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SPECIAL REPORT

The View from Japan

Gary Fisher

The country we Americans often think of as Japan, Incorporated is an unlikely king of manufacturing excellence. In the U.S., we're used to plentiful raw materials and cheap real estate on which we build sprawling factories. But in Japan, raw materials are at a premium — 98 percent are imported — real estate is several times as expensive as it is where I live (none-too-cheap Marin County, California), and Japan has had to rebuild its manufacturing base from the ground up in the years since World War II.

But, as we all know, Japan has triumphed. The extra cost of buying from abroad simply pressures the Japanese to be inventive and cost-efficient.

I got to see this firsthand earlier this year, when Tom Ritchey and I traveled to visit a number of Japanese manufacturers. We made the trip to encourage component manufacturers to make components better suited for our off-road bicycle business (Ritchey MountainBikes). Our buying power is small, but we were welcomed as the pioneers of a new cycling activity.

The bicycle market is flat this year in Japan, Europe, and the United States, and both Shimano and Ishiwata were producing car parts (transmission, differential, and drive shaft parts) when we visited. Herein lay the reason for our warm welcome; they need to stay abreast of trends to keep their factories running, and no one wants to be the last company to spot a new market. They all look at Shimano's success in BMX — which started in the United States and has since spread to become a lucrative worldwide fad — and this makes them especially eager to stay abreast of U.S. trends. They're willing to pay an inordinate amount of attention to off-road bikes because they can see them becoming popular worldwide as BMX has done.

Representatives of our trading company served as interpreters, guides, and appointment secretaries for us. They introduced us to the awesome pace of Japanese business: long, tightly scheduled days with intense discussions.

Almost without exception, the people we spoke with genuinely wanted to understand how our bikes were used, and they wanted to know how to make their products better suit that use. This was a welcome change from the typical American attitude of, "It's a toy, why take it seriously?" The Japanese were much more open with us, in a cooperative spirit, than most American manufacturers have been. (I'm told that the president of one major U.S. manufacturer has ordered his employees, "Don't ride those things around in the parking lot; we have enough problems already without you going and finding more.")

So our hosts listened intently to lengthy explanations of off-road riding, of how our designs have evolved broken bike by broken bike, and of where component designs could be improved. They spoke in metric terms, but they used U.S. names and numbers for metallurgical processes.

Extensive Lab Testing

Generally, they knew very little about what off-road riding is like. For example, they thought there was no place to go off-road riding anywhere in Japan, but Tom and I quickly found several appropriate trails on a hill outside of Kobe. They thought off-road riding was an outgrowth of BMX, and we explained to them that it was more related to touring.

These people don't ride bikes (I suspect it's because their long hours at work preclude it), and Japan has a very limited domestic enthusiast cycling market. Thus, they can't test equipment the way Italians do, which is to have a professional team use it in race conditions. The country has millions of cyclists riding hundred-dollar fat-tire single-speed commuter bikes, but that won't do for testing of high-quality products. These factors leave only one option: extensive lab testing.

Our first stop was in Tokyo at Nitto, the handlebar manufacturer, and even this company with its limited product line had many interesting things to show us. Nitto personnel told us that Japanese are now using seamed chrome-moly steel tubing. They like it — they've failure-tested it, and it com-

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pares favorably to seamless tubing — but we told them that we won't use it for reasons of customer acceptance. (This is a painful decision, because the seamed tubing is available in just the right sizes for off-road handlebars, and it saves money.)

Nitto's products range from an eight-pound handlebar/stem for domestic post-office bikes to lightweight aerodynamic bars. And all get tested on a remarkable machine which never stops running.

Nitto's handlebar and stem tester is set in its own concrete foundation so it won't vibrate the rest of the building. A weight of perhaps 10 kilograms is clamped on each side of the bars. The machine shakes the bars at perhaps 200 cycles per minute, with an amplitude of about 3/4-inch at the top of the bar. It's common for a set of handlebars to endure a couple of weeks of this before breaking, but when we were there, we saw a set of bars that had broken after six days. The bars were aerodynamic ones, drilled for enclosed brake cables, and the failure had occurred at the holes. Nitto told us it would work on reinforcing those holes.

Ishiwata sends its products out of house for testing, so our visit there didn't bring back any testing stories. However, we saw its chrome-moly steel investment cast lugs, from the Prestige 810 series, and we were very impressed. The lugs come to incredibly thin tapers, much thinner than we've seen before. Oddly, though, the bottom bracket shell is available only in the bizarre angles of 58 degrees, 30 minutes and 64 degrees, 40 minutes.

From Tokyo, we flew 500 miles south to Osaka, a heavily industrialized city with a cosmopolitan downtown.

Shimano's Osaka complex has its own street signs like those at the finish of a European classic race. The American flag was flying and the billboard read, "Welcome MountainBikes." The computer-controlled plant even has a 10-story high shelving system serviced by a computerized pallet-picking system; 20-foot tall punch presses spit out crankarms; sprockets are punched out a dozen at a time.

We'd hoped to scrutinize Shimano's wind tunnel, site of the company's most intense recent efforts, but a quick glance from a distance was all we were allowed. It was in use at the time, and the D.C. motor gauges read 400 amps. The powerful motor put a tremendous draft through the huge room.

SunTour won our hearts through its friendly desire to understand our work as much as possible. SunTour's large meeting room with an historic display of components from around the world was evidence of its belief in understanding its business through discussion, and of its enthusiasm for bicycles.

The most impressive of SunTour's testing machines was the computer controlled and monitored derailleur drive system. It looked like something Frank Berto would love to build if he had the necessary funds. The testing machine could shift under pressure in any predetermined order. The drive could be constant for wear analysis or erratic to simulate the stroke of the cranks a rider would apply.

The machine could be programmed to measure shifting precision, with a chart recorder telling you how far it pushed the shift lever to achieve a given shift. It could also tell the life expectancy of chain, front and rear derailleurs, and freewheel. While we were there, SunTour's new aluminum alloy freewheel was being tested.

SunTour's coaster brake tester accelerated a rear wheel weighted with 140 pounds to 15 mph and jammed on the brakes for a panic stop. This repeats for about a week, or 15,000 cycles; a graph reads out the time and power of each stop. I was impressed with how long the coaster brakes last.

In addition to lab testing, SunTour also performs actual road testing. The company sponsors road and track teams, and provides them with a team room. The teams race internationally in the type of events we're used to.

The word "National" is seen on many electrical appliances in Japan, as well as on some of the trains we rode in. This large company also makes 700,000 bicycles per year, and they do it with only 250 production employees and 150 administrators. During our visit, we saw bicycles in two different price ranges being built, and we were impressed with both assembly procedures.

Conveyer belts and tram lines carry tubing and components from warehouses into the main assembly building. Complete bikes come out the other end. What happens in between is quite instructive.

The lesser-priced bicycle was machine-made with computer control replacing hand labor every step of the way. One of the rare humans puts pre-cut tubes in a jig with brass rings stuck on the tube ends. An automatic press pushes the tube ends into the lugs. Then the whole jigged frame assembly goes down a tram line, where computer-controlled rings of torches braze each joint. The computer is hooked to a heat sensor, and it pulls the frame away from the torches when sufficient heat for brazing has been applied. The tram line even rotates the frames from one side to the other to greet successive banks of computer-controlled torches.

Then the one truly manual step takes place: the frame goes to one of three tweak tables, where a worker shows off his sharp eye and quick hands by deftly checking the frame alignment and quickly performing any necessary cold-setting to bring the frame within alignment tolerances. The table and all its fixtures are unimaginably heavy.

Then the frame goes back onto the tram line for sandblasting and painting. The five paint booths are cleverly designed: the frames orbit around the perimeter of the booth and are rotated as they orbit. In the center, paint is dropped onto a disc that spins rapidly and oscillates four or five feet up and down with a frequency of about once per second. Hand-held spray guns are used to touch up the hard-to-reach nooks and crannies, the paint is dried, and women apply the decals with a speed I found amazing.

The more expensive bike was the Schwinn Super Sport, with a double-butted chrome-moly steel frame, and I found its assembly equally impressive. About 20 framebuilders, each with his own work area, work side by side churning out hand-brazed frames. From there, the frames go on the assembly line to the cleanup and tweaker.

The builders work fast; little jobs like mitering are done very quickly, in assembly-line fashion, and the end product is almost indistinguishable from far more expensive handbuilt frames. It's frightening to me how well and how quickly these people produce bikes. They know their bikes are built as well as any in the world, and they also know their bikes don't take over the world market because they don't have the flashy image of more expensive bikes, especially those from Europe.

In between these two extremes of manufacturing method are many variants, mostly based on the amount of cleaning time. The same methods can result in very different levels of craftsmanship, particularly in variations of the amount of time spent finishing off the roughly finished pressed lugs used on these bicycles. (Investment cast lugs cost more than twice as much, so their use is impractical for bikes of medium price range.)

