz furnace. Brazing temperature is 1650°F, not hot enough to damage the alloy. The assembled lug is kept at brazing temperature for 15 minutes to let the copper and nickel diffuse into the adjoining pieces of titanium. This strengthens the joint and also raises its melting point; the same filler compound could be used again to fasten the frame tubes into the lug, and the first joint would not melt.

The frame tubing is from a supply of 12 frames' worth that Behringer had custom-drawn by Zirtech, of Albany, Oregon, when he and Morroni started making titanium frames. As in the "accidental" frames, it is drawn to the same diameters and gauge as a set of .025-inch straight-gauge Reynolds 531 (which Behringer took to Zirtech and asked them to match).

The frame tubes are brazed into the lugs with a filler of nickel-copper-manganese or of aluminum-copper-tin-silicon, in an inert-atmosphere enclosure. In the current procedure, the enclosure is a 10-mil plastic bag around the frame subassemblies. Behringer flushes the bag twice by filling it with argon, heating the frame with infra-red lamps, and emptying the bag with a vacuum pump, to minimize any traces of water vapor or other contaminants. Finally he fills it again with very well-dried argon, and checks with a mass-spectrometer to see that its dew point is no higher than minus 100°F.

For brazing, the joints are heated by electrical resistance from current applied through aluminum clamps. (Clamps of other materials could contaminate the titanium.) The brazing temperature for these joints is 1200°F and is held just long enough to wet the joint.

The sputtering process is to be done in an insulated furnace. The whole-frame-sized furnace is under construction (as of November 1981) but Behringer has done test runs on smaller parts. The part being treated is hung from a tungsten wire, and a large titanium plate is hung beside it; the plate acts as one electrode for the arc process and the part acts as the other.

The first step of the sputtering process is a cleaning procedure to ensure that the coating will be uniform. Surface oxides from handling must be removed. To accomplish this, the chamber is filled with argon and the charge — 20,000 volts — is applied in reverse polarity. This removes 1,500 to 2,000 angstroms of material. The chamber is then vacuum-pumped for a half-hour to remove the contaminants.

The charge is then applied in the proper polarity with a superimposed high-frequency alternating voltage. The part glows with a purple halo. Dry nitrogen is fed into the enclosure continuously to maintain 1 or 2 psi above atmospheric pressure as it is consumed. The high voltage dissociates it, and the nitrogen ions are carried in a plasma arc into the surfaces of the part, forming titanium nitride. The length of application time controls the depth of penetration. (The "accidental" frames have nitride layers about 1 or 2 ten-thousandths of an inch thick.) The electrical discharge heats everything to 600°F, but the temperature is uniform and causes no structural distortion.

In addition to the predicted stiffness increase, the process imparts a very hard surface and a uniform golden color. Behringer plans to run structural tests soon on the new frames and on test scraps processed with them. He hopes to have numbers on stiffness, strength, and fatigue resistance by early 1982. He's also testing the process on turbine blades for one of his aerospace clients. We'll publish the bicycle results when they become available.

Price for a frame? Not for sale. Behringer thinks someone could probably mass-produce them for $1,000 or so, but wants it to be someone else. "I wouldn't consider taking an order for less than $10,000. I like to make these things as sort of a test bed for my metallurgical techniques, but I'm not so sure titanium is the best thing to make bikes out of."

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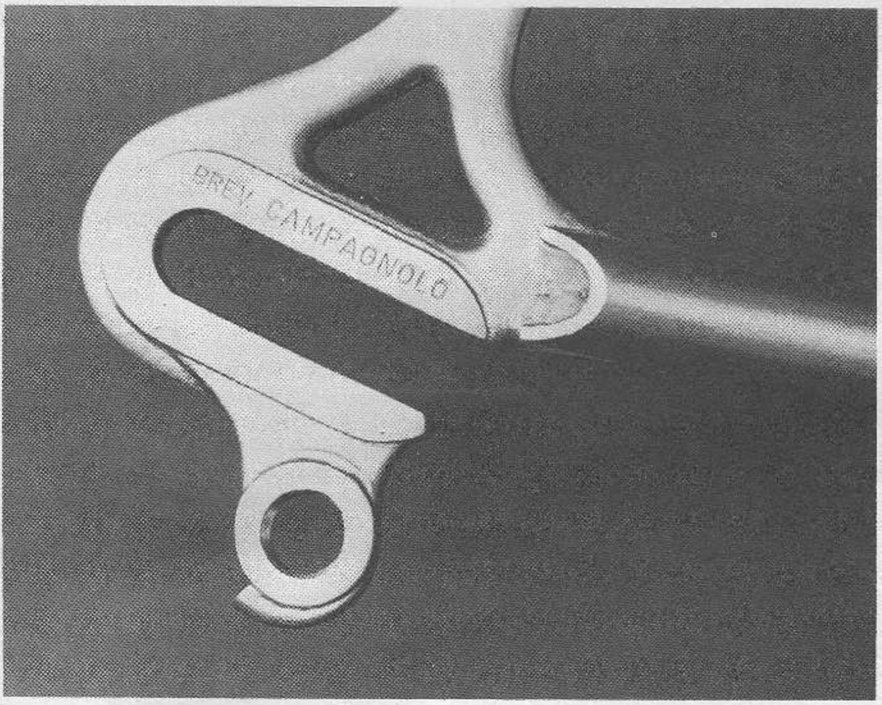
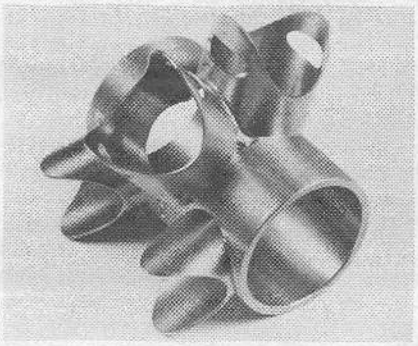


Malone Bradley

1 Track dropout of 6A1-4V titanium brazed with titanium-copper-nickel in vacuum.

2 Campagnolo titanium dropout brazed with titanium-copper-nickel in vacuum.

3 Titanium bottom bracket shell weight—87 grams. Each of the five pieces of the shell was hand-machined and then the shell was brazed together.



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TEST RESULTS

Silver vs. Brass Brazing

What Is the Real Strength Difference?

Mario Emiliani

What are the effects of brazing on the mechanical properties of Reynolds 531 and Columbus SL tubing? I answered that question in the September/October 1981 issue of *Bicycling* magazine. In turn, I received a number of critical letters which raised points I had not considered, including one about the strength difference between silver and brass brazing.

During torch brazing a temperature gradient is set up along the tube. The higher the brazing temperature, the farther back the gradient reaches. So if a high-temperature brazing alloy is used, the tube will be tempered (i.e. have significantly reduced tensile and yield strengths caused by exposure to temperatures between 1150°F and 1350°F) farther back, closer to the thinner unbutted section.

If this is the case, then the tube is weakened outside the lug, where it may not be thick enough to compensate for the loss of strength. Would it be possible to temper the tube beyond the butt using a high-temperature brazing alloy? In this case, the load the tube could support would be substantially reduced because the unbutted portion is usually very thin.

However, if a low-temperature brazing alloy were used, the tempered portion of the tube would be reinforced by the lug. My critics contend that the joint would be less prone to failure, and so they favor the use of low-temperature silver brazing alloys. I consider this hypothesis worth looking into. How far back a tube is tempered may be determined by testing actual brazed joints. Since I am not adept at brass brazing, I asked framebuilder Richard Sachs to braze one Reynolds 531 top tube/head tube joint[1] with a brass alloy (1630°F liquidus) and another Reynolds 531 top tube/head tube joint with a low-temperature silver alloy (1145°F liquidus). To have control over the experiment, the same tube lengths, tube gauges, and lug styles were used. The marked ends of the top tubes (short butt) were brazed into the lug.

To determine how far back the tubes had

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[1] The tubes were supplied by SRC GROUP INC., Portland, Oregon.

been tempered, hardness tests were performed along the length of the top tubes (Figure 1). A Rockwell digital hardness tester was used on the 30-T scale (30 kg major load, with a 1/16-inch steel ball indenter). The 30-T hardness values were then converted to a diamond pyramid hardness (D.P.H.) values.

The conversions to D.P.H. were made so the yield strength of the tube could be determined using the equation

$$\text{yield strength} = \frac{\text{D.P.H.}}{3.6} (B)^n (1422), \text{ in psi}$$

where $B = 0.1$ and $n = 0.08$ for steel[2]. The results of the hardness tests are given in Table 1.

Table 1 shows a drop in hardness about 22 millimeters from the lug point for the brass brazed joint. The tube has been tempered at that place. Similarly, the silver brazed joint has been tempered up to at least 7 millimeters from the lug point. So it is true that high-temperature brazing tempers the tube farther back than low-temperature brazing. But is this something worth worrying about? It's impossible to say, since the stresses a top tube undergoes are unknown. Practical experience has shown that failures of properly brazed brass joints are very rare. However, I think that under the right loading conditions, the tempering could become a problem if the thickness of the butted section were less than 0.8 millimeters (21 gauge).

To determine if the tempered zones were beyond the butt, I split the tubes in half. They had a butted section 75 millimeters long, and a tapered section about 45 millimeters long. Thus, the tempered zones were well within the butted section in both cases (Figure 2).

I also received a bit of criticism over the heating procedure I used to simulate brazing in my initial studies. Table 2 is a comparison of actual brazing data from the experiment described in this article, and the data I presented in the September/October 1981 issue of *Bicycling*. As you can see, the data is in excellent agreement (less than 5% difference).

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[2] J. R. Cahoon, W. H. Broughton, and A. R. Kutzak: *Metal. Trans.*, Vol. 2, July 1971, pp. 1979–1983.

Table 1

Average D.P.H./Average Yield Strength, lb/in.² Silver-Brazed Joint	Average D.P.H./Average Yield Strength, lb/in.² Brass-Brazed Joint	Distance From Lug Point, mm
213/69,980	255/83,779	2
198/65,050	257/84,436	7
281/92,321	268/88,050	12
283/92,880	251/82,465	17
286/93,965	215/70,637	22
290/95,280	277/91,010	27
284/93,307	285/93,635	32
292/95,935	299/98,235	37
298/97,910	297/97,580	42
294/96,593	299/98,235	47
299/98,235	308/101,192	52
306/100,535	310/101,850	57
305/100,206	307/100,865	62
306/100,535	307/100,865	100

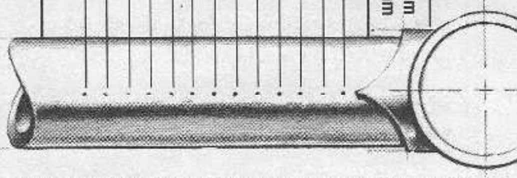


Figure 1: Top view of the top tube/head tube joint showing one set of hardness indentations.

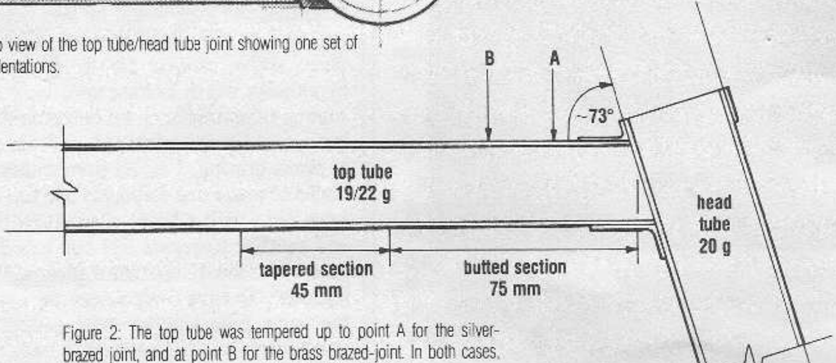


Figure 2: The top tube was tempered up to point A for the silver-brazed joint, and at point B for the brass brazed-joint. In both cases, the tubes were tempered well within the butted section.

Sandy Roth

Table 2

	531 after Brazing at 1300°F for 5 Minutes	531 after Brazing at 1700°F for 5 Minutes	Silver Brazed Joint 2mm from Lug Point	Brass Brazed Joint 2mm from Lug Point
Average Yield Strength, lb/in.²	66,670	87,370	69,980	84,683

Where the Information Is Lacking

David Gordon Wilson

Editor: Many of us know Wilson, a professor of mechanical engineering at Massachusetts Institute of Technology, for his innovations in bicycle technology such as the Avatar 2000 recumbent bicycle and the Positech brake (which, unlike the Avatar, has not yet been manufactured). We also know Wilson for his pleas for the bicycle industry to conduct more research. Here is Wilson's laundry list of neglected areas that need scrutiny.

To design vehicles which put less strain on the human body to propel, we need to do more research in the ergonomics of human power production, the aerodynamics of enclosed wheel-driven vehicles, the rolling resistances of tires, and the transmission efficiencies of alternative drives in actual working conditions. To design vehicles which are safer to use, we need to know more about the mechanics and biomechanics of various types of collisions and falls, and the friction of wet sliding surfaces. To use the new lightweight composites for construction, we need fatigue data taken in conditions of realistic loading.

To see that the necessary research takes place, we need to create a mechanism to fund that research. I'll present here some more detail on each of these topics and my proposal for funding research.

My list of topics is subjective and personal; other people would come up with their own lists. Although I present the areas of human power output and energy dissipation first, I consider the safety-related areas more important.

Ergonomics

Before the development of the sliding-seat rowing shell and the pedaled Michaux velocipede in the 19th century, most human power production was produced by straining mightily with arm and back muscles against a slowly yielding resistance, as in rowing galleys and in most agricultural work. The advantage of using muscles at a good impedance match with the load through the use of optimum leverage or gearing (Figure 1) led to the dominance of circular constant-velocity-ratio pedaling motions being used for cycles, and to sliding seats and long lightweight oars or sculls for racing boats.

The power outputs measured on ergometers have been very similar for these two very different motions. This finding has led to the general belief that the human being is so adaptable that so long as the large leg muscles are used, and so long as the impedance match or gearing is within a fairly wide range of the optimum, the exact configuration of the motion does not have a major effect on the peak performance (Figure 2).

We have seen considerable skepticism about variations of normal pedaling, such as extra-long cranks and oval chainwheels. While there have been many proponents of these variations over the years, the bicycling world is convinced by results, and no major races have been consistently won by riders using either arrangement. Neither has ergometer testing shown clear advantages. Sometimes subjects using oval chainwheels produce more power than the same subjects do with regular circular chainwheels, and sometimes not.

The oval chainwheel case may be used as an illustration of the difficulty of coming to a conclusion about any variation of existing pedaling. First is the problem of definition. Oval chainwheels are not identical. The degree of ovality—the ratio of major to minor diameters—may be as high as 1.5. Most investigations seem to show that these high degrees of ovality are disadvantageous, but there is some evidence, far from conclusive, that most people produce a little more power with chainwheels of 1.1 ovality than with circular.

It may be that the virtues of oval chainwheels are being lost to millions of riders because we are not sufficiently discriminating in describing what is being used.

Second is the problem of training. Almost all ergometer testing has been carried out using people who are likely to have used bicycles since childhood. They will have become used to the action and motion of circular chainwheels and circular foot motions.

When an athlete is required to change techniques, perhaps of pitching in baseball or serving in tennis, several months of constant practice are usually needed before the advantages of the new technique begin to be realized. The period of acclimatization to unaccustomed motions which is allowed in most ergometer tests is on the order of minutes, rather than months.

We might conclude that any unusual motions or mechanisms for which ergometer tests show increased, or even similar, outputs compared with normal bicycle pedaling should be regarded as promising candidates for allowing much-increased outputs after an extended period of training.

It seems very likely that there are, or will be, motions of the feet, possibly together with coordinated motions of the hands, by which athletes can produce considerably higher outputs than is generally thought possible.

A NASA chart (Figure 3) puts the varying levels of human power output for varying lengths of time in perspective. The chart shows NASA's given output levels for "healthy men" and for "first class athletes." To this I have added some data calculated by Frank Whitt for amateur British bicyclists on time trials. Whitt's data points are above the extrapolations of the NASA lines.

I also added other data: individual performances by Eddy Merckx on an ergometer in 1975, the astonishing double-crossing cross-country record by Lon Haldeman last summer, and a prediction I have made about the power output which will probably be achieved by the end of the century by the best athletes using feet and hands in an optimum manner.

A desirable research program to find the optimum motion would test men and women (it is surprising how few data on women are available) over a period of at least a year on pedaling, and pedaling combined with hand-cranking, on at least these variables:

1. Amplitude (stroke) of motion.
2. Ellipticity of motion (from straight-line to circular in perhaps six steps).
3. Angle of major axis of ellipse with the seat or saddle line.
4. Saddle (seat) height or distance from crank center.
5. Angle of seat line from horizontal.
6. Angle of seat back (when used) with seat line.
7. Ellipticity of chainwheel (from circular, 1.0 to 1.5).
8. Frequency of motion.
9. Duration of effort.

The results of a program of this type (which we have proposed to the National Science Foundation) would include not only record-breaking vehicles of various types, but an increased use of human power for tasks ranging from lawnmowing to driveway snow-clearance to breadmaking and garden cultivating.

Aerodynamics

After a century of aerodynamic research on vehicles of increasing speed and sophistication, we do not know all about low-speed incompressible flow around wheeled vehicles running on smooth surfaces. We know that for minimum drag of a circular-cross-section vehicle of fixed volume traveling in an infinite fluid, the length-to-diameter ratio should be around 4.5. There is no general agreement on what the shape should be for a vehicle of fixed maximum cross section (the rider) traveling close to a fixed plane (the roadway) with two or more wheels piercing the vehicle's surface, despite the excellent enlightenment given to us by Chester Kyle and his co-workers.

Here are some questions to which we still need answers:

1. For minimum drag, should the vehicle cross section be a semicircle with skirts almost scraping the road surface and all wheels enclosed in the envelope, or should it be a full circle, above the road surface (how far above?), with the wheels either piercing the skin (in wheel wells or not?) or on outriggers in their own fairings?

2. When several riders one behind the other are to be enclosed, is it better to use a minimum-diameter parallel section as on aircraft, submarines, and zepplins, or is lower drag achieved by increasing the cross section to give the shape used by blimps?

3. What compromises should be made to the minimum-drag shape, whatever it is, to lessen side forces from cross winds? Should we be concerned about nonlinearity in behavior in cross winds, such as a sudden movement of the point of flow separation which would give unpredictable handling?

4. Would it be beneficial to use some form of passive boundary-layer control, such as the vortex generators we see on the suction surfaces of many airliner wings, or active systems with a suction or blowing section using pumps which would necessarily be powered by some of the rider's output?

5. Can any of this sophistication be combined with a practical commuting vehicle which will be bumped and scraped, and buffeted by gusts from passing trucks, and used in the steamy summer heat of south Texas and the frigid winter cold of north Michigan?

Rolling Resistance

There are large differences between the rolling resistance of apparently similar tires of different manufacturers. Are these differences due to the hysteresis-loss variations of different rubbers, to variations in tread deformation, or to the way in which the whole tire casing deforms under load? It would be worthwhile finding out.

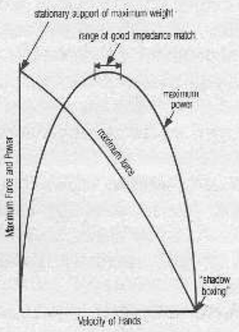
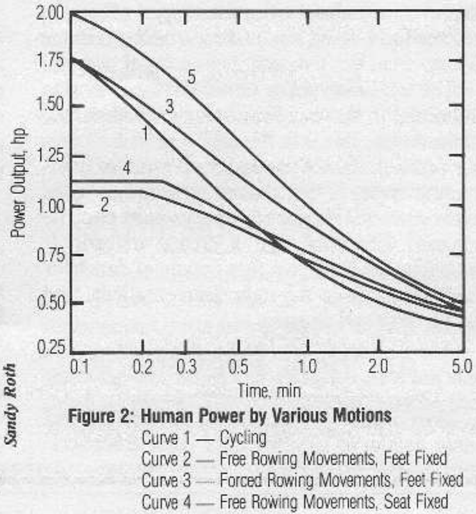


Figure 1: Impedance Matching



Sandy Roth

Figure 2: Human Power by Various Motions

Curve 1 — Cycling
Curve 2 — Free Rowing Movements, Feet Fixed
Curve 3 — Forced Rowing Movements, Feet Fixed
Curve 4 — Free Rowing Movements, Seat Fixed
Curve 5 — Forced Rowing Movements, Seat Fixed

Source: J.Y. Harrison, "Maximizing human power output by suitable selection of motion cycle and load," *Human Factors*, Vol. 12, No. 3, 1970.

Sandy Roth

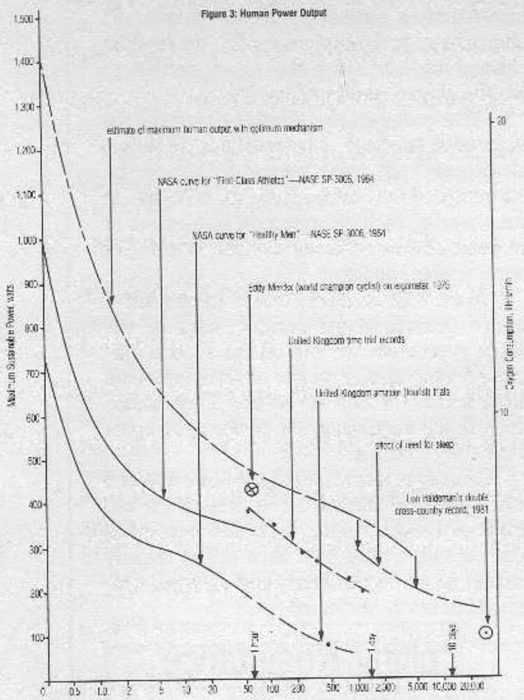


Figure 3: Human Power Output

From *Bicycling Science* (2nd Edition) 1982

Transmission Efficiency

The multi-ratio (presently up to 21) derailleur gears are almost unchallenged for lightweight bicycles, with three-speed and five-speed hub gears popular for middleweight machines. Some ingenious methods for simplifying gear changing and gear selection on derailleurs have been developed or are about to be introduced.

Most people would say that the transmission is one area of cycling in which they are fairly well satisfied. Yet most of the innovative energy being devoted by engineers and inventors in the cycling field seems to be devoted to transmissions.

There seems to be little ergonomic incentive for change, so long as the input continues to be circular constant-velocity-ratio foot motion, because humans have quite flat-topped efficiency curves for varying impedance matches (Figure 1).

The efficiency of a derailleur gear is also reckoned to be very high, around 98–99%.

However, this is in the new condition. A major problem for the everyday all-weather commuting cyclist is that chains and derailleur cogs wear fast, and the jockey pulleys soon become clogged with a mixture of grease and grit. It would be good to have test results of derailleur and hub gears in the new clean condition, and when dirty and worn.

Accident Prevention

Most injuries, serious and otherwise, and most deaths to bicycle riders come from accidents in which no motor vehicle is involved. The variety of causes of front-wheel jamming shows that many of these serious accidents could be easily avoided. Yet most of us are survivors of potentially serious spills and collisions. We tend to boast about our skill in avoiding injury. We say we know how to fall, we wear helmets, we are healthy and supple, and so forth. Yet we also know of world-class racing cyclists who have been seriously injured or killed in similar accidents. Why do some survive "headers" and some not?

Are there changes we could make in the bicycle to increase the chances of survival? (I believe that at least some recumbent bicycles greatly decrease the chances of fractured skulls and spines, which is the principal reason I ride one.) We need research of simulated collisions, perhaps with instrumented and automated dummies, to examine the mechanics of falls and collisions, together with interviews of people who have survived accidents, to try to learn factors which are favorable and which should be stressed, and unfavorable factors which should be eliminated. Before fairings become too popular to be easily changed, we need research to find how they affect injuries in accidents. We especially need research on the protection of children carried on bicycles.

Wet Braking

Perhaps bicyclists' greatest immediate need is for brakes which are effective in wet weather and which are acceptable to the user of lightweight bicycles. There are some good drum and disc brakes which appear to be effective in wet weather, but which are not used on lightweight bicycles because of increased weight and cost.

Since our MIT studies of the wet and dry friction of various brake pad materials, which showed extraordinary reductions in friction when a wheel rim went from dry to wet, a large range of improved materials has been introduced by Scott-Mathauser, Kool-Stop, Ferodo, and Raleigh, to give some prominent examples. And yet the wet-weather performance of these pad materials in actual bicycling use is unexplainably highly variable, in my own experience.

Some manufacturers have switched from steel to aluminum rims because of the generally better wet-braking performance of aluminum, but then the dry-braking action can be deficient when, for instance, the pads become impregnated with aluminum or aluminum-oxide powder.

Fatigue Failure Data

Although we are conditioned to believe that the ultimate tensile strength of a material is the prime indicator of its worth, in fact most material failures are due to repeated loading—"fatigue." In the last decade we have seen recalls of at least two manufacturers' bicycles due to fatigue failures of the front forks, one type being of steel and one aluminum alloy. The injuries which result from such failures are often extremely severe. In these cases the designers and manufacturers had not paid sufficient attention to the fatigue life of the materials in actual use, perhaps after incorrect heat treatment; the major effect of stress raisers such as sharp corners and notches; and the peculiar nature of the loading pattern of bicycle components, which might be completely different from the loading pattern for which the fatigue data were obtained.

These problems can be far worse for non-isotropic materials like fiber-reinforced composites. And yet in many cases we do not have usable fatigue data for composites even under conditions of simple loading, such as bending across the fibers.

Clearly, we need research on the fatigue of lightweight alloys and composites under realistic combined loading before they can be safely used in critical areas, like the forks of bicycles.

Funding Research

The likelihood of more than a small proportion of the research topics described being investigated by industry is, unfortunately, poor. There are no Bell Laboratories in the bicycle manufacturing world. There is, in fact, a fairly widespread belief that the pioneers often suffer in the marketplace or in the law courts.

If someone is injured on a bicycle which is almost a carbon copy of all other machines on the market, there would be little chance of a successful suit against the manufacturer on the grounds of design inadequacy. But should a new feature be introduced, one which perhaps brings about improved safety in 19 out of 20 accident situations, the manufacturer is likely to be sued by a large proportion of the people in the 20th category.

So manufacturers hold back, perhaps learning from the misfortunes or the mistakes of the innovators, more usually deciding that making no significant change is the best option.

In many other countries, and in at least one industry in this country, government has encouraged the creation of an industry-wide research establishment, perhaps funded by a small tax on the products. The Electric Power Research Institute (EPRI) is the prime example in this country, financed by a small increment on our electric rates.

There is a strong case for something similar to be set up in the bicycle industry. With sales in the region of 10 million units per year, at an average retail cost in the region of $100, a half-percent tax would give the possibility of a five million dollar annual research program.

If this prevented one broken spinal cord a year it would have repaid its cost. It would certainly result in far greater savings than that.

It would also undoubtedly project the U.S. human powered vehicle industry into a position of world leadership. It would be heartwarming to be proud of our nation for exporting a way of life which brings health, harmony with the environment, and a huge reduction in the use of our globe's resources.

ISO Develops International Bicycle Standards

Fred DeLong

What is ISO, and how did ISO become involved with bicycles?

ISO, the International Standards Association, is comprised of the national standards organizations of 86 countries. Its 1,900 technical committees in various fields have developed almost 4,000 international standards, which facilitate world trade, reduce costs to consumers, and promote interchangeability worldwide. Committees have dealt with measurements and measuring, nut and bolt dimensions, computer language, and automobile safety requirements, to name a very few subjects.

In 1968, the International Organization of Consumers' Unions, International Center for Quality Promotion, and International Labeling Center petitioned the ISO to initiate work on standards for bicycles. National member bodies voted to take up this suggestion, and the ISO commissioned its technical committee TC/149. At its first meeting, in March 1973, two subcommittees were established. SC/1 studies bicycle construction and safety; SC/2 studies parts interchangeability.

The standards organizations of 14 countries, participate fully in the work of the committee, funding the work, providing laboratory workers and equipment to run needed tests, and sending representatives to meetings. Nine additional nations send observers. Minutes of the meetings and resolutions approved are sent to the standards organizations of all ISO member nations. The United States is a full participant through its standards organization, the American National Standards Institute (ANSI).

Nations have drawn on bicycle engineering experts, consumer representatives, government safety organizations, and transportation and standards representatives to recommend and review standards for the ISO committee. Additional experts were drawn in for consultation when necessary.

Working groups of each ISO subcommittee delve into the details of each particular subject (such as braking requirements or freewheel threading). Once agreement is reached, findings are brought to the full subcommittee for discussion. When consensus is reached, a proposal, called a Draft International Standard (DIS) is written. The central ISO council in Geneva, Switzerland, then transmits this standard to the standards organizations of member nations for discussion, approval, disapproval, or comment.

Comments are transmitted back to the ISO and to all participating countries. Differences are ironed out either by mail, or in the case of larger problems, through further investigation. When 75 percent of nations voting on a standard have approved it, it is proclaimed as an ISO international standard.

ISO standards are voluntary in many countries and do not prohibit continued use of previous standards or inhibit new design and innovation. As technology, manufacturing procedures, and requirements change, standards can be revised if needed.

Fred DeLong is an ANSI delegate to the ISO TC/149.

A Look at the Standardization Process — and Its Impact

John S. Allen

Fred DeLong has described the work of the ISO in developing standards for bicycles and bicycle parts. I will attempt now to draw some conclusions about the impact of the ISO's work on the bicycle industry and on bicycle users.

Three entirely different types of standards apply to bicycles: standardization of markings; of fit and threading; and of safety requirements. Each has a different type of impact.

Standardization of Markings

Standardization of markings is the establishment of a uniform way of indicating which parts fit or do not fit each other, are interchangeable or not. The most dramatic example in the bicycle industry has been the Universal Tire Marking System which now finally makes it possible to compare sizes of tires and rims from different countries. Under previous systems, tires and rims of different sizes might have the same marking (for example, the Schwinn and British 26 x 1⅜-inch sizes), while tires and rims of the same size might have different markings (for example, the Canadian 28 x 1½, British 28 x 1⅝, and French 700 x 38C tires, which all fit the same rim). Standardization of markings is of unquestionable benefit to bicycle users and to all segments of the bicycle industry. It simplifies supply problems for manufacturers, distributors, retailers, and users alike. The ISO has adopted the Uniform Tire Marking System with little controversy over any but technical points. Markings for other components are being standardized as part of the work on fit and threading of parts.

Standardization of Fit and Threading

Standardization of fit and threading is of greatest advantage to the distributor, retailer, and user. To the distributor and retailer, it means that duplicate parts need not be stocked to fit different bicycles. To the user, it makes replacement of parts easier. As DeLong notes, the original impetus toward the ISO's work on standardization of bicycle parts came from consumer organizations.

For manufacturers, standardization can have mixed effects. Making nonstandard parts can give a competitive advantage, with varying effects to distributors, retailers, and users. Raleigh and Schwinn are two major bicycle manufacturers some of whose threading and fit standards differ from others common in the industry. These large manufacturers are able to support dealer networks to stock their parts, and their nonstandard threading helps to prevent the installation of inferior parts on their customers' bicycles. The well-respected Schwinn mechanics' training program is directly linked to the franchising process and to Schwinn's nonstandard parts.

Schwinn and Raleigh parts, though nonstandard, remain interchangeable from year to year. The same is not true of some component manufacturers, so customers often are unable to buy replacement parts. This "planned obsolescence" is endemic in other industries where products are designed from the ground up. In the bicycle industry, much manufacturing is on a relatively small scale, and manufacturers of complete bicycles usually buy parts from a number of sources. Consequently, major national standards and manufacturers' dimensioning for fit of components to the frame have remained relatively constant in recent years. Problems with replacement parts for bicycles usually have to do with subparts of components, requiring replacement of the entire component. This is an annoyance to retailers and users, but it does not make entire bicycles obsolete.

In sum, any increase in standardization of fit and threading will be advantageous to the distributor, retailer, and user, but will have mixed effects for manufacturers. It will tend to increase the competitive advantage of smaller manufacturers. This is the end result, but there are also transition problems.

Transition Problems

As an old standard goes out of use, manufacturers must retool, and the dwindling stock of replacement parts forces some users to retire equipment which would otherwise be serviceable. Certain steps can be taken to minimize these problems. The new standard may be the same as the most convenient or widely used of

Proposed International Bicycle Component Standards as of the July 1981 meeting of ISO Technical Committee TC/149

Fred DeLong and John S. Allen

Draft International Standard (DIS) number	Status (S: submitted; D: under discussion; C: Circulated to member countries for voting; A: approved	Title and Description of Standard			Compatibility with earlier standards	Comments
DIS 4881	**C**	**Spoke Diameter and Threads**			See note	These spoke dimensions are already standard in Japan. Wire diameters are standard ISO and also standard French, though French threading is different U.S.A. and British .072- and .080-inch sizes are very close to 1.8 and 2.0 mm, and threads are also 56 tpi, so spokes and nipples are compatible. 56 tpi threading for all sizes eases retooling from divergent standards.
		1.8 mm 56 tpi				
		2.0 mm 56 tpi				
		2.3 mm 56 tpi				
		2.6 mm 56 tpi				
DIS 6692	**A**	**Marking of Components for Identification of Threading**			Not an issue	This is a marking standard, as distinguished from an interchangeability standard. It will do much to reduce mechanics' confusion, like the tire marking standard. Noncontroversial, approved.
		Examples:	Metric	British		
		If enough space	M 34.7 x 1	B 1.375 x 24		
		If little space	M 34.7	B 1.375		
		If very little	M	B		
DIS 6693	**C**	**Cottered Crank and Axle Attachment**				The 16-mm axle is the current metric standard. British (5/8-inch) cranks will have to be reamed slightly to fit. .375-inch, the British standard cotter pin diameter, is almost identical to 9.5 mm — interchangeable. Steyr, Thompson, other German manufacturers use 9.5 mm; other cotter pins are thinner but redrilling cranks is easy.
		Axle diameter	16 mm		M	
		Flat for cotter				
		Depth	3 mm			
		Width	8 mm			
		Cotter pin				
		Diameter	9.5 mm (.374 inch)		M, B	
		Length	43 mm			
		Taper	6 degrees			
		Thread	M 7 x 1 mm		See note	
DIS 6694	**D**	**Pedal to Crank Thread**				Sufficient strength is assured with the small diameter by increasing the length of threads. See additional comments in text.
		Threading	B .500 x 20		Only compatible with 1-piece cranks, but see note	
		Length of thread	12.5 mm +0.5 −0			
		Thread angle	60 degree ISO			
DIS 6695	**S**	**Cotterless Crank (Square End) Fitting**				The 2-degree taper angle is compatible with all current cranks except the less expensive melt-forged Japanese cranks. The dimension across the flat is compatible, for all but Stronglight, T.A., and swaged Japanese (Maxy, etc.), which have a larger flat. They might be made to fit ISO spindles by grinding the spindle ends. Stronglight dustcaps are 23.5 mm, T.A. 23.0 mm, others 22 mm. Crank fitting dimensions contribute to a chainline standard, but ISO has not yet developed one.
		Included taper angle	4 degrees		Most	
		Length of flat				
		Right	18 mm		Most	
		Left	16 mm		Most	
		Dimension across flat				
		1.5 mm from end	12.6 mm +0.02 −0.05		See note	
		Spindle end to bolt seat				
		Loose	3 mm			

		Tightened	1.5 mm min.		
		Crank fixing threads			
		Bolt type	M 8 x 1	All	
		Nut type	M 10 x 1.25	All	
		Dustcap threads	M 22 x 1	Most	
DIS 6696	C	**Bottom Bracket Threads**		British	The current British standard is 1.370 x 24. The ISO standard is compatible, and allows the same tooling for rear hub/freewheel and bottom bracket parts. The left-threaded right cup avoids unscrewing problems; compatibility with existing Italian and French frames (e.g. by rethreading at the larger, Italian diameter) would not be possible while gaining this advantage.
		Left side	B 1.375 x 24		
		Right side	B 1.375 x 24 L		
DIS 6697	D	**Hub Axle Threading**			Metric threading: see comments in text. 9.5-mm diameter axles are currently common for rear, and for some front — BMX, tandem, Sturmey-Archer Dynohub. ISO discontinues this diameter, going to either 9 or 10 mm.
		Solid			
		Front	M 8 x 1	French	
		Rear	M 9 x 1	None	
		Hollow			
		Front (and MX solid)	M 9 x 1	French	
		Rear	M 10 x 1	Some Japanese	
DIS 6698	C	**Freewheel Threads**		British, Italian	Threading diameter is intermediate between current British and Italian standards, which are already close enough to be partially compatible.
		Threading	B 1.375 x 24		
		Thread angle	60 degree ISO		
DIS 6699	S	**Seatpost clamp bolt**	M 8 x 1	Not an issue	Fits any frame
DIS 6700	S	**Brake bolt hole**	6.2 mm	Most	Compatible with most brake bolts, which are M 6 x 1
DIS 6701	C	**Exterior Dimensions of Spoke Nipples (in mm)**			Compatibility is for wrench flats; other dimensions are not critical, and rims can be redrilled in most cases. Wrench sizes for the two largest spoke diameters are different from any current sizes, though others are close and may work: French 3.7 mm, 4.6 mm, USA 3.9 mm. See complete chart of spoke sizes on p. 175 of 1978 edition of *DeLong's Guide to Bicycles and Bicycling.*
		Spoke diameter	Wrench flat Nipple shank Nipple head Rim hole		
		1.8	3.3 4.0 6.0 5.0	USA	
		2.0	3.3 4.0 6.0 5.0	USA	
		2.3	3.8 4.8 6.5 5.5	See note	
		2.6	4.5 5.5 7.5 6.5	See note	

The ISO has no standards for:
- *bottom bracket spindle lengths*
- *bearing surface dimensions of spindles and bottom bracket cups*
- *oversize bottom bracket cups for use in frames with stripped threading*
- *bottom bracket widths*
- *chainlines*
- *over locknut distances*
- *chainwheel bolt circle diameters*
- *chainwheel fixing bolt dimensions (and other parameters of chainwheel interchangeability)*
- *headset press-fit dimensions (which are the biggest standardization mess in the bicycle business)*
- *bearing cone and cup dimensions for hubs*
- *freewheel removers*
- *fender eyelet threading*
- *dropout derailleur tab dimensions*
- *handlebar diameter for fitting to stem and brake levers*
- *toe clip size marking (the markings "large," "medium," and "small" do not currently correspond to the same size for different manufacturers)*
- *toe clip to pedal mounting dimensions*

Standardization of any of these parts would eliminate many headaches for distributors, retailers, and mechanics. Standards *are* being developed for fork threads, one-piece crank threading, handlebar stem to handlebar clamping bolts, front fork inside diameter, and perhaps some of the others, but they are still in an early stage at which committee members are not free to make their deliberations public. *Bike Tech* suggests that the ISO examine the items listed above, if it has not begun discussion of them. You, our readers, may have additional suggestions. You may forward them to the American National Standards Institute.

Standardization...

the old ones. The new standard may even be chosen to be compatible with more than one existing standard. This is the case with freewheel threads. The new ISO standard of 1.375 inches diameter and 24 threads per inch (tpi) is compatible with both the English 1.370 and Italian 1.378. French freewheels and hubs, however, are not compatible with any of these standards.

A third step is to note how older equipment can be adapted to the new standard. Hub axle threads are an example. Though the ISO hub axle threading doesn't work with many older bearing cones, the cones are inexpensive, and it is a usual practice to replace them along with the axle.

The choice of a ½-inch, 20 tpi pedal thread by the ISO committee has provoked some controversy, yet when examined more closely this decision is well-justified. It is a good example of how the new standard can account for the old. Many cranks which currently use the ½-inch thread do not have enough extra material at the outer end to tolerate a larger hole for the pedal spindle. Retooling for these cranks would be expensive. The ISO recommended the ½-inch thread only after stringent tests with aluminum cranks under heavy loads. Cranks with larger holes can be adapted with bushings.

The French, and other nations using metric standards, will suffer most during transition to new standards. This is ironic, because metric measurements are the world standard. But the decline of metric standards for bicycle parts is already underway, and the ISO standards only ratify an existing trend. British standards have gained new strength with the greatly increased Japanese production of the past decade. Fortunately, bicycle components are specialized enough that they need rarely accommodate to other types of mechanical parts. Manufacturers of spokes, freewheels, hubs, pedals, and bottom bracket parts will suffer some minor inconvenience in finding machine tooling to accommodate the British standard.

Small nut-and-bolt parts, wrench flats, and hub spindles *will* be metric under the ISO standards. The decision is sensible, since these are the parts most likely to be manufactured, ordered, or serviced outside of the specialized bicycle industry.

Ultimate Impacts on International Competition

The greatest benefits of standardization will come to nations with smaller bicycle industries. These nations will have wider choices in both importing and exporting products. Increased freedom of trade does, however, lead to a decrease of stability in domestic markets. French and Italian manufacturers, particularly, have enjoyed considerable immunity from Japanese competition in their home markets. Manufacturers in previously protected markets may be slow to abandon their own standards or may seek protectionist import policies to preserve their domestic markets. The development of multinational manufacturing corporations has been slow in the bicycle industry, but it may be expected to accelerate as standardization makes it possible to shuttle manufacturing to whichever country offers the lowest cost.

Will Standardization Prevail?

I see a drift toward standardization, but a slow one; and in some areas, reverses are occurring.

The main force toward standardization is the size of the North American market and the need for manufacturers from all around the world to produce components which can be used on the bicycles — mostly to British standards — sold in that market.

Another force toward standardization is the extensive program of testing which backed up the ISO standards. This testing has produced some durable designs. Spoke nipples made to ISO standards, for example, have enough material under the wrench flats to discourage their stripping. As tooling for parts to older standards wears out, there is often little additional cost in retooling to new standards.

A third force toward standardization, already mentioned, is its direct impact in making business easier, especially for smaller manufacturers and smaller nations.

Destandardization comes from the competitive forces I mentioned earlier, from the cost of retooling, and also from technological changes which require deviations from old standards. One example is in the freewheel-hub combinations now available from Shimano and Maillard, which have no freewheel to hub threads. Another is the Shimano single-bearing pedal, which requires a larger hole in the crank. A third is in the recent drift to narrower tires, which has turned the 27 x 1¼-inch size into three different sizes of noncompatible or partially compatible rims and tires. Yet, as mentioned before, bicycles already are far more standardized than most products.

All in all, standardization seems to be gaining. Yet, if you have an older bike with, for example, French threads, you have little to worry about. It will be a very long time before you can no longer find French bottom bracket cups or a French headset.

JSA

ISO's Bicycle Safety Standard: Just How Safe Is It?

If you were given the task of developing a standard for the safety of bicycles, how would you do it? There is more than one approach, but the task is more complicated than it might seem at first.

The International Standards Organization's Technical Committee on bicycles has tackled this difficult task and has come up with a standard, DIS 4210, which reflects some significant progress, but also some important practical limitations on the standardization process.

What standards has the ISO set, then?

There are two impact tests for the frame, one simulating a head-on crash, the other simulating a ride over a sharp bump. In each case, the frame may bend within certain limits, but not crack. There are static load tests of the pedals, chain, handlebar and stem, seat and seatpost, wheel, and brake cable assembly. There is a braking performance test and a wheel roundness test. The only fatigue test is for the pedal spindle.

There are no tests of the cranks, bottom bracket, or hub axles. There is no direct test of spoke tension. There are no wear tests of bearings.

In other words, the standard is not a comprehensive quality assurance standard. Clearly, the ISO committee has thought about which parts of the bicycle pose significant accident risks and which do not, and limited the safety standard's scope accordingly.

The impact and static load tests prescribed by the ISO committee impose large loads, greater than those encountered in normal service. Bending is permitted; breakage is not. The apparent aim is to reject brittle, fatigue-prone parts. A large-load test is the closest possible simulation of a fatigue life test without a prolonged test procedure requiring expensive equipment and destruction of many units (bicycles). Yet the two tests do not produce identical results. ISO is obviously trying to minimize the expense of the test procedure to which manufactures must subject bicycle components, even though the validity of the test results must be compromised somewhat. Smaller manufacturers will benefit from this economy-minded approach. Many could not afford to conduct destructive fatigue testing.

The braking performance test is much more severe if the bicycle is equipped with dual brakes than if it is equipped with only a single brake such as a coaster brake. In this instance, the ISO committee based its judgment of performance standards not on what is possible, but on what is common practice in the industry.

Such compromises are to be expected in the real world. If a testing procedure is too cumbersome and expensive, it will drive some manufacturers out of business even though their products might be perfectly acceptable. If a standard prohibits common, accepted products, then that standard is bound to be rejected or ignored by manufacturers, and can become the basis of lawsuits against them by consumers. Progress comes in small steps.

The ISO standard, then, reflects practical realities and compromises. It will certainly drive some of the very worst products off the market. This is what it is designed to do, and I'm glad it will do that.

The ISO committee has attempted to get around the knotty issue of double standards for different types of equipment by making some arbitrary judgments as to when certain performance requirements apply and do not apply.

For example, the standards do not apply at all to small children's bicycles whose saddle is less than 25 inches above the ground; and bicycles with only a single brake are required to have no gear over 63 inches. If there is a single brake, it must be on the rear wheel. Because they are arbitrary, these judgments sometimes miss the mark.

A bicycle has the same top speed downhill regardless to its top gear. A fixed-gear bicycle is generally safe with only a front brake. In other words, an ISO-approved bicycle with a single brake on the rear wheel can be operated at speeds which result in unsafe stopping distances, and a bicycle with a single brake on the front wheel can be far safer than ISO standards suggest.

If a cyclist gets into an accident or is cited for defective equipment on a bicycle which is, in fact, safe but violates ISO requirements, the burden of proof in a court of law might be swayed unfairly. ISO safety standards are voluntary in some countries, but mandatory in other countries. I'd like to see the ISO committee try to develop a way around this quandary.

Besides setting requirements for mechanical performance, the ISO standard also sets certain requirements for safety features and reduction of hazards. Some of these requirements make good sense to me: requirements for minimum insertion depth markings on seatpost and handlebar stem; requirements that exposed protrusion be rounded; requirements for a set of instructions to be included with each new bicycle, explaining basic maintenance and adjustment.

Some requirements for safety features, however, suffer from the same arbitrariness as the performance requirements. Protrusions are prohibited on the top tube within 12 inches of the front of the saddle. This requirement presents difficulties to the manufacturers of folding bicycles. The hinges in the low top tubes of folding bicycles are technically prohibited but pose no serious hazard. But stem shifters and console shifters are permitted, in the most hazardous area of the bicycle. Brake levers for front and rear brakes are required to be on the side of the handlebar "appropriate to the country in which the bicycle is to be used" (oddly, the standard does not say which side).

The real requirement should be for cables to be exchanged easily so individual cyclists can accommodate the levers to their individual habits. Sharp edges are prohibited, in language that technically would seem to require a cyclo-cross ring with double chainwheels.

The standard permits handlebars only between 350 and 700 mm wide, to disqualify the poorly controllable, faddish handlebars often seen on children's bicycles; yet the most controllable dropped handlebars for children or small adults are only 310 to 320 mm wide. And there are other oversights and questionable points.

Very little reliable data exists as to the seriousness of hazards posed by any mechanical features of bicycles. Logic, experience, and stories from other cyclists point to some conclusions that can be trusted: front forks that break are dangerous; brakes must work smoothly and powerfully; a headlight is needed for night riding.

But how hazardous are chainwheel teeth; is a cyclo-cross ring worth the extra expense to buy and the extra weight to ride it? There's no proof one way or the other.

One study of bicycle accidents, Kaplan's survey of regular adult bicycle users, showed that only three percent of accidents resulted from mechanical failures. Is a safety standard needed at all? Should the present standard be called a safety standard? To be sure, the riders Kaplan surveyed were discriminating in their purchase of good equipment and their ability to maintain it. Other riders might not be so discriminating.

And there have been certain "time bomb" components such as the notorious Lambert front forks which have caused a number of nasty accidents.

Yes, a standard and a series of required tests can help prevent such problems. The ISO standard will do this. But I think that calling the present standard a safety standard is not entirely accurate. I'd call it a limited quality assurance standard, with a list of required features of hazard reduction. That title would lead to fewer exaggerated expectations for the standard.

The work of the ISO committee is not over. The committee may revise the standard at any time. Also, the committee has not yet passed a standard for lighting and reflectors. This is one of the areas where the greatest confusion abounds. I would like to see a requirement for standard lamp and reflector mounting on frames, headsets, racks, and fenders so lamps and reflectors can be moved to where they are visible as equipment and baggage are added. The U.S. Consumer Product Safety Commission requires reflectors and lighting equipment installed in positions that become hidden behind baggage. I hope that the ISO committee can avoid following this precedent. **JSA**

Chainwheel Interchangeability Quirks

Even though two chainwheels have the same bolt circle diameter and hole size, they may not be interchangeable. Watch out for these problems:

- Chamfer on one face/both faces. Older Stronglight 93 chainwheels were chamfered on only one face. The chamfer was made to face the outside of the outer chainwheel and the inside of the inner chainwheel. The teeth of both chainwheels were flush with the faces that attached to the spider, and the spider was unusually thick (about 4.7 millimeters). Newer Stronglight 93, 104, and 105 chainwheels have the same bolt circle, but are chamfered on both sides, with the teeth centered on the thickness of the chainwheels. The spider is thinner, about 3 millimeters. Newer chainwheels cannot be used on the old cranks unless the spider is thinned. Older chainwheels can be used on the newer cranks if the inner chainwheel is reversed, although the sleeve nuts will protrude farther toward the chainstay.
- T. A. Cyclotouriste inner chainwheels thinned/not thinned at bolt circle. Newer T. A. Cyclotouriste inner chainwheels in the larger sizes are thinned at the bolt circle and use spacer washers 3 millimeters thick. The purpose of thinning the chainwheels seems to be to adjust chainwheel spacing to the difference in size between chainwheels. You may have to use new spacer washers when replacing chainwheels, so it's a good idea to order a new bolt set.
- Fit of chainwheel inner lip to flange of spider. An example: Sugino Mighty Tour and Super Maxy 5 chainwheels have the same bolt circle and hole diameter, but the Mighty Tour spider has a flange which interferes with some Maxy 5 chainwheels. Some metal must be filed off the Maxy 5 chainwheels if they are to fit the Mighty Tour cranks.
- Spider thickness as it relates to chainwheel size difference. The Stronglight 99 has an unusually thick spider, about 4 millimeters. The chain tends to fall between the chainwheels when the chainwheels are only a few teeth different in size. Yet as a wide-range double, this crankset shifts beautifully. The greater the difference in the number of teeth between chainwheels, the farther the chain deflects to the side during shifting, and the farther apart the chainwheels should be. Select your crankset, add washers, or thin the spider as necessary for optimum shifting with the tooth difference you have chosen. T. A., as mentioned before, seems to have addressed this problem. The new SR Apex crankset which is a copy of the Stronglight 99 (28 teeth minimum, chainwheels interchangeable) has the same thick-spider design.
- Good news: the new Sugino AT inner chainwheel (minimum 24 teeth) is interchangeable with Avocet; and bad news: the new Shimano Deore inner chainwheel (minimum 26 teeth) is *not* interchangeable with Stronglight 99 and SR Apex. The bolt circle is a silly 1.5 millimeters smaller. **JSA**

SHOP TALK

Measuring Crankset Bolt Circles

The circle of bolts that attach chainwheels to the spider of a crankset — or to each other — has a diameter which is an integral number of millimeters for most cranksets. This diameter, along with the size of the bolt holes, is the main factor which determines whether chainwheels are interchangeable between cranksets. However, this diameter cannot be measured directly in most cases, because the number of holes is odd. With the usual three or five holes, no two holes are directly opposite each other.

Here's how to measure these diameters:

1) Measure the spacing between any two adjacent holes. For increased accuracy, take several measurements of different pairs of holes, and average them. A small (150 millimeters or 6 inches long) metal metrically-divided ruler is handy. Beware of wooden and plastic rulers, which expand and shrink as the weather changes. Measure from the left or right side of one hole to the same side of the next hole. This is the same as a center-to-center measurement, since all of the holes have the same diameter. Try to be accurate, within ½-millimeter or less. Use a magnifying glass if it helps.

Then, to derive the bolt circle diameter, multiply your measurement by:

1.155 if there are three holes
1.701 if there are five holes
2.000 if there are six holes (or measure the diameter directly).

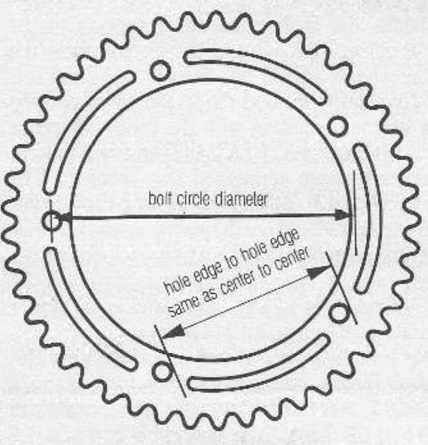
These multipliers are derived from the formula

$$\frac{1}{\sin\left(\frac{180}{n}\right)}$$

where n is the number of holes. This formula results from a geometrical construction which need not be shown here.

Your measurement, times the multiplying factor, is the bolt circle diameter. *Sutherland's Handbook for Bicycle Mechanics* gives tables of bolt circle diameters and hole spacings, but it is useful to be able to find the bolt circle diameter yourself when dealing with new models of chainwheels or if the handbook is not right by your side.

JSA



Sandy Roth

Chainwheel Dimensions

INVENTIONS

New Backpedaling Braking System: Use It On Any Bicycle

Fred DeLong

Canadian engineer Winnett Boyd has designed a backpedaling brake actuator which can be used on any bicycle, even a bicycle with derailleur gears, equipped with caliper, disc, or drum brakes. Mr. Boyd is an accomplished engineer, head of Canadian operations for Arthur D. Little, Inc., a Cambridge, Massachusetts, consulting company. He is also a partner in a specialized machine design and manufacturing business which has designed, among other things, a high-performance jet engine.

The initial response of accomplished cyclists to backpedaling brakes is usually "we have good results and no control problems with hand brake actuation and finger tip sensitivity. Why go back to the brake control used on children's coaster brake bicycles?" It was with this "show me" attitude that I visited, examined, and tried this innovation.

The test started in Mr. Boyd's driveway. The test bicycle was equipped with Mr. Boyd's actuator, operating a rear-wheel brake, and an independent front hand brake. Reaching the curb cut upon exiting the driveway, I applied reverse motion to the pedals without even thinking about it. We then continued over rolling and winding streets, through traffic, around cul-de-sacs, aiming straight for obstructions at speed. Then we rode down a steep path to a lower-level park, and back up. On the up-climb, there was occasion to stop on the grade. The bike rolled back a few inches, actuating the brake sufficiently to hold the bike motionless on the hill. Very useful!

At all times, despite not having used a backpedaling brake for many years, I found the braking action completely automatic and natural. I did feel more secure with the independent front hand brake when descending the very steep path; and independent finger-actuated control of the front hand brake is also preferable to avoid the problem of pitchover in hard emergency brake application. Yet riders experienced with hand brakes can make good use of backpedaling brakes. Hand fatigue on long hills, hand brake operation when heavily gloved in cold weather, and the much larger forces available with foot braking are significant factors.

The actuator uses the principle of wrapping a rope around a capstan as is done on shipboard. Each turn, or partial turn, of the rope multiplies the tension which can be exerted on the rope without its slipping: for example, if a sailor pulls on the shipboard end of a rope with a force on one pound, then the rope might hold a ten-pound anchor if wrapped around the capstan once. Two turns would then hold 100 pounds, and three turns, 1,000 pounds. The rope, gripping the capstan, acts as a force amplifier. In this example, the amplification factor is ten for each turn. The multiplying factor per turn varies depending on the coefficient of friction between the rope and capstan.

Incidentally, the same principle explains the dramatic increase in friction when the cable of an ordinary caliper brake goes unlubricated.

In Mr. Boyd's actuator, a seven-turn close-fitting pilot coil of small square-section steel wire is wrapped around the bottom bracket spindle. One end of this pilot coil is attached to a looser-fitting larger-area power coil of four turns (see illustrations). Upon reverse pedaling, the pilot coil tightens the power coil, which grips the bottom bracket spindle tightly and transfers braking power to a yoke.

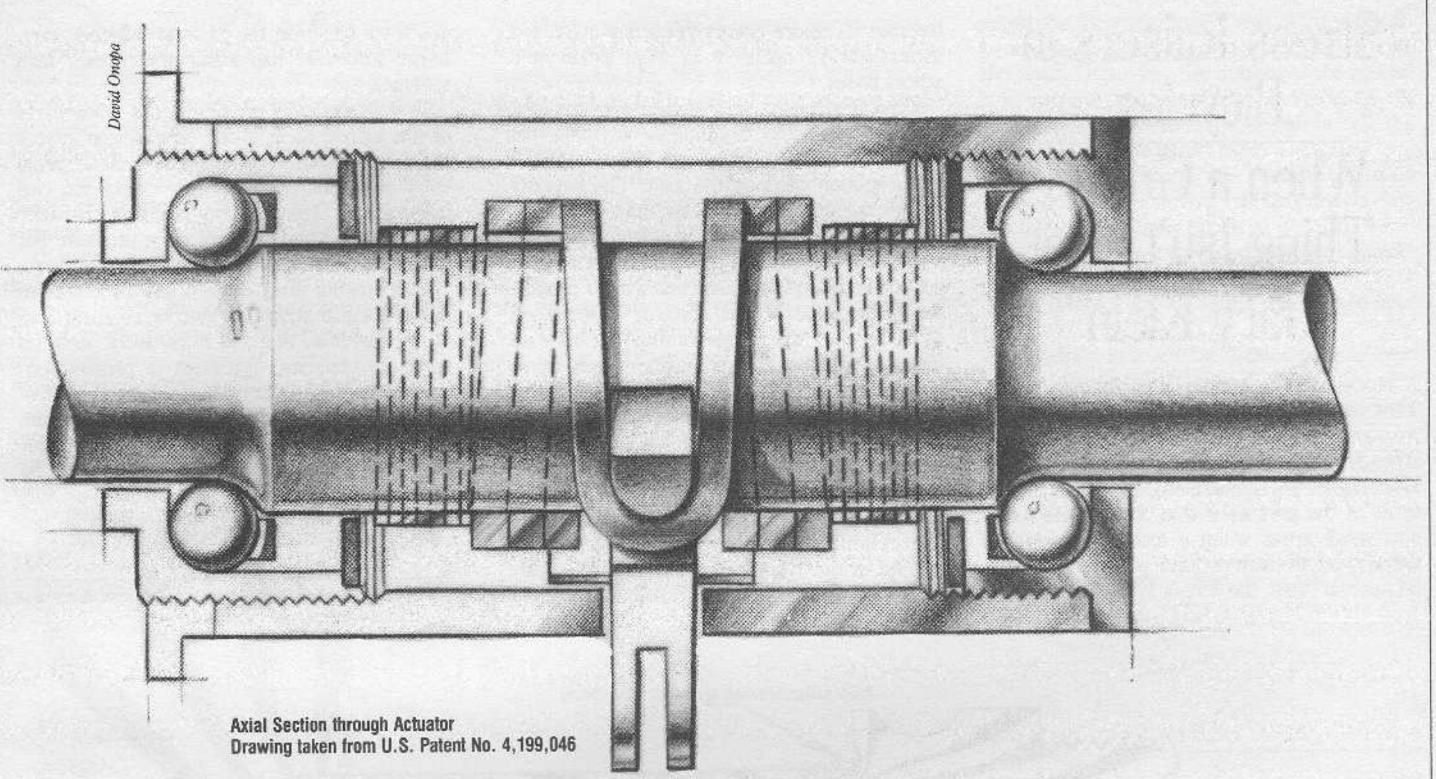
Two sets of these coils are looped over the spindle, one set on either side of the central yoke. An extended lever arm, attached to the yoke, projects through a slot cut into the bottom of the bottom bracket shell. On the test bicycle, the lever arm actuates a special "wedge" caliper brake patented by Mr. Boyd. Through cable and casing, the lever arm could also operate disc, drum, or standard caliper brakes in their normal locations.

Mr. Boyd points out that the much larger forces available with foot braking allow the use of brake pads made of automotive brake lining material. While these have a lower dry coefficient of friction than rubber pads, there is much less of a drop in the coefficient of friction in wet weather.

Though either set of coils around the bottom bracket axle will withstand the full weight of the rider on the reversed pedal, the pilot coil's friction in the forward driving mode is so slight that, with the chain disconnected, the cranks keep rotating if spun in the forward direction.

It is necessary to pedal forward to release the brake. But the brake itself, through the chain, keeps the chainwheel from turning. Mr. Boyd has consequently developed and patented an unlocking scheme. The chainwheel is capable of 20° of free rotation with relation to the bottom bracket spindle. When starting, the cranks turn 20° before applying power to the chainwheel through a rubber half-bushing. In practice, this motion is almost undetectable.

Mr. Boyd's simple wedge brake is similar to the rod brake used on the Raleigh Tourist bicycle.



David Onopa

Axial Section through Actuator
Drawing taken from U.S. Patent No. 4,199,046

The Boyd Brake Actuator Raises Some Issues of Bicycle Engineering

John S. Allen

Fred DeLong's article about the Boyd brake actuator raised some questions for me about how inventors look at bicycles and bicycling.

Mr. Boyd is clearly, as Mr. DeLong states, an accomplished engineer. The mechanical principles of the actuator are sound; Mr. DeLong's test shows that the actuator does what it is intended to do, and does it well.

But I think that there are better ways to use the actuator than those Mr. Boyd proposes. As Mr. DeLong notes, experienced bicyclists (and motorcyclists, too) prefer an independently hand-operated front brake. Foot operation cannot provide the fine and rapid control a front brake needs on a two-wheeled vehicle.

Only a rear brake is safe for foot operation, yet one of the chief advantages of foot operation, as Mr. DeLong states, is to avoid hand fatigue on long downhill runs. But to avoid rim overheating and tire failure, the braking load should be divided between both rims on long downhill runs. One of Mr. Boyd's drawings shows his actuator controlling both front and rear brakes. A much better alternative would be to have the actuator control a rear drum or disc brake.

With such a brake, Mr. Boyd's actuator might find favor on wilderness touring bicycles. These bicycles have multiple gears, frequently get their rims wet, and need prolonged downhill braking.

Probably the most promising application of the actuator, though, would be to a hand-cranked machine: either a special machine for handicapped persons, or a hand-and-foot powered high-performance recumbent machine. A rider who had lost the use of one hand would also find the Boyd actuator useful on a conventional bicycle.

An interesting feature is that Mr. Boyd's actuator locks the brake when the bike is rolled backward. This can be an advantage, as Mr. DeLong states, but it could also be somewhat of an inconvenience when parking the bicycle or when walking it.

Boyd's wedge brake is a rear-wheel rim brake and so is not suitable for long downhill runs. It bears against the inner surface of the rim, requiring a rarely-attained degree of wheel roundness for smooth operation. And with the rider's full weight on the pedal, it could cause an excessive increase in spoke tension. The wedge brake is, in my opinion, the weakest part of the invention. Fortunately, the actuator can be used just as well with other brakes.

The strong and weak points of this invention present an interesting pattern, typical of inventors who are highly skilled mechanically but who are not experienced bicyclists. I suspect that Mr. Boyd set out in search of a mass market, trying to solve a problem which already has a better, if imperfect, solution. Foot-operated brakes tend to appeal to people whose main experience with bicycling was in childhood, on coaster brake bicycles. Without free backpedaling, it is not always possible to put a foot on the forward pedal for a quick start. For the same reason, backpedaling brakes are not very compatible with the use of toe clips and straps. Also, a precisely controlled high-deceleration panic stop is much easier with dual hand brakes than with one hand brake and one foot brake. Cyclists who ride long distances or ride fast prefer to use dual hand brakes for these reasons. And persons who retain the habits and preferences of their childhood coaster brake experience often fail to continue cycling as adults — or to develop their potential for speed and distance — because they cannot trust their braking skills. An industry-wide adoption of the Boyd actuator to replace a rear hand brake would have an adverse effect on the bike-handling skills and safety of the cycling population.

Still, there is a genuine need for a good backpedaling brake actuator in the applications I mentioned earlier, and perhaps in other applications. Mr. Boyd has apparently succeeded in producing this device. He has solved an important problem, even if it is not the problem he thought he was solving. I wish him luck with his invention, and hope to see it made available both as original equipment where appropriate and as a retrofit kit.

Stress Raisers in Bicycles

When a Groovy Thing Isn't Cool

Gary Klein

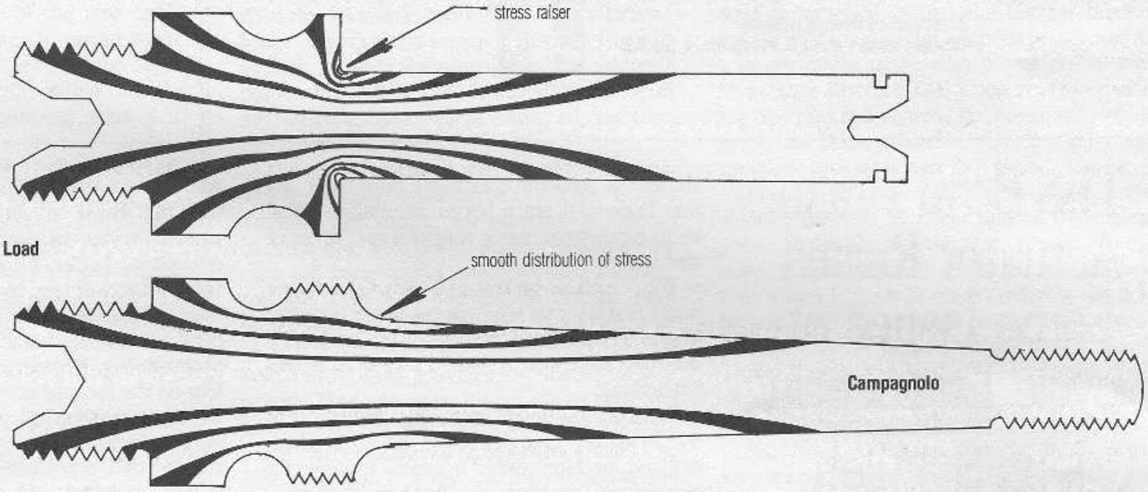
Stress raisers lurk in many bicycle parts. They can snap pedals and crack frames. They weaken a part to a mere fraction of its apparent strength and can drastically shorten its life. What are they? They are shapes—surface features of the part itself that concentrate force into small areas when a load is applied. In these areas the stress (force per unit area) can be several times the stress in nearby areas of the part. If failure occurs in normal use it will almost always occur or at least begin at a stress raiser.

Typical stress-raising shapes are notches, grooves, shoulders, and holes—anything that causes a sudden decrease *or increase* in the cross-section carrying the load. The severity of the stress increase is strongly correlated with the sharpness of the concave curvature, but it also depends on other dimensional proportions and on the elastic and plastic properties of the material used. Fatigue[1] is the mode of failure that stress raisers most strongly affect—normal use is exactly where they cause trouble.

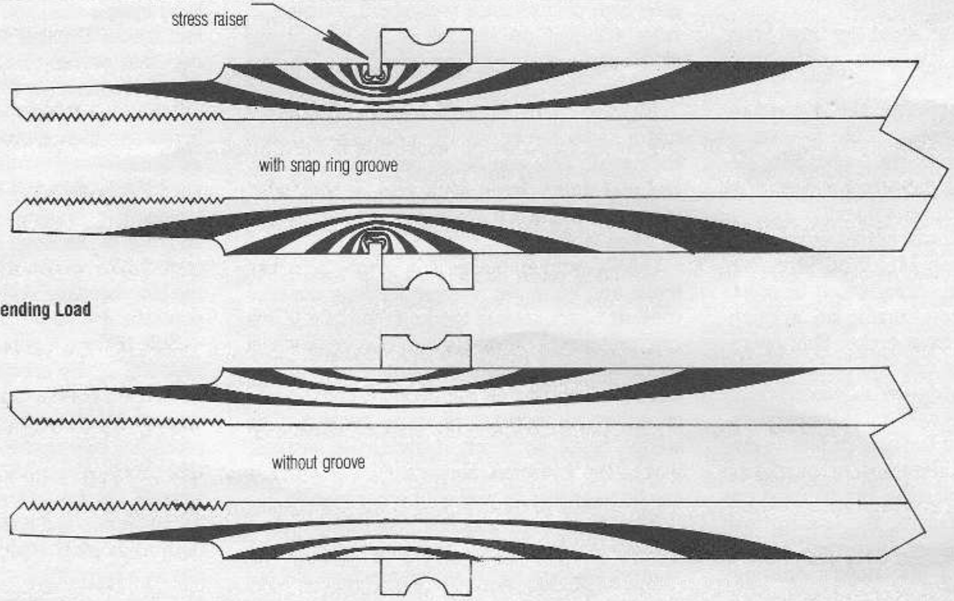
How do stress raisers concentrate the loading force? Not just by uniformly crowding it into a smaller cross-section—the effect can be much worse than that. They do crowd the force by a bottleneck effect, but the crowding is uneven: if a part narrows abruptly, the load carried in the truncated portion must quickly shift sideways into some remaining portion, and it all lands on the nearest adjacent part. Large forces in this small area create high stresses.

In this article I'll briefly discuss a few parts of the bicycle to illustrate how design affects the stress raiser. The examples will be pedal spindles, crank spindles, hub axles, and two frame joints. These are by no means the only areas where stress raisers are a problem, but I chose them as illustrations.

The contour lines in the drawings follow regions of equal strain (stretch or compression) in the material, and the increments between lines are constant. Each set of parallel contours represents a series of zones of progressively higher strain, generally increasing from inside to outside; strains in different places (or stresses, which vary correspondingly) can be compared by comparing the number of lines separating each area of interest from an unstressed area.



Pedal Spindles under Bending Load



Bottom Bracket Spindles under Bending Load

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[1] Fatigue is failure caused by many repetitions of a stress lower than the material's yield stress.

The exact magnitude of stress at a sharp-bottomed recess is difficult to determine because the minute detail at the bottom can make a difference, and because the behavior of the particular metal becomes a large factor, modifying the value that geometry alone would predict. The contours shown here are estimates based on photoelasticity studies[2] of similar shapes.

One can also deduce some idea of magnitudes from the East Rochester pedals in the example shown. Based on the material and on how long the pedals last, I estimate that the spindles fail from fatigue at a stress of 50,000 psi. Theoretical stress without the stress-raising shoulder would be about 12,000 psi at the upper and lower surfaces for a 400-pound sprinting force applied 2 inches out the spindle; thus the stress raiser magnifies the stress about fourfold, according to these estimates.

Rather than measure stress raisers, though, I prefer to avoid them by proper design.

Pedal spindles: The East Rochester pedal (no longer made) has a severe stress raiser designed into it at the shoulder where the inboard bearing sits. Not surprisingly, these pedals have a high failure rate. I have seen several broken ones and know of at least one resulting accident. Ancient Campagnolo relieved the potential stress raiser with a smooth transition from spindle to bearing cone surface and a reduced shaft section between bearing and crank. The rate of fatigue failure on these is very low. Pedal shafts typically fail during a sprint when the greatest stress is applied. Unfortunately, this is the worst time for sudden spindle failure, since it often results in a bad spill and possible injury.

Bottom bracket spindle: These also need to be carefully designed. A spindle with snap ring grooves is not likely to be as strong as a straight shaft even the *smaller diameter* of the snap ring groove. This is particularly true if the snap ring is in the most highly stressed portion of the shaft. Again the stress raisers (the two sharp corners at the bottom of the groove) are amplifying the stress many times at those points. Cracks can form there and propagate through the shaft.[3] Rounding the bottom of the groove can improve the durability dramatically. Of course, the least stressed design is still the full-size shaft with no grooves.

Hub axles: These are available in many styles and configurations, but they can be classified into three basic types:

1. 10-mm hollow threaded axle (most quick-release road hubs)
2. 10-mm solid threaded axle (fixed-gear hubs)
3. ½-inch hollow tube (sealed-bearing-type hubs)

For the 140-pound rider they typically all work

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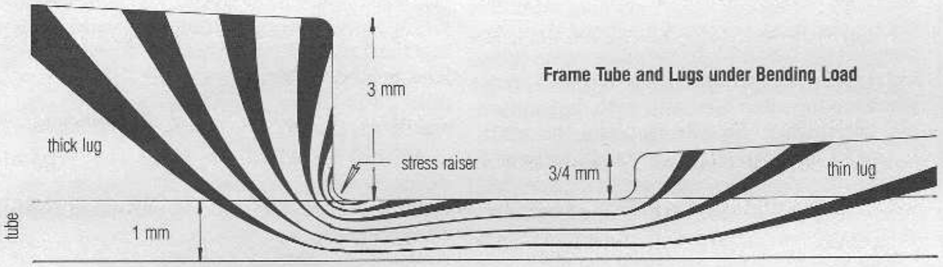
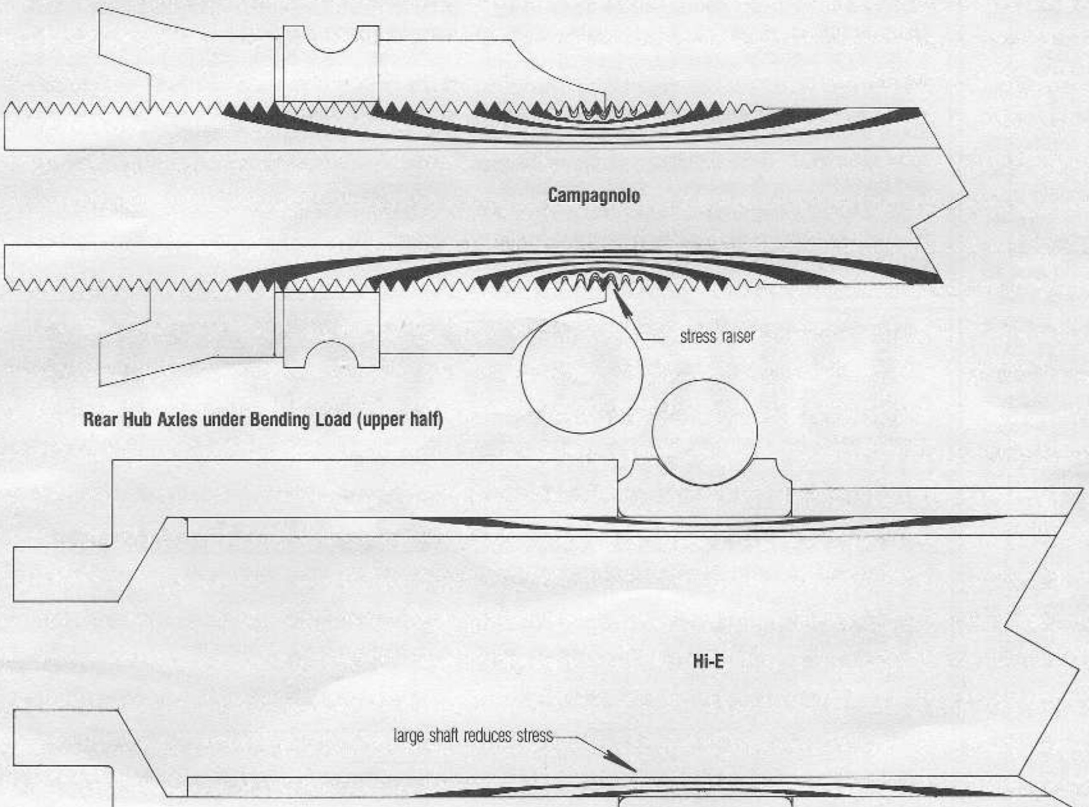
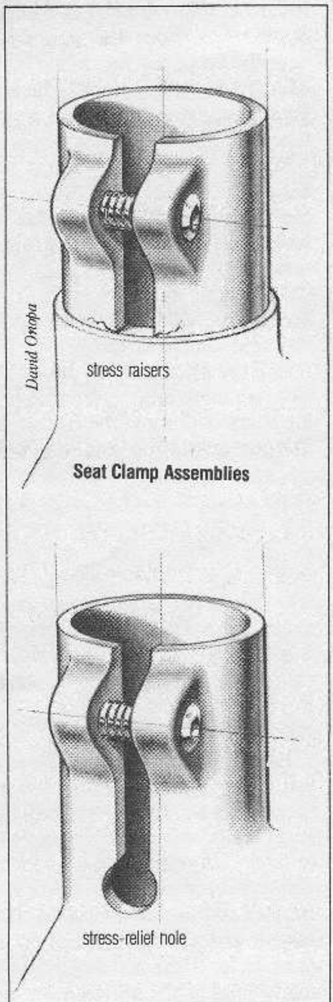
[2] Photoelasticity is a technique that makes such contours visible by using clear plastic models and stressing them while viewing them in polarized light.

[3] I haven't actually seen a failure of this kind, but I think the design asks for trouble.


Frame Tube and Lugs under Bending Load


Rear Hub Axles under Bending Load (upper half)


Seat Clamp Assemblies

Stress Raisers

fine. Heavy riders tend to bend or break the 10-mm hollow threaded axles. These riders can develop chain tension of half-a-ton in a sprint. During a sprint in a high gear, extra leverage is developed on the right-hand bearing of the hub; the chain position is much farther outboard than the bearing. This leverage applies a large forward force on the axle where it carries the right-hand bearing. The 10-mm solid axle probably could take this bending load if it were not threaded; but the threads remove needed material, and the base of each thread acts as a stress raiser. The third type of axle with one plain hollow tube and sealed precision bearings seems to be the best solution for the strong, heavy rider. The larger shaft gives more rigidity and strength with less weight, and there are no threads to create stress raisers.

Frame lugs: A common type of frame failure occurs on the down tube at the lower head tube lug. The design and shape of the lug points are important; if the point of the lug is too thick, there is a stress concentration in the down tube. When the tube flexes in normal use, the tip of the lug, being stiffer, does not. The down tube can crack or buckle at this spot. Poor practice is a lug point twice as thick as the tube wall. Good practice is a tapered lug thickness, distributing stress evenly through the lug and down tube. To flex with the tube, the lug tip should be no thicker than the tube wall, which is typically 1 mm in the butted section near the lug.

On some early prototypes of the Klein frames, we had problems with stress raisers in the seat clamp assembly. We had underestimated the fatigue stress there. The seat clamp slot was made with a slitting type of mill, leaving sharp corners in the bottom of the groove. To make matters worse, the wall thickness of the seat tube was turned down at this end to reduce tension on the Campagnolo seat binder bolt. In the thinned tube, the sharp corners developed cracks that would slowly work their way around the seat clamp. Present design, with which we have had no problem, uses a longer slot with a ¼-inch diameter stress-relief hole at the base. A 6-mm high-strength bolt clamps the seat reliably, eliminating the need for turning down the tube wall. The stress raisers are greatly reduced.

Bicycle parts are typically designed to be just heavy enough for the stress anticipated. Stress raisers, by concentrating that stress in small areas, can drastically reduce the durability and allow early failure, with possible accident and human injury. Designers and manufacturers obviously should be aware of stress raisers and should try to avoid them or compensate for them; and most components on the market today are adequate for average use or even rigorous use by a lighter cyclist. But every rider, and especially the stronger, heavier rider, should examine his or her own equipment, preferably before buying it, to check its suitability for the intended use.

Letter from the Publisher

Welcome to BIKE TECH, a new newsletter from *Bicycling* magazine.

For years the readers of *Bicycling* have been telling us that they would like to receive more technical information from us—even more than we put into the magazine, which is considerable. Similarly, many professional bike mechanics have requested we publish more articles on advanced repair and maintenance. And the industry regularly solicits our views on inventions, prototypes, and new equipment lines.

Add the above points to the renewed interest in bicycle technology, particularly as reflected in aerodynamic and human powered developments, then you have a distinct need for a technical publication.

That is how we saw it at *Bicycling.* Thus the birth of BIKE TECH.

Our primary objective is this: to publish a thorough, well-documented, exciting newsletter on the most important technical developments in the bike field. In the process, we hope to bring science and authority to research areas which are too-often filled with myth, half-truths, and gut feelings. Equally important, we want to provide an open forum for the discussion of bicycle research, inventions, and standards that will affect the consumer, retailer, and industry at large.

The editorial lineup for this issue gives you some idea of the breadth of our coverage. Our "In the Lab" department explores a new way of treating titanium frames which may make them as stiff as steel at half the weight. This is a technical breakthrough in every sense of the word.

BIKE TECH untangles much of the idle talk about silver vs. brass brazing and the effect on tube strength. Mario Emiliani examines joints and finds their soft spots.

In the most thorough article ever published on the International Standards Organization (ISO), Fred DeLong provides a detailed progress report on the changes in international standards that are currently being considered. And John Allen explains what these changes will mean to the consumer, the retailer, and the industry at large.

An important editorial objective of BIKE TECH is to vigorously suggest and encourage research areas of vital importance to the collective future of all of us associated with the sport. And we could have no more eloquent voice raising such issues here than Dr. David Gordon Wilson, professor of mechanical engineering at the Massachusetts Institute of Technology and author of *Bicycling Science,* a landmark book on bike technology.

BIKE TECH will offer regular columns on design criteria, such as the one here by Gary Klein, who analyzes stress raisers in bicycle parts. We will also have "Shop Talk" for the professional mechanic, and frequent articles on the value and usefulness of new inventions.

To bring this meaty package to you we have an impressive lineup of technical editors. Crispin Mount Miller, mechanical engineer, bicycle mechanic, and journalist, will be the Executive Editor responsible for putting the actual issue together. He will receive strong support from John Schubert, John Allen, Fred DeLong, and other well-known individuals listed on the masthead.

All of us associated with BIKE TECH feel it definitely fills a publishing void, in that it extends technical coverage we provide in *Bicycling* magazine into new areas. *Bicycling* will continue to provide in-depth treatment of maintenance and repair, equipment comparisons and evaluations, road tests, and new product reports. In fact, *Bicycling* is expanding its coverage in these areas.

On the other hand, BIKE TECH will deal more with research, inventions, prototypes, design, and industry trends. We feel this new publication will be of interest to recreational cyclists with a technical bent, professional mechanics, and industry representatives.

We hope you agree.

James C. McCullagh
Publisher

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