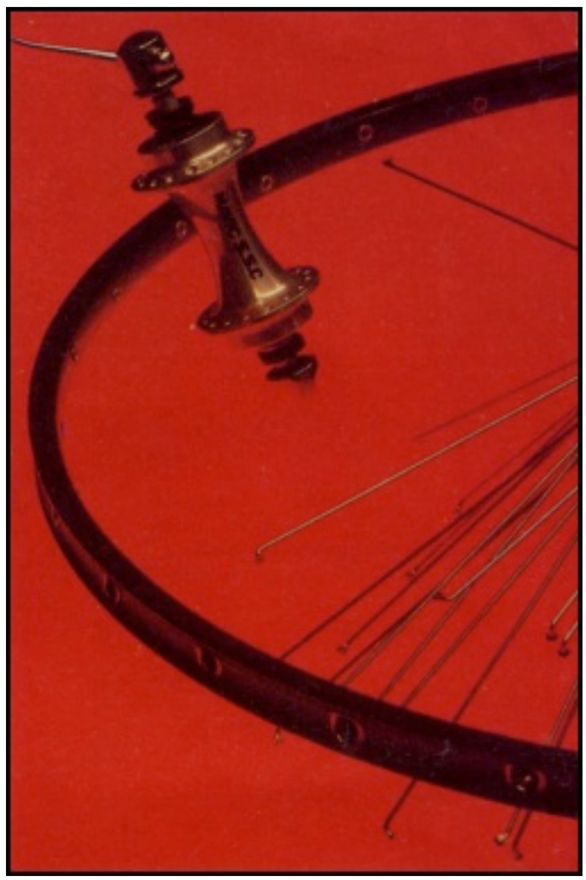
BICYCLING - JANUARY 1986 - Pages 116 to 120

BUILD YOUR OWN WHEELS

Part 1 - Yes, Even You Can Design and Construct A Great Pair of Wheels

This is part one of a three-article series about designing and building quality wheels. Author Eric Hjertberg, the well-known wheel builder and co-founder of Wheelsmith, begins by discussing component choices. This information will help when you buy machine-made and custom-built wheels or when you shop for the parts necessary to build wheels yourself. Succeeding articles will tell you how to lace the spokes into the hub and rim, then how to tension and true a wheel to perfection. –Editor

By Eric Hjertberg



Sooner or later, you're going to want a pair of new wheels. Maybe you'll yearn for something lighter and racier; maybe heavier and more durable. At the worst, you'll need them because your present pair didn't survive a crash or the pounding of a bad road. (We won't mention what happened when you tried to leap those railroad tracks in a single bound.)

The type of wheels you build or buy can increase your bike's performance or durability -- sometimes both. The weight of the individual components you select results in an overall wheel weight that has a direct bearing on your bike's riding characteristics. Judicious component choices will help you tailor the new wheels and the bike itself to your needs.

You can take the process to the limit with hand-built wheels. For a given weight of rim and spokes, they are usually more durable than factory- or machine-built wheels. That means you can enjoy the extra performance of lighter rims or fewer spokes without sacrificing strength.

Or, without increasing rim weight, you can increase durability. That may sound like having your cake and eating it, too. Not exactly. To get the better wheels you must pay for a skilled assembler's time, or you must acquire the skill to build them yourself.

As you'll see, wheel building is not as difficult as you might fear. Let's start by looking at the various component options and how to combine them to create wheels for specific purposes.

Rims

There is a confusingly large number of rims out there, but remember that the choice boils down to just three things: type of construction, width, and weight. Then remember two important rules:
1. Don't try to understand manufacturers' descriptions of their rims, because they're usually poorly translated by the importers and may not have come from engineers in the first place.
2. Don't trust listed rim weights. Either weigh them yourself or find somebody who has. Rim weight, because it is an easily obtainable number and it correlates quite well with important factors such as cross section and wall thickness, is still your most reliable and accessible indicator of rim strength.

Aluminum rims are the only type worth considering when performance is a concern. Steel rims should be reserved for juveniles, inner-city cycles, and third-world bikes. As opposed to steel, aluminum is light, can't rust, and offers vastly better braking in the wet. The world of aluminum rims can be divided in terms of the two tire types, tubular and clincher.