National's testing facilities were awesomely sophisticated. Like most manufacturers, National concentrated on fatigue testing of frames. On one testing machine, two air cylinders alternately pump the two pedals on a bike, while another pair of sensing cylinders measures how far the frame has deflected. A row of clamped down tubes with bottom bracket shells were being stressed. Another machine held a frameset with crankset much the same way as *Bicycling's* new frame flex tester (see "Frame Rigid-

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ity," *Bike Tech*, June 1982) with the addition of cylinders pushing back the fork to simulate front brake action.

Most impressive, though, is a complete robot bike rider, made up of cylinders for muscles and weighing about the same as a person. The robot rides on rollers with built-in bumps. Attached to all these machines are computers and chart recorders. Testing like this gives more positive answers about longevity. The engineers at National are keen on stringent testing; every bike must pass 100 percent of the time.

The Japanese bicycle industry standards book very much outclasses our U.S. Consumer Product Safety Commission rules, not to mention the BMA/6 self-imposed rules that preceded them. The book is readily available within the Japanese industry, and it's a very useful guideline on how to make a well-built bicycle. It includes plenty of the kind of information that U.S. manufacturers are forever calling "proprietary." It goes down to such minute detail as the amount of elongation and adhesion you would want on both cloth and synthetic handlebar tapes. I recommend this book to anyone who wants to build high-quality bicycles.

Our last visit was with Tange, makers of tubing and forks. A tour of the fork manufacturing plant revealed — again — quick and good manufacturing processes. A brass insert is placed in the fork crown before the straight chrome-moly blades are lightly pressed in. The fork joins others on a conveyer which takes the fork past ring torches. The penetration is excellent; misalignment is corrected on an automatic straightening machine. Then the fork is raked and sent on to another straightening machine. These straightening machines handled six forks at a time, and did the job as fast as they could be loaded. We had Tange build 300 forks for us. That was less than a day's work.

The Japanese are manufacturing in huge numbers; we expected that. What impressed us were the big investments in high technology and the dedicated management and work force behind the technology. I've seen large manufacturers here in the United States, and the state of the art in bicycle design and execution are all right here, but the question is, can we combine high volume production with the product quality our buyers have come to demand? The Japanese have.

MATERIALS

The Metallurgy of Brazing, Part 2

Filler Metal Characteristics

Mario Emiliani

Not all filler metals are suitable for use in bicycle frame brazing. A filler metal must satisfy several conditions, some having to do with its own physical behavior such as its solidus and liquidus temperatures, and some having to do with its chemical interaction with the base metals. One way that several of these qualities become important is by their effect on the capillary flow that enables the filler metal to penetrate the joint. This installment will describe the implications of some of these qualities, with a detailed description of capillary attraction as context for several of them.

Both silver-based and copper-zinc (brass)-based brazing alloys (filler metals) are commonly used to join bicycle frames. All are known by a string of letters which is their American Welding Society (AWS) designation. Fourteen of the more widely-used alloys are listed in Table 1, along with two fluxes compatible with each.

Of the nine silver-based alloys, each has advantages and disadvantages. Low melting temperature, narrow melting range,* and nice flowing characteristics are the advantages of BAg-1, BAg-1a, and BAg-3. The low melting temperatures save both time and energy. BAg-2 and BAg-2a contain less silver and are therefore less expensive. However, they have wider melting ranges.

All five of these alloys have a potential health hazard: they contain appreciable amounts of cadmium. The cadmium fumes

Table 1: Filler Metals Commonly Used on Bicycle Frames

Filler Metal[1]	Average Chemical Composition,[2] %												Other Elements	Solidus, °F	Liquidus, °F	Brazing Temperature Range, °F	AWS Flux
	Ag	Cu	Zn	Cd	Ni	Sn	Fe	Mn	Si	P	Pb	Al					
BAg-1	45	15	16	24	—	—	—	—	—	—	—	—	0.15	1125	1145	1145-1400	3A, 3B
BAg-1a	50	15.5	16.5	18	—	—	—	—	—	—	—	—	0.15	1160	1175	1175-1400	3A, 3B
BAg-2	35	26	21	18	—	—	—	—	—	—	—	—	0.15	1125	1295	1295-1550	3A, 3B
BAg-2a	30	27	23	20	—	—	—	—	—	—	—	—	0.15	1125	1310	1310-1550	3A, 3B
BAg-3	50	15.5	15.5	16	3	—	—	—	—	—	—	—	0.15	1170	1270	1270-1500	3A, 3B
BAg-4	40	30	28	—	2	—	—	—	—	—	—	—	0.15	1240	1435	1435-1650	3A, 3B
BAg-5	45	30	25	—	—	—	—	—	—	—	—	—	0.15	1250	1370	1370-1550	3A, 3B
BAg-6	50	34	16	—	—	—	—	—	—	—	—	—	0.15	1270	1425	1425-1600	3A, 3B
BAg-7	56	22	17	—	—	5	—	—	—	—	—	—	0.15	1145	1205	1205-1400	3A, 3B
RBCuZn-A	—	59	Bal.[3]	—	—	0.63	—	—	—	—	0.05	0.01	0.5	1630	1650	1670-1750	3B, 5
RBCuZn-C	—	58	Bal.	—	—	0.95	0.73	0.26	0.09	—	0.05	0.01	0.5	1590	1630	1670-1750	3B, 5
RBCuZn-D	—	48	Bal.	—	10	—	—	—	0.15	0.25	0.05	0.01	0.5	1690	1715	1720-1800	3B, 5
RBCuZn-E	—	50.5	Bal.	—	—	—	0.1	—	—	—	0.5	0.1	0.5	1595	1610	1610-1725	3B, 5
BCuZn-F	—	50.5	Bal.	—	—	3.5	—	—	—	—	0.5	0.1	0.5	1570	1580	1580-1700	3B, 5

[1] "B" designates an alloy as a brazing alloy; "R" means that it can also be used for braze welding. "Ag," "Cu," "Zn" indicate principal ingredients.
[2] Ag = silver, Cu = copper, Zn = zinc, Cd = cadmium, Ni = nickel, Sn = tin, Fe = iron, Mn = manganesee, Si = silicon, P = phosphorus, Pb = lead, Al = aluminum.
[3] Bal. = Balance

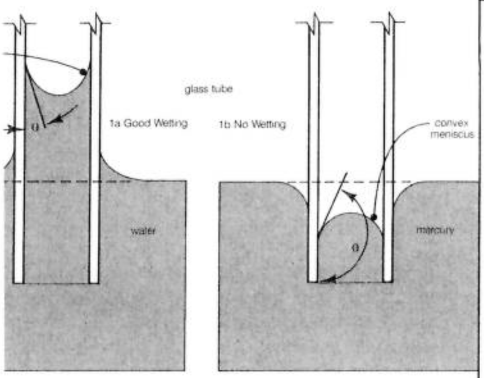


Figure 1: If adhesion between the liquid and tube is greater than the cohesive forces of the molecules, capillary attraction (or wetting) occurs as in 1a. If cohesion is greater, capillary attraction won't take place. Notice that the contact angle Θ in 1a is much less than in 1b.

formed during brazing can be lethal, so these filler metals should be used only if there is excellent ventilation.

There are cadmium-free silver brazing alloys — BAg-4, BAg-5, BAg-6, and BAg-7 — but they exchange the freedom from cadmium fumes for higher melting ranges. Thus, it's important to be sure the brazing temperature is 50-100°F above the liquidus of the filler metal. If it is not, some constituents of the brazing alloy won't be melted entirely. This can affect the strength of the joint, in addition to making it more difficult to achieve good penetration of the joint (since the viscosity of the not-fully-molten filler metal is high).

The RBCuZn-type filler metals are very popular (especially with Italian framebuilders) because they cost much less than silver brazing alloys (at today's prices, BAg-1 costs 50 times more than RBCuZn-C). But they too have drawbacks; these copper alloys contain large amounts of zinc, which is a very volatile metal. If the filler metal is overheated, zinc fumes will form. This will cause filler metal inclusion (penetration among grains) in the tube or lug, and/or porosity in the filler metal.

Small amounts of silicon are added to two of the brasses listed in Table 1 to reduce the fuming tendencies of zinc. Hence, RBCuZn-C and RBCuZn-D are better known as "low fuming brass" and "low fuming brass, nickel" respectively.

In addition to alloying techniques, there is a torch-handling trick that will minimize zinc fumes: use a neutral or oxidizing flame (excess oxygen) when torch brazing. This creates a thin layer of oxide on the surface of the molten filler metal so zinc can't escape as easily, but your flux won't last as long.

**An alloy's melting range is the range of temperatures between its solidus (highest fully-solid temperature) and its liquidus (lowest fully-molten temperature).*

Many framebuilders have sentimental favorite filler metals. One example of this is Sifbronze #1, which is made in England. But Sifbronze #1, like many other foreign and domestic brand-name filler metals, conforms to an AWS specification. Instead of ordering Sifbronze #1 from across the pond, it's much easier to buy the equivalent RBCuZn-A, which is readily available at your local welding supply store.

The copper-based filler metals listed in Table 1 are usually referred to as bronzes, but that's a misnomer. Bronze is an alloy of copper and tin (95%Cu-5%Sn, for example) which doesn't contain any other major intentional alloying elements. Two of the CuZn filler metals in Table 1 don't contain any tin, and they all contain large quantities of zinc. Thus, these filler metals aren't bronzes.

RBCuZn-D (which is the same as Sifbronze #2) contains an average of 10% nickel, and therefore has a silvery appearance. This filler metal is frequently called "nickel silver," but as you can see from Table 1 it doesn't contain any silver. A better name for this alloy is "white brass."

For a number of reasons, a framebuilder may choose to use a couple of different filler metals on a frame. It might be advantageous to braze the dropouts in with a filler metal that's easy to build up; RBCuZn-C for example. However, it's been my experience that every joint on a frame can be brazed successfully with even the most fluid of filler metals, BAg-1.

While most commercial fluxes conform to the AWS Specification given in Table 1, some brand-name fluxes are proprietary compositions which the manufacturers believe work as well or better. As long as the flux is compatible with the filler and base metals, any commercial flux should work well. I haven't seen an exception yet.

Whenever you braze, even if it's with cadmium-free filler metals, always have good ventilation. Constant exposure to fumes from filler metals and fluxes will surely lead to serious health problems.

Capillary Attraction

By definition, the two things that make brazing different from other joining processes are that temperatures lie between 840°F and the solidus of the base metals, and that the molten filler metal is distributed through the joint by a force called *capillary attraction.*

A capillary is usually thought of as a small tube with a very small inside diameter. When applied to brazing, a capillary is simply two solid surfaces which are close enough together so that capillary attraction can occur.

If you immerse a small, clean glass tube into a favorable liquid (such as water), you will notice that the liquid travels up into the tube and also up along the outside of the tube, but not as high. You will also notice that the surface of the liquid inside the tube is concave. This curved surface is called a meniscus, and its presence means that the liquid is wetting the solid.

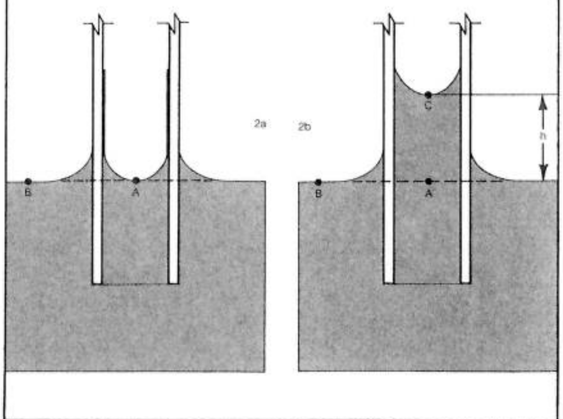
Another way of looking at this is that the adhesive forces between the liquid and tube are greater than the cohesive forces among the liquid molecules. Thus wetting occurs; and since wetting results in a low contact angle, the meniscus is concave. Figure 1 shows examples of concave and convex meniscuses.

Capillary attraction occurs by the following sequence: when a glass tube is immersed, a thin film of liquid runs up the sides of the tube, creating a concave meniscus (see Figure 2a). The surface tension of this concave surface exerts an upward force and a difference in pressure; the pressure at point A is less than that at point B, so the liquid flows into the tube. It flows until it reaches a height where the resulting column of liquid compensates for the pressure difference; that is, when the liquid reaches point C the pressure at A will be equal to the pressure at point B (see Figure 2b).

The same thing happens when a lugged frame joint is properly brazed together: some molten brazing alloy coats the inside of the lug and the outside of the tube, and sets up an imbalance of forces which sucks the filler metal into the joint. The filler metal will keep going into the joint until equilibrium is reached.

The magnitude of the pressure difference, called $\triangle P$, depends on three variables: the surface tension of the liquid, γ; the contact angle, Θ; and the distance between surfaces, d (see Figure 3). Written as an equation,

$$\triangle P = \frac{2\gamma \cos \Theta}{d}$$



George Retseck

Figure 2: The moment the tube is immersed, a thin film of liquid travels up its walls (2a). This causes a difference in pressure which makes the liquid rise to a height h, so that the pressures are again balanced (2b).

Liquid metals such as molten brazing alloys have high surface tensions, between three and ten times as great as water. From the above equation, it's clear that a high surface tension is a prerequisite to having a high $\triangle P$.

If a joint is cleaned and fluxed properly prior to brazing, most molten brazing alloys compatible with low-alloy and plain carbon steels form a contact angle approaching zero. As Θ approaches zero, the cosine of Θ approaches 1. Thus, the cos Θ term does not significantly affect $\triangle P$ for a well-prepared joint.

As the distance between solid surfaces decreases, $\triangle P$ increases — but up to a point. Very small clearances won't allow the filler metal through. Conversely, if d increases, $\triangle P$ decreases, and capillary attraction isn't as strong. This is one reason why the AWS recommends joint clearances between 0.002-0.005 inches for both silver and copper brazing alloys; larger or smaller clearances will result in poor capillary attraction.

For bicycle frame brazing, there is a high γ, low Θ, and small d. Thus if no problems arise (like de-wetting of the flux or filler metal, burning of the brazing alloy which may change γ, or joint clearances outside the range of 0.002-0.005 inches), capillary attraction will be close to the maximum possible value. For example, if we have a joint as in Figure 3, and assume that at 1740°F RBCuZn-C has $\gamma^* = 0.0031$ lb_f/in; $\Theta = 5°$; and $d = 0.004$ inches; $\triangle P$ turns out to be 1.54 psi (or 0.0106 N/mm^2). Thus, there is a pressure of 1.54 psi pulling the molten filler metal into the joint.

The viscosity of brazing alloys is also an important factor. As the brazing temperature increases, the viscosity of the filler metal decreases. Thus, the filler metal becomes more fluid, and is able to penetrate

**G.M.A. Blanc, et al.,* Welding Journal, *Vol. 40, #5, p. 214-s.*

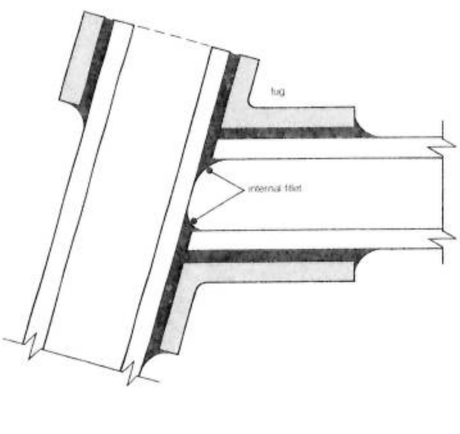


Figure 5: The lack of an internal fillet may be due to changes in filler metal composition. By the time the brazing alloy reaches the miter, its liquidus may be high enough to solidify it.

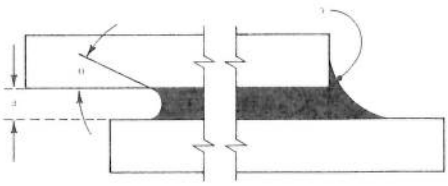


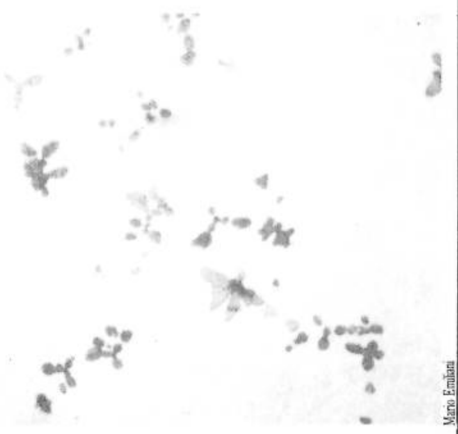
Figure 3: the magnitude of capillary attraction depends on three variables: γ, Θ, and d. When brazing bicycle frames, γ is high, Θ is low, but d can vary considerably.

the joint more easily. But remember, filler metals should never be overheated.

Up to now I've talked about capillary attraction without discussing one important factor — flux. *Most framebuilders and manufacturers use mineral rather than gaseous fluxes.* Until the filler metal is applied, the gap between lug and tube contains molten flux, which would appear to be an obstacle to capillary flow. What happens to the molten flux when the filler metal is introduced?

The capillary attraction between the base metal(s) and molten filler metal is much greater than the capillary attraction between the base metal(s) and flux. Thus, the molten filler metal simply displaces the flux to areas outside of the joint. For a lugged joint, the flux ends up either on the periphery of the lug, or inside the mitered tube (i.e., the tube whose end is open inside the joint).

The viscosity of mineral fluxes can have profound effects on the quality of the joint. As the viscosity of the flux increases, the ability of the filler metal to push the molten flux out of the way decreases. A joint brazed with too viscous a flux will not be bonded completely. Fortunately most if not all commercial fluxes compatible with steels aren't viscous enough to cause extensive problems.



Mario Emiliani

Figure 6: These flower-like crystals were found in the fork crown joint of a well-known production Italian racing frame. The filler metal is an (R)BCuZn-type, and the base metal is Columbus SL. The average diameter of the crystals is about 0.00085 inches (magnified 240 times).

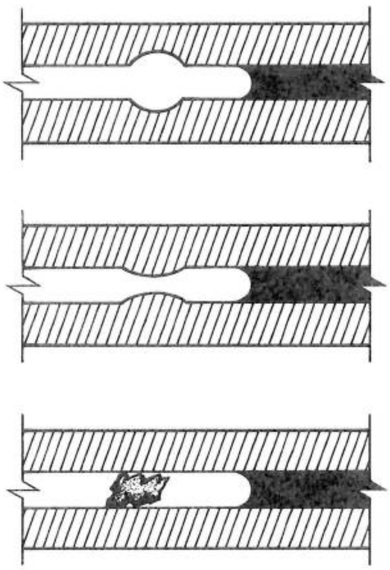


Figure 4: Capillary dams can be caused by sudden increases in clearance, sudden decreases in clearance, and foreign material lodged in the gap. Too many of these dams will result in a poorly bonded joint.

Capillary Dams

Most joints on a bicycle frame don't have uniform clearances. There is usually a range of clearances, from zero inches to sometimes as large as 0.025 inches or larger. Before the use of investment cast components became widespread, lugs, bottom brackets, and fork crowns were either sandcast, stamped, forged, or bulge formed. These aren't precision manufacturing methods, so the tube to component clearance always varied. Furthermore, unless you were a large framebuilder, it was hard to find these components in the required angles. Lugs and bottom brackets usually had to be bent to the desired angles. This would worsen an already poor clearance situation.

Investment cast components are now used by many framebuilders. These are made to very close tolerances, so initial variations in clearance aren't as big a problem. However, these components sometimes have to be bent to the proper angles, too. Clearances can also be affected by misdirected files, uneven filing, and the like.

Variations in joint clearance can cause capillary dams, which are barriers to capillary attraction. Capillary dams are caused by four situations: sudden increases in clearance; sudden decreases in clearance; foreign substances; and a change in composition of the brazing alloy. Figure 4 shows three of the four situations.

When the molten brazing alloy meets a sudden increase in joint clearance, capillary attraction (ΔP) decreases. In other words there is a pressure drop, so the flow slows down while the dam gets filled. Once it is filled, the brazing alloy can continue to penetrate the joint. However, if the joint is vertical so that the filler metal must flow against gravity, a large increase in clearance will stop the flow because it creates too low a ΔP to lift the filler metal. If filler metal can't be introduced elsewhere to reach the rest of the joint, it may help to change the orientation of the joint so that gravity aids the flow.

Sudden decreases in joint clearance cause a brief increase in capillary attraction when the filler metal first reaches them, but act as bottlenecks afterward, so the rate of flow past them decreases. If a constriction is too small, the rate of flow past it may be so slow that the joint won't get filled in a reasonable time. Adding more filler metal elsewhere around the joint may be necessary to complete the joint.

If the clearance is zero, the filler metal won't be able to get through at all. Either the filler metal must go around the dam, or more filler metal must be added elsewhere. Either way, there is a spot where bonding doesn't take place.

In all framebuilding shops, there is quite a bit of dirt and metal filings around. It's very easy for some of this stuff to end up between a lug and a tube to create a capillary dam. If the foreign substance is large enough, bonding won't occur because the filler metal can't get through.

Changes in Composition

Capillary flow can cease during brazing because the composition of the filler metal in the joint changes. At brazing temperatures, the thermal energy is high enough that the filler metal dissolves some of the base metal. This can raise the liquidus of the filler metal, so that it solidifies before complete penetration of the joint is achieved. To finish the joint more filler metal will have to be added elsewhere, or the temperature of the joint must be raised (but not so high that it overheats the filler metal).

A case in point is lugged joints which have been brazed with (R)BCuZn-type filler metals. I've examined many of these joints from top-quality frames, and found that rarely is there a fillet inside the joint (see Figure 5). I suspect that since the filler metal composition changes, it solidifies before penetration is complete (either that or the joint isn't hot enough). The framebuilder, noticing that capillary attraction has stopped, figures the job is done (as anyone would). In practice, lugged frames seem to have a large safety factor, so not having a complete fillet obviously isn't critical.

The amount of iron dissolved depends on the chemical composition of the brazing alloy, and especially its liquidus. The higher the liquidus, the more iron will be dissolved. That's why incomplete filleting is usually more common in brass-brazed joints. The filler metals listed in Table 1 dissolve anywhere from 1/2% to 4% iron.

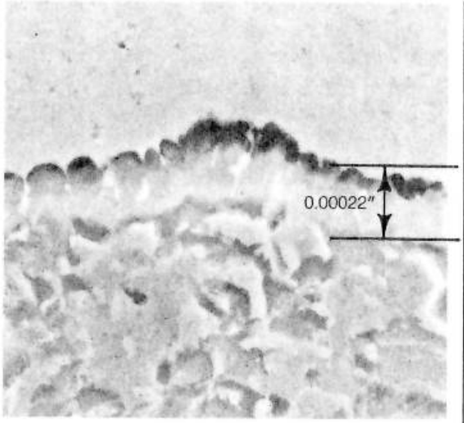


Figure 7: This is a Scanning Electron Photomicrograph of the alloying which can take place at the filler metal-base metal interface. The region above the interface is RBCuZn-A filler metal, while the region below the interface is Reynolds 531 tubing. The average thickness of the intermetallic layer is 0.00022 inches. This photo was taken from the head tube joint of a custom frame built by a well-known American framebuilder (magnified 1550 times).

When a frame brazed with RBCuZn-A gets in an accident and needs a new tube, the joints to be dismantled have to be heated well above 1650°F (the original liquidus of RBCuZn-A). This can cause extensive filler metal inclusions in the lug and adjacent tube because zinc fumes are likely to form. This makes brass-brazed frames more difficult to repair than low-temperature silver-brazed frames.

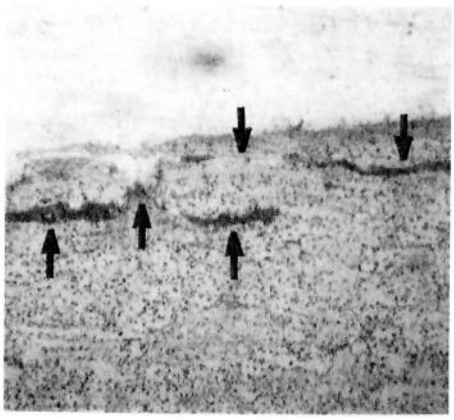


Figure 8: This photo, from the fork blade-dropout joint of another custom American frame, shows that filler metal inclusion doesn't affect just brass-brazed frames. The arrows point to areas where BAg-1 has entered the grains of Reynolds 531. The maximum depth of the inclusions is only about 4.5% of the thickness of the tube. Overheating the brazing alloy will result in much deeper filler metal inclusions (magnified 240 times).

The brazing time isn't as great a factor as filler metal composition or liquidus. For a fixed brazing temperature, the filler metal dissolves about as much base metal as it can in a minute or so.

The elements responsible for dissolving steel appear to be copper and zinc. Since these elements are present in all filler metals listed in Table 1, dissolution of some of the base metal can't be avoided. Provided the joint is filled with brazing alloy, changes in filler metal composition don't seem to adversely affect the mechanical properties of the joint. Figure 6 shows what copper-rich iron crystals look like in a frame joint brazed with (R)BCuZn-type filler metal.

Brazing should always take place 50°F-100°F above the liquidus of the filler metal, then, for the following three reasons: it ensures that the filler metal is completely liquid; it reduces the viscosity of the filler metal; and it will offset the effect of changes in filler metal composition.

Intermetallics

During brazing there is usually some degree of alloying at the interface between filler metal and base metal. Figure 7 shows what this alloying looks like on a frame brazed with RBCuZn-A. It's not necessary to have an alloy form at the interface to develop a strong bond; pure silver is virtually insoluble in iron at its brazing temperature, yet extremely strong joints can be made.

Some filler metal-base metal combinations can lead to the formation of intermetallic compounds at the interface. These are strong but usually brittle compounds which, because they are brittle, can affect the strength of the joint.

An example of the formation of a brittle intermetallic is the formation of iron silicide when brasses containing over 0.25% silicon are used to braze steels. This compound can form in sufficient amounts to impair the mechanical properties of the joint. Furthermore, when this intermetallic forms, the reaction involved gives off enough heat to locally melt the steel (it's an exothermic reaction).

When a joint containing sufficient amounts of iron silicide is stressed, failure is likely to occur at the brittle interface. Conversely, joints which don't contain large amounts of harmful intermetallics are much stronger, and when tested to failure, they fail midway between the joined surfaces.

Another example occurs when steels are joined with BCuP filler metals (copper-phosphorus brazing alloys that contain a minimum of 5% phosphorus). At brazing temperatures, the phosphorus combines with iron to form the brittle intermetallic iron phosphide.

Other harmful intermetallics can form if silver is alloyed with over 30% zinc or over 20% tin (i.e. 65% Ag-35% Zn, or 70% Ag-30% Sn). Notice that none of the filler metals listed in Table 1 contain large amounts of elements which can significantly affect the mechanical properties of the joint.

Filler Metal Inclusions

During brazing it's inevitable that some filler metal finds its way between the grains of the base metal, even if the filler metal isn't overheated. This happens because grain boundaries are less stable than the grains, and therefore more prone to attack. This phenomenon is commonly called "brass inclusion," but it can happen with any brazing alloy. Thus, a better name would be "filler metal inclusions."

If brazing is done in the temperature ranges given in Table 1, it's extremely unlikely that filler metal inclusions will be extensive enough to significantly affect the mechanical properties of the joint. But if the filler metal is overheated, inclusions will be present to a much greater depth. A deep filler-metal inclusion disrupts the continuity of the steel, and can affect the strength of the joint, especially if the frame tubes are extremely thin like those found in Columbus Record or Tange Pro tubesets. Figure 8 shows filler metal inclusions in a frame joint.

Surface Finish

Prior to brazing, the surfaces of the base metals on a frame can have a variety of surface roughnesses. They can be filed, sandblasted, sandpapered, etc., or some combination of these. Surface finish can affect the strength of the joint because it will influence capillary attraction.

Fine scratches aren't a problem if they are parallel to the flow of filler metal. In fact, they can even speed filling of the joint. This can be very helpful, especially when brazing with brass filler metals. Scratches perpendicular to flow can create capillary dams if they are deep enough. In practice, frame joints aren't usually rough enough to cause problems. Furthermore, dissolution of the filler metal by the base metal will smooth out fine scratches.

After reading the first and second parts of this series, you're probably becoming uncomfortably aware that a lot can go wrong during brazing. But do these problems significantly affect the mechanical properties of the joint? We'll find out in Part 3.

Part 3 of The Metallurgy of Brazing will cover tensile, yield, impact, and fatigue strengths in joints, and the role played by defects. Subsequent installments will cover the strength of steel tubes after brazing, annealing and hardening, temperature gradients versus the length of the tube's butt, and proper framebuilding procedures.

INDUSTRY TRENDS

ISO Develops International Bicycle Standards

Fred DeLong

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

ISO, the International Standards Association, is composed 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. Sponsoring companies and organizations in the individual countries, and some individual delegates, see to the funding, including the ISO's costs; provide laboratory workers and equipment to perform needed tests; and send 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 with Fred DeLong

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 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 × 1³/₈-inch sizes), while tires and rims of the same size might have different markings (for example, the Canadian 28 × 1¹/₂, British 28 × 1⁵/₈, and French 700 × 38C tires, which all fit the same rim). Standardization of markings is of unquestionable benefit to bicycle

Proposed International Bicyc
as of the July 1981 meeting of ISC
Fred DeLong and

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				Threading of larger U.S. and British sizes is different from new ISO sizes. For a complete table of sizes, see p. 175 of the 1978 edition of *DeLong's Guide to Bicycles and Bicycling.*
		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		The markings "M" and "B", to be used where there is very little space, do not distinguish an Italian, British, or ISO freewheel or headset. This problem is under discussion.
		If enough space	M 34.7 × 1	B 1.375 × 24		
		If little space	M 34.7	B 1.375		
		If very little	M	B		
DIS 6693	A	**Cottered Crank and Axle Attachment**				The 16 mm axle is the current metric standard. British (5/8-inch) cranks will have to be reamed to fit in the distant future when 5/8-inch spindles become rare. .375 inch, the British standard cotter pin diameter, is almost identical to 9.5 mm, and interchangeable. Steyr, Thompson, other German manufacturers used 9.5 mm; other cotter pins are thinner but redrilling cranks is easy. Cotter pin taper angles vary widely among and within countries. Various tapers were tested before the final ISO selection was made.
		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 × 1 mm		See note	
DIS 6694	D	**Pedal to Crank Thread**			Only compatible with 1-piece cranks, but see note	Sufficient strength is assured with the small diameter by increasing the length of threads. See additional comments in text.
		Threading	B .500 × 20			However, B 9/16 × 20 has been approved as an alternate standard, due to its prevalence.
		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 most current cranks except the less expensive melt-forged Japanese cranks (3-degree taper) and most Italian cranks (1¾-degree taper). Older 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	12.3 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 × 1		All	
		Nut type	M 10 × 1.25		All	
		Dustcap threads	M 22 × 1		Most	
DIS 6696	C	**Bottom Bracket Threads**			British	The current British standard is 1.370 × 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
		Left side	B 1.375 × 24			

at the larger, Italian diameter) would not be possible while gaining this advantage

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. Maillard, Pelissier, Perrin, Sanshin, Shimano, SunTour hollow rear axles are M 10 × 1. Campagnolo and Zeus are 10 mm × 26 tpi — close but not on the money.
		Solid						
		Front	M 8 × 1				French	
		Rear	M 9 × 1				None	
		Hollow						
		Front (and MX solid)	M 9 × 1				French	
		Rear	M 10 × 1				See note	
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 × 24					
		Thread angle	60 degrees ISO					
		Length of thread						
		Freewheel	10 mm min.					
		Hub	10 mm					
DIS 6699	S	**Seatpost clamp bolt**	M 8 × 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 × 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 the 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	
DP 6742	D	**Lighting and Reflectorization**						This is a Draft Proposal (DP), not yet a Draft International Standard. Fred DeLong is preparing an article describing it for a future issue of *Bike Tech.*
-----		Threading of Fork and Headset					British, Italian	This and following proposals are in preliminary stages
		Headset						
		tpi	Diameter, mm					
			major	pitch	minor		British, Italian	
		24	25.522	24.836	24.379			
		Fork						
		Max	25.496	24.810	24.209			
		Min	25.316	24.685	------			
		Thread form ISO 965/1 (60 degree) modified to H/6 truncation at root						
-----		Assembly of Handlebar and stem					Many aluminum	
		Handlebar diameter 25.4 mm +0 −0.20 mm						
-----		Front Hub width 100 mm ± 1 mm					Many	This is for M 8 × 1 solid axle and M 9 × 1 hollow axle. Another, narrower spacing remains to be determined.

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 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 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. Retooling can proceed gradually as tools to the old standards wear out, keeping up a supply of spare parts to the old standards. The new standard may be the same as the most convenient or widely used of 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 1/2-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 1/2-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 1/2-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.

While Japanese manufacturers do make components to French and Italian standards, they do not make frames to these standards, and the new-bike market in continental Europe still remains largely dominated by home manufacturers. On the other hand, Italian, French, Spanish, and other European component manufacturers make parts to British standards. Everyone's tooling cost is raised, and consumers must pay for this. Still, 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 forces toward standardization are 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 × 1 1/4-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.

ISO's Bicycle Safety Standard:

Just How Safe Is It?

John S. Allen

If you were given the task of developing a standard for the safety of bicycles, how would you do it? 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 simulates a head-on crash, the other simulates 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, drive system, handlebar and stem, seat and seatpost, wheel, wheel retention, and brake cable assembly. There is a braking performance test and a wheel roundness test. The only fatigue test is for the pedal spindle.

The cranks and bottom bracket are tested only as parts of the drive system, not individually. Similarly, hub axles are tested only as parts of the drive system and wheels. 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 manufacturers 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.

Another important point is that there is little reliable research data about the actual risk of various features of the bicycle. Frankly, the members of the ISO committee have had to base their judgment on incomplete information. This is recognized in the standard-setting process, as the standard is open to continual revision. However, it should not be forgotten that some substantial hazards must exist which are not recognized; and that some standards protect against risks which are in fact unimportant.

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 (a separate standard is being developed for these); 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 at least one type of 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, forcing the installation and use of inappropriate equipment on some types of bicycles. 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 easily exchangeable 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.

As mentioned earlier, little reliable data exist 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

MATERIAL STRENGTH

What Is Fatigue?

Richard Brown

For cyclists, metal fatigue is a problem that lurks in the shadows, poorly defined and poorly understood. How it affects a bicycle's performance during thousands of miles of travel, over surfaces varying from smooth to very rough, is not at all clear. Two extreme opinions exist. Some riders suggest that fatigue is never a problem, while others suspect that frames lose their rigidity with extended use because of fatigue.

Fatigue failure could also be a safety problem, of course. A few components that have come and gone in the bicycle market have had failure-prone designs that contributed to accidents. In steel frames, however, fatigue failure has not been a widespread problem. Only in rare cases have outright failures of frames been attributable to metal fatigue.

The aim of this article is to define clearly what constitutes metal fatigue, how it occurs, and what problems for a cyclist may be associated with it.

Repeated Stress

Fatigue is usually defined as failure of material due to repeated stressing. A simple example is the breaking of a piece of wire. Rapid bending back and forth eventually causes the wire to break — this constitutes a simple fatigue failure.

If the wire is examined after a few bending cycles (but before it breaks) it will not be straight as it was at the start. The extent to which the material remains permanently bent after the load is removed is termed "plastic deformation."

(The deformation of a material under load can be either plastic or elastic. Elastic deformation, like the stretching of a rubber band, is fully recoverable when the load is removed. Plastic deformation, which occurs if the material is deformed beyond its maximum elastic deformation or "elastic limit," is not recoverable when the load is removed.)

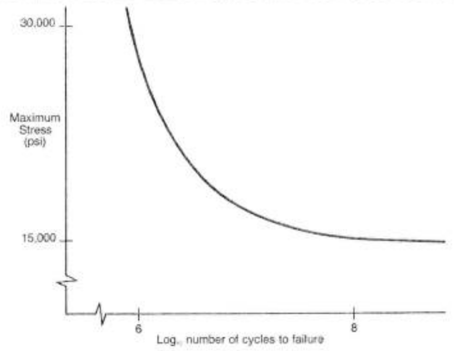


Figure 1a: Typical S-N curve for nonferrous materials.

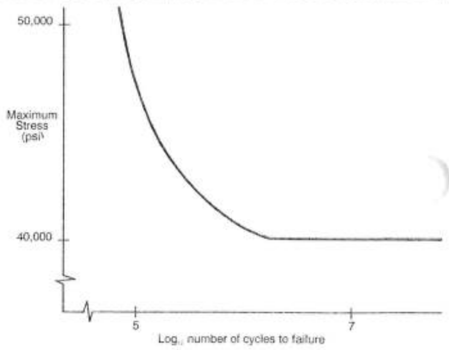


Figure 1b: Typical S-N curve for ferrous materials.

This plastic deformation, repeated some number of times, is the cause of fatigue. The number of repetitions before failure may vary from half-a-dozen with a coat-hanger wire to millions with a machine part designed almost well enough but not quite.

Subtle Deformation

In the case of the wire, the amount of plastic deformation is large and visible to the eye. For strong, complex alloys such as titanium alloys and high-strength steels, the plastic deformation necessary for fatigue failure may be immeasurably small, detectable only by extremely sophisticated techniques such as scanning electron microscopy. However, some amount of plastic deformation is always a necessary condition for fatigue failure.

Because the plastic deformation may be so subtle, designers may work under misconceptions. For example, many designers and engineers use a material's yield point as the basis of safety margin calculations. (The yield point is a measure of the stress at which a *large amount* of plastic deformation begins to occur.) But high-strength alloys, because they are vulnerable to such small plastic deformations, can fatigue at stresses much lower than the yield point; significant fatigue can begin in some titanium alloys at a stress level of about half the yield point. Designing according to the yield point, then, is not very good for titanium alloys (though fortunately not too bad for steels, whose fatigue strengths are closer to their yield points). Clearly, fatigue strengths for frame materials must be considered as well as tensile strengths.

The repeated plastic deformation may result from several kinds of stresses. Tensile, bending, and torsional loads are three directly applied stressing modes, all of which can produce metal fatigue. In addition to these, stress concentration effects from "stress raisers" — concave surface features such as corners, scratches, and bolt holes — can multiply applied stresses by factors up to ten and greater. The radius of the concave curvature strongly influences the stress multiplication factor. Residual stresses from processing treatments such as forging, rolling, and brazing must also be considered.

Fatigue Limit

Laboratory tests for fatigue are performed by applying stresses of cyclically varying magnitude, with a specific range between the maximum and minimum stresses, and recording the number of cycles to failure. (Usually the stresses are tensile stresses produced at the surface of a specimen by bending it equal amounts alternately in opposite directions, so that the "minimum" tensile stress is actually negative — i.e., compressive — and of the same magnitude as the maximum tensile stress.)

If many smooth, similar-shaped specimens of the same material are tested, each at a different stress range, and the stress range applied is plotted against the logarithm of the number of cycles to failure, the data form a curve known as an S-N curve.

A typical example is shown in Figure 1a for nonferrous materials. At around 10^8 (100 million) cycles the curve becomes approximately parallel to the "number of cycles" axis. A further reduction in stress range essentially results in an infinite life.

For ferrous materials, a discontinuity in slope, or "knee," is observed (Figure 1b). For stresses below this knee, no fatigue occurs.

Safety Standard:

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. It would make it less likely that the standard could be used unfairly as evidence in lawsuits against manufacturers, or in court proceedings involving bicyclists who have had accidents if the title and wording of the standard explicitly explained its tentative status, and its lack of a firm statistical basis.

The work of the ISO committee is not over. As mentioned, the committee may revise the standard at any time. Also, a standard for lighting and reflectors is in the works, but has not yet been approved by the ISO member countries. Nighttime equipment 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.

The stress that allows 10^8 cycles before failure in nonferrous metals, or the stress at which the "knee" occurs in ferrous metals, is called the "fatigue limit": below this stress, fatigue is unlikely to be a problem. Stress ranges should be kept below the fatigue limit for a safe fatigue life.

In applications where the stress range is not centered around zero, the mean stress, or average of the maximum and minimum stresses applied, affects fatigue life. The higher the mean stress level, the lower the stress range that can be applied. The stress range must be reduced because, with a given stress range, a higher mean stress is accompanied by a higher maximum or "peak" stress; and the closer the peak stress applied is to the ultimate (breaking) tensile stress, the shorter will be the fatigue life. When the peak stress applied is greater than the ultimate tensile stress, the specimen fails in the first cycle and the fatigue test becomes a tensile test.

Anatomy of Failure

The process by which fatigue induces failure is by crack initiation and growth, after plastic deformation. Early in the fatigue life, usually before 10 percent of it has passed, slip lines appear on the metal surface due to shearing within the metal. Slip lines are the exposed edges of "slip planes" between layers of atoms within the metal; when metal shears, material above such a plane moves permanently with respect to the material below it. An analogy would be pulling a rug across a floor — the rug moves relative to the floor, and the surface between them is the "slip plane."

One might expect that shearing would result only when loads were applied in the shearing orientation (such as torsion), but in fact, shearing stress also occurs, along oblique planes within the material, when loads are applied in tension or compression; and except for brittle fracture, shearing is the mode by which metals deform plastically under any type of loading. (The overall effect on an object may be one of stretching or shortening, but it occurs as the result of many oblique shearing motions within the object.)

When metal is stressed in pure tension or compression, the resulting internal shearing stress is strongest along planes oriented at 45 degrees to the applied stress, so it is in this direction that slip planes appear (Figure 2). The dotted area shows the original material position; clearly an extension or plastic deformation has occurred. Many slip planes result in a large amount of plastic deformation. A single slip plane is immeasurably small, but still may cause fatigue failure.

Eventually a crack begins on a slip line and progressively grows into the bulk of the specimen (Figure 3). When the area of material not cracked is so small that its tensile strength is reached when load is applied, the component fails. Fatigue, therefore, has

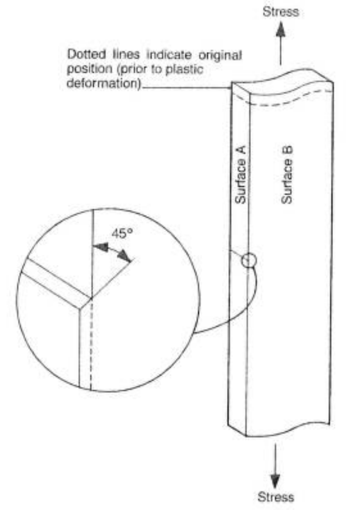


Figure 2: The slip plane is at 45 degrees to the surface A during the initiation stage of a fatigue crack. In the case of a bicycle frame tube, surface A would be the tube's outside surface and surface B would be a cross section of the tube wall. Fatigue cracks may be initiated at a tube's midsection — a piece of metal need not have an exposed edge to start fatigue cracks.

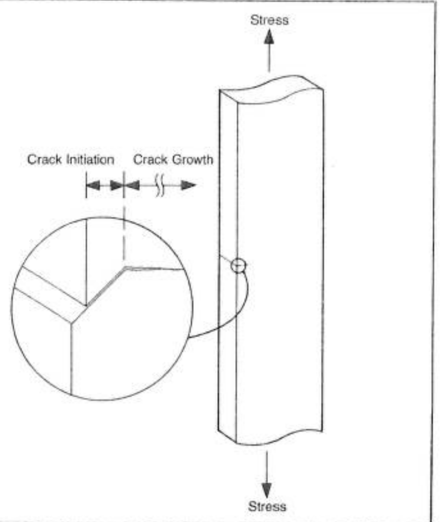


Figure 3: Crack initiation on slip line followed by crack growth perpendicular to the applied stress. When the cross section is reduced to the point where it can no longer support the load, fracture occurs.

three stages: crack initiation, crack growth, and tensile overload.

Fatigue and Cyclist

The crucial question is, does fatigue affect a bicycle's performance? The answer, as usual, is maybe. Laboratory tests show that steel, for example, may form slip lines and deform plastically below the fatigue limit, but cracks do not initiate or grow. The more stressing, the more slip lines and plastic deformation.

I do not know of research or testing which has shown whether the stress levels in a bicycle frame are sufficient to produce these slip lines. If the process does occur in bicycle frames, it may be responsible for the alleged loss of rigidity in aging bicycle frames. Cracks would have a similar effect, but are unlikely since they would probably cause more failures than have been reported.

Other frame materials, such as titanium alloys, almost certainly have failed by fatigue. For more information watch this space. The only way the frame aging question can be resolved is by experienced, unbiased metallurgists inspecting bicycle frames after periods of use to look for slip lines and cracks. However, as always, money is required to fund such research. When this is forthcoming the question of fatigue and stability of frame materials will be answered.

Manufacture and Fatigue

Manufacturers often unsuspectingly degrade the strength of a product by using inappropriate joining and finishing processes. In bicycle frames, thin-section tubes amplify any major defects from manufacturing processes. Examples already apparent from my limited investigations include surface cracks from extensive pitting in a titanium alloy frame, and extreme surface roughness and embedded particles in a steel frame.

In the former case, application of an anodized finish by electrochemical means resulted in excessive pitting of the surface. These pits initiated cracks by acting as stress raisers. Both internal and external surfaces contained a large density of fatigue cracks. The frame would not have had a long user life.

In the second case, sandblasting on the outer tube surface was used to remove brazing flux and help paint adhesion. Cracks and sand particles embedded in the frame surface by excessive sandblasting were an aid to the fatigue crack which eventually produced frame failure.

The quality of joint brazing can also affect frame performance. A joint incompletely filled cannot transmit load from tubes to lug effectively. Stresses result in the braze metal that are higher than expected, perhaps leading to failure. In addition, porosity in brazed joints can create effective fatigue crack initiation sites hidden from visual inspection.

Overall the quality of manufacture can affect frame performance greatly. I wish to make it clear that the incidents related above are isolated and appear to be rare. The long-evolved, well-used and tried techniques of current frame manufacturers seem to be very adequate. However, it appears that significant deviation from the accepted frame-building processes requires careful consideration.

Dr. Richard Brown is an Assistant Professor of Metallurgy in the Chemical Engineering Department of the University of Rhode Island.

PHYSIOLOGY

Elite Athlete Program

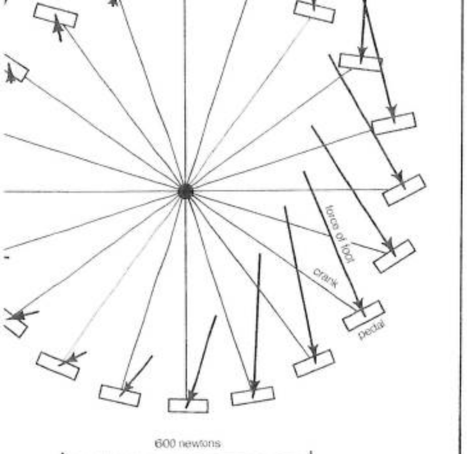
Sports Science and Technology for the U.S. Olympic Cycling Team

Ed Burke, PhD

Opening the sports pages of their local papers after the 1976 and 1980 Olympics, Americans were faced with the headlines that the countries of eastern Europe were dominating the sport of competitive cycling. The immediate response of many Americans was "Why don't we do better?"

There must be many reasons. Sports science and sports medicine have been named often as one of the reasons. I have spent a good deal of time reading, writing, discussing, and listening to a lot of material on subjects such as this. Finally, in cooperation with the United States Olympic Committee, with initial funding from the Committee augmented by contributions from American cycling industries, I have developed a comprehensive plan to apply the latest developments in technology, biomechanics, physiology, medicine, and psychology to the sport of cycling. Sponsors include *Bicycling* Magazine, The Southland Corporation, Campagnolo, Excel, Bell Helmets, and Nike.

For this program we have assembled a comprehensive team of sports scientists to solve critical performance and engineering problems. These scientists, coaches, and athletes met last January in Colorado Springs and discussed their concerns in the areas of biomechanics, aerodynamics, bicycle design, and sports psychology. Briefly I will describe the approaches we are taking in this work and what the benefits can mean to cyclists and the cycling industry.



Biomechanical Research

The laws of physics apply equally to any system in motion, be it person or machine. Surprisingly few studies have been devoted to analyzing human motion to improve cycling performance, either competitive or recreational. Of those that have, most have investigated the pedaling of the bicycle in the laboratory. They have been concerned with the force exerted on the chainwheel, the pedal, and/or the crank. Few have used a standard bicycle, and none of the experimental situations has provided a realistic simulation of the inertia of the bicycle-rider system that exists during riding on the open road or velodrome.

In our current research we will combine the data of laboratory research (showing the normal and tangential components of force exerted by the feet of competitive cyclists throughout each cycle of pedaling) with kinematic analysis of their cycling technique during actual competition. (Kinematics is the branch of mechanics dealing with the motion of objects without regard to the forces causing the motion.)

An example of the results learned in the laboratory is shown in the figure. The diagram shows the angle of the pedal and the direction and magnitude of forces developed, averaged for 30 seconds for John Beckman during a simulated pursuit. The bicycle was mounted on a specifically designed stand to allow the workload to vary. An important feature of this apparatus was that it provided the rider with an amount of inertia similar to that achieved while riding on the velodrome. This research is being conducted at the Biomechanics Laboratory of Penn State University by Dr. Peter Cavanagh and Mario LaFortune.

A fundamental necessity for kinematic studies is an accurate method of measuring the positions of parts of the body during motion in space. Our kinematic research technique begins with the filming of body motions, generally at film speeds ranging from 64 to 200 frames per second (in some work the speed could be as high as 10,000 frames per second).

Positions of body features in the film image are then coded as digital information. Each frame is projected on a screen that has strip microphone sensors along two adjacent edges which are taken as x and y axes. With a sonic pen that emits a "buzz" of sharp clicks, the investigators mark the body joint centers on the picture; the microphones receive the pulses an instant later, the delays being determined by the distances from them to the pen (divided by the speed of sound). A computer digitizer measures the delays, calculates the exact distances (which can be considered as the x and y coordinates), and transmits them to a display.

Once the film speed and the displacements of the joint centers are known, computer programs calculate velocities and accelerations of different body parts. Suitable programs combine and analyze this information to obtain resultant forces with their angles of application and movements, coordination of motion between portions of the body, etc.

The actual field filming was done during the Bicycling/7-Eleven Grand Prix, the National Sports Festival, and the World Championships this summer. When combined with the laboratory data, it will give us a complete picture of cycling mechanics, kinematics, and kinetics. The field filming will be conducted by Dr. Robert Gregor from UCLA, Dr. Peter Francis from San Diego State University, and Dr. Charles Dillman from the Biomechanics Laboratory of the U.S. Olympic Training Center.

Dr. Francis is also conducting three-dimensional kinematic time histories of the lower extremities of some of our national team members who have had chronic knee or foot problems. The resulting information will allow him to prescribe various orthopedic devices or changes in their foot position or shoes to improve their performance.

Aerodynamic Research

Drag force is the term used to describe the effect encountered from wind resistance. It depends on three main factors:

- air speed — air flow velocity relative to an object and therefore not always the same as velocity of the object over the ground;
- frontal area — the size of the object confronting the air flow; and
- drag coefficient — a value given to express the relative resistance of any object to the movement of air around it.

The drag force is directly related to the frontal area and drag coefficient, but varies with the square of the air speed. Each time the speed doubles there is a fourfold increase in wind resistance. The power (rate of energy output) required to overcome that resistance is the product of the drag force and speed, and is therefore roughly proportional (in still air) to the cube of the air speed. For example, you need eight times as much power to overcome wind resistance at 24 mph as you need at 12 mph.

Wind resistance at 12 mph is only a little greater than rolling resistance generated by tires and internal resistance of the bicycle. At 25 mph, air resistance can consume up to 90 percent of the cyclist's energy output. And while power output depends partly on ground speed, increases in air speed due to head winds still have a dramatic effect: a cyclist maintaining a speed of 12 mph in the face of a 12 mph head wind is working four times as hard as would be required for 12 mph in still air. Thus streamlining, reduction of frontal area, and cleaning up of bicycle components are of paramount importance to the competitive cyclist and the long-distance tourist.

Until the past few years aerodynamic shapes on standard racing bicycles were rare or unknown; however, UCI rule interpretation has recently been relaxed to permit such things as skin-tight slick suits, aerodynamically shaped helmets, teardrop-shaped tubing, and smoothed bicycle components. This modification of the standard racing bicycle has been especially rapid the past two years.

Although the world cycle manufacturers have gone a long way toward aerodynamically improving the standard racing bicycle, they have not come close to what can be done ultimately within the UCI rules. The International Human Powered Vehicle Association (IHPVA) has stepped forward, led by Dr. Chester Kyle (founder of the IHPVA), Dr. Paul MacCready (winner of the two Kremer Prizes for human powered flight), Paul Van Valkenburgh (several times winner of the IHPVA Speed Championships), and several others who have agreed to work on this project to ensure that the U.S. Olympic Team is the best mechanically and aerodynamically prepared team in 1984. Since February, initial work has been completed on several helmet and clothing designs which have been tested in the wind tunnel at California State University, Long Beach. Work is also being completed on spoking patterns, moments of inertia, and rolling resistance of wheels.

The group's primary objective is to design, develop, build, and test a completely integrated aerodynamic racing bicycle system for the Olympic team in the following events: 4000-meter individual pursuit, 4000-meter team pursuit, and 100-kilometer team time trial. The bicycles and associated equipment will be completed and tested well before the 1984 Olympics, so that the cycling team can become accustomed to the use of the new equipment. The intention is that no other team should have an advantage over the U.S.A. solely due to equipment.

However, the design of an integrated aerodynamic bicycle will be expensive. Therefore, we are still looking for a manufacturer(s) to sponsor this project under the guidance of the IHPVA group.

The cycling industry has much to gain from sponsoring projects such as the independent research described in this article. The weak growth of the U.S. cycling industry is (in my opinion) due to low expenditures on research and development, too much government regulation, and conservative corporate management.

A second approach could be the establishment of a trust or foundation to support cycling sports science and technological research. Businesses would lose the benefits of advertising support of teams and events, but cyclists would gain a more secure and equitable form of R and D funding.

RESEARCH

Getting the Numbers Right, Part 3

Evaluating Stability and Safety

Paul Van Valkenburgh

In this issue we present the third of three installments of Paul Van Valkenburgh's paper from the IHPVA Scientific Symposium of November 1981. This part covers stability and safety evaluation; parts one and two (published in the June and August issues of Bike Tech*) covered ergonometry, computer simulations, and drag measurements on human powered vehicles. Proceedings of the entire IHPVA symposium are available for $16.60 postpaid from: IHPVA, c/o Dr. Allan Abbott, P.O. Box AA, Idyllwild, CA 92349.*

I've been involved in the study of human-powered vehicle stability in two interesting ways: I designed an HPV which turned out to be quite unstable, and then worked on a government study which eventually explained why. (In the course of the study, I learned that my four-wheel vehicle would have been more stable with three wheels!)

The four-wheel, diamond-configuration, hand-and-foot powered "Aeroshell," which held the singles speed record in 1977 and 1978, was a bit of an embarassment, since my specialty is vehicle dynamics and accident avoidance.

I chose the diamond configuration solely for straight-line aerodynamic packaging reasons, and I never intended it to be turned more than a few degrees.

But when it overturned and crashed five times in four speed events, it demanded some stability research. Although all crashes were due to mechanical failures (tire or steering) and a camera crew in the way, I must admit that the configuration was both directionally unstable and easily overturned.

Subsequently, I participated in some detailed research requested by the U.S. Department of Transportation (DOT) and Department of Energy (DOE) on "Stability of Three-Wheeled Vehicles," which indirectly shed some light on the problem of the four-wheel diamond configuration. The methodology of evaluating stability is described in detail in the official 125-page government report[1] and summarized in an SAE paper[2]. (Two-wheel vehicle stability evaluation is best described by co-worker Dave Weir[3].)

The maneuvers used for stability evaluation are listed in the table. Especially noteworthy is the crosswind disturbance test[4] which is particularly applicable to the assumed problem of crosswind gusts on lightweight, aerodynamic HPVs. In fact, these problems are solvable. We subjectively evaluated faired motorcycles, mopeds, and streamlined bicycles with 45 mph crosswind generators (a series of eight 10-foot cubes, each with an eight-foot propeller and a 50 hp gasoline engine), and any stability problems do not seem to be insurmountable. While the instrumentation used in these maneuvers was rather sophisticated, including four channels of analog recording, inertial reference instruments, and computer and photographic analysis, in most applications a subjective or stopwatch evaluation would be adequate.

In the case of overturn resistance evaluation, we developed equations to predict accurately the lateral gs or speed and turn radius at which a given design would overturn. These predictions are based on track width, wheelbase, vertical and horizontal center of gravity (c.g.) location, longitudinal acceleration, and tire and suspension characteristics.

We developed methods to measure the c.g. location accurately, and to predict the effects of moving the c.g. Dividing the overturn g limit by the tire cornering g limit gives an overturn safety margin figure which can be used to compare different vehicle designs. We discovered that three-wheelers can be made as overturn-resistant as four-wheelers, even in the worst cases of braking with one front wheel or accelerating with one rear wheel.

Incidentally, for three-wheelers with overturn tendencies we also discovered that either a one-in-front or a one-in-rear configuration could be balanced on two wheels and ridden like a two-wheel motorcycle for short

Test Maneuvers

Category	Research Objective	Test Maneuver
Handling: Stability	Lateral acceleration limit Steady state yaw gain Stability factor Overturn	Constant radius circle
	Returnability	Free returnability
	External disturbance response	Crosswind disturbance Bump in turn
	Transient yaw response Time constant	Step steer
Handling: Control	Math modeling	Steering sweep
	Evasive action response	Single lane change (Emergency lane change)
Braking	Stopping distance Path maintenance Force gain	Straight line brake
	Path maintenance Overturn	Brake in turn
	Overturn	Brake in turn on slope

distances — if the maneuver was anticipated and carefully controlled with the throttle and steering wheel.

The general conclusion was that there are few handling and stability differences between three and four-wheelers. The worst that can be said is that the one-in-front configuration has a strong tendency to oversteer. At the limit of cornering traction, this creates an unstable condition. This is difficult for an inexperienced driver to control, and almost impossible to prevent in design.

The one-in-rear configuration does not have this problem, and can have handling characteristics indistinguishable from a four-wheeler. In other words, a well-designed three-wheeler can be made as stable as a well-designed four-wheeler.

Although the four-wheel diamond configuration was not tested in this project, our inference is that it must be more unstable than the one-in-front three-wheeler. Under deceleration and/or cornering, the center of gravity transfers weight from the lone rear wheel to the front and side wheels, producing the undesirable one-in-front three-wheel configuration described before.

But, more importantly, when the weight shifts off the rear wheel and the effective wheelbase is cut in half, this sharply decreases the turn radius (for any given steering angle) and the vehicle suddenly oversteers. If not corrected in time, and if the c.g. is high enough, this oversteering leads to overturn. In other words, although this vehicle was never intended to be turned, the smallest perturbations made it want to turn of its own accord.

Safety Evaluation

So — are these vehicles safe?

The first level of safety is accident *avoidance* (covered in the preceding section). But the second level, accident *protection*, is an equally important question. The U.S. Department of Transportation (DOT) and auto industries spend hundreds of millions of dollars each year evaluating the safety of automobiles — which legally cannot travel as fast as some HPVs.

Unfortunately, HPV production does not justify such expensive research at this time. Fortunately there have been no serious accidents in them — yet. In fact, the empirical accident data to date (accidental accidents) indicates that enclosures provide considerable impact protection for cyclists.

The reason for the incredible cost of impact research is that accidents are by nature unplanned, unstandardized, and largely unrepeatable. Therefore, a number of artificial and carefully detailed impact scenarios must be designed and all variables controlled or measured to an extreme degree of precision.

To get meaningful data, a precision-instrumented realistic anthropometric dummy must be used in each test. Even if real humans could be used, they do not give repeatable data. (Nor do cadavers, which are sometimes used.)

Automotive impact tests are a good example to follow, considering the similarity in purpose, speeds, design, and environment — if not size and weight. The U.S. DOT has established over a dozen standardized impact tests which all automobiles must pass. All of these tests are reasonably realistic and desirable for any vehicle that is to be marketed.

But the costs of performing these tests can run from three to five thousand dollars *each*. (For government reportage, double the cost.) And that does not include the cost of the two or three vehicles destroyed.

While such tests have not been recommended for motorcycles, bicycles, or three-wheelers, the legal liability requirement of "due care" would suggest that a designer at least be aware of safety-related design considerations.

Conclusion

Before starting any research, one needs to ask, "What is the ultimate purpose?" Is there a burning need for the data, or just a casual interest? Will the results have to stand up in court or simply mean a won or lost race? And what is the balance between cost and accuracy?

Bicycles, even HPVs, are relatively simple vehicles compared to automobiles or aircraft, where all these research methods have been proven. Most of the basic research questions proposed by David Gordon Wilson[5] could probably be resolved to everyone's benefit and satisfaction for a few hundred thousand dollars. Even accident avoidance and impact protection problems could be solved for less than a million, or ten cents for every bicycle sold in one year.

There is certainly no problem in getting the right answers, using state-of-the-art methods. But such research is unlikely as long as the government and the bicycle industry remain apathetic, and there is no reward for individuals to carry the burden.

[1] *Van Valkenburgh, Klein, Szostak* Evaluation of 3-Wheel Vehicle Stability, *G.P.O., (in press).*
[2] *Van Valkenburgh and Kanianthra,* 3-Wheel Passenger Vehicle Stability, *S.A.E. paper No. 820140*
[3] *Zellner and Weir,* Development of Handling Test Procedures for Motorcycles, *S.A.E. paper No. 780313*
[4] *Klein and Jex,* Development and Calibration of an Aerodynamic Disturbance Test Facility, *S.A.E. paper No. 800143*
[5] *Wilson also spoke at the IHPVA symposium. He suggested research to improve human power production (i.e. to discover optimal postures and motions) and to improve HPV aerodynamics, rolling and transmission efficiency, and accident prevention (especially braking and structural integrity). He proposed funding this research with a very small tax on new bicycles.*

Let Us Hear

We'd like *Bike Tech* to serve as an information exchange — a specific place where bicycle investigators can follow each other's discoveries. We think an active network served by a focused newsletter can stimulate the field of bicycle science considerably.

To serve this function we need to hear from people who've discovered things. We know some of you already; in fact some of you wrote articles in this issue. But there's always room for more — if you have done research, or plan to do some, that you want to share with the bicycle technical community, please get in touch.