Tubular

Tubular (sew-up) tires are difficult to repair and must be glued to their rims. Compared to clinchers, they have little to offer those who ride for recreation, fitness, touring, or even most types of racing. Tubular rims are a different story, however. The lightest models can reduce the rotating weight of a pair of wheels by as much as half a pound compared to the lightest clincher rims. Rotating weight is very important because the greater it is, the greater the amount of energy required to change its speed. This is critical in criteriums or any other event where there are many accelerations and other adjustments to speed. A lighter wheel is simply more responsive. Unfortunately, it is also less durable.

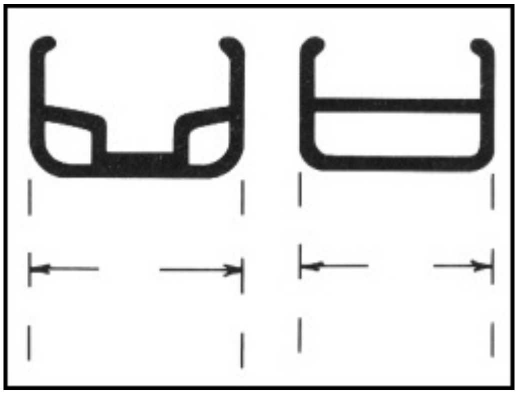
It is useful to sort tubular rims into three categories:
1. *Extra light*, 280-320 grams. For limited use such as time trials, solo competition, and riders less than 130 pounds.
2. *Lightweight*, 320-380 grams. For smooth roads, criteriums, and track racing.
3. *Team weight*, 380-460 grams. For general road racing and training.

Clincher

Among clincher rims the choir is vast and the terminology is confounding. Since there are few common standards for labeling, nearly anything goes. I divide them into these categories:
1. More than 600 grams and outside widths of at least 28 mm (see illustration). For larger tires and all-terrain bikes.
2. Weight of 500-600 grams and outside widths of 22 mm. For all-purpose touring and ATB racing. Tire size is 28 mm (1 1/8 inch) to 38 mm (1 1/2 inch).

3. Weight of 420-500 grams and outside widths of 20 mm. For tires between 19 mm (7/8 inch) and 28 mm (1 1/8 inch). This category is often called "one inch" and covers most racing and sport riding.

Rim width is usually measured from outside to outride.



Other Rim Factors

So-called "hardened" or "heat-treated" rims have gained considerable popularity in recent years. Almost without exception, these rims are gray because of surface anodization, not true heat treatment. This hard shell contributes only a little to the overall strength of the rim. Cynics will note that the reputation for durability gained by "hardened" tubular rims was due to the heavy weight (approximately 400 grams) of the pioneering models. Base your choice on reputation or color preference.

The next decision is between ferruled ("double-eyelet") and washer-reinforced rims. At one time virtually every tubular rim positioned the head of the spoke nipple against the inside wall. When a washer is put between the nipple head and the rim, this design works quite well. The 1970s saw the introduction of a new design with thimble-shaped ferrules that tied together the inner and outer rim walls as they spread the load under the nipple heads. Today there are fans of each design, although it's certainly easier to lace up a ferruled rim. You won't have a choice with V-section aerodynamic rims, which don't have space for ferrules and don't need them for strength, anyway.

Because of its deep, V-shaped cross section, an aero rim has more radial and torsional rigidity, but slightly less lateral rigidity, than a conventional rim. This means greater resistance to the perils of potholes. It's a benefit that may even outweigh an aero rim's real, but slight, aerodynamic advantage.

When you hear claims about exotic materials and treatments, remember that cross section and wall thickness are the major determinants of rim strength. Because the bicycle industry is so closely knit, we find most companies operating with similar technologies and similar materials. To a great extent a company's reputation is based on its recent success (or lack of it) in making the joint that's part of every rim. On a narrow rim, this seam is usually riveted and/or glued, whereas heavier rims are often welded. In our experience, every company occasionally produces uneven, undesirable seams. A good seam is tight and almost imperceptible when you run your finger across it. Once you've selected a rim model, carefully compare several pairs and choose the smoothest before making the purchase.

Spokes

Fortunately, there's more consensus on spoke design than on rims. The best advice I can give is to use the strongest spokes you can get. Spoke strength has a great bearing on a wheel's reliability. Professional wheel builders demand these brands over most others: DT, Wheelsmith, and Alpina.

Stainless steel is the best material for spokes. Although the extra-shiny finish of chrome-plated spokes keeps them close to the hearts of fair-weather riders, their vulnerability to corrosion makes them second best.

Plated brass nipples are almost universally favored because of their low-friction threads, which make truing easier. Aluminum nipples, which save approximately one ounce per wheel, should be used only on special-purpose wheels destined for light duty. The price for saving that precious weight may be paid later in truing difficulties.

Two gauges, or sizes, of spokes prevail. Remember that gauge numbers run opposite diameter size. That is, the lower the gauge, the thicker the spoke -- 14 gauge spokes are larger and stronger than 15 gauge. It may be less confusing to refer to the diameter measurement. Rather than 14 gauge, think 2.0 mm. Fifteen gauge is 1.8 mm.

Straight-gauge spokes have a constant diameter from threads to head. They account for more than 90 per cent of all spokes used. The major decision you must make is between 2.0- and 1.8-mm diameters, a weight difference of about 40 grams (1 1/2 oz.) per wheel. For most of us, that 40 grams is worth it in spoke strength. Leave 1.8-mm spokes to riders who weigh less than 130 pounds. But even they must be cautious using them in competition. A broken spoke can exact the same time penalty as a puncture, so more and more competitors are opting for 2.0-mm butted spokes.

Butting reduces a spoke's center section. For example, the diameter of the elbow and threaded end will be 2.0 mm while the center section is 1.5 or 1.8 mm. This provides 2.0- mm strength where breakage is most likely, while delivering overall weight closer to straight-gauge 1.8 mm. Despite this advantage, butted spokes don't enjoy great popularity. Extra cost has been the main reason; butted spokes can add $10 to the price of a wheel. Of course, that doesn't seem like much when a pair of rims can cost $60 or more.

Butted 1.8-mm spokes have traditionally been mated with extra-light rims. Today, because most racers are concerned with reducing wind resistance, 32- and even 28-spoke wheels are commonplace. This loss of spokes, combined with the trend toward 6-speed freewheels and the extra rear-wheel dish they require, puts a premium on the strength of the spokes that remain. That's a good argument for 1.8-mm straight-gauge or even 2.0-mm butted spokes.

Aero spokes, like aero rims, offer a small decrease in wind resistance that is mainly of value to competitive cyclists. There are two considerations (besides greater cost) when changing from round to aerodynamic spokes. First, in almost every case, the aero spoke must still fit through the hub flange, which means it cannot be very flat. Second, the less round the spoke, the more easily it twists during wheel construction. That's an aggravation. Most riders find their needs best filled by standard, round spokes.

**After you've decided on hubs, rims and pattern, your source for spokes should be able to determine the spoke length you require. If not, try to find Sutherland's* Handbook for Bicycle Mechanics.

Hubs

Small-flange hubs have supplanted large-flange during the last 10 years. There is nothing "wrong" with large-flange hubs. It's just that small-flange hubs do the job well enough, and the amount of extra strength afforded by large flanges isn't worth their extra weight. One conspicuous exception is track racing, where large-flange hubs are still practical and popular.

When choosing among small-flange hubs, weight is a relatively minor factor because most models are of similar size and their mass is concentrated close to the wheel's rotating center. Wind resistance is also a minor consideration. An aerodynamic shape is worth a lot more in looks than performance.

As a rule of thumb, choose hubs that cost the same or a little less than the pair of rims you've selected. It makes little sense to combine a $20 pair of hubs with $70 worth of rims. Cheap hubs may give good service, but only for a couple of years. On the other hand, a pair of quality hubs ($50 and up) will outlast several rims. Before buying, make sure replacement parts are available for conventional bearing hubs and that "sealed" units are easily serviceable.

If you're heavy and/or very strong and regularly have rear wheel problems, here's your opportunity to do something about it. Order your rear hub with a 126-mm (6-speed) axle and obtain some small axle spacers. Disassemble the rear hub (see "Master Mechanic" in *Bicycling,* April 1985) and decrease the spacing between the right-side bearing cone and locknut by 5 or 6 mm. Then add the same amount of spacing between the left-side cone and locknut. You'll only be able to use a standard-width 5-speed freewheel, but the dish will be substantially reduced, increasing the wheel's durability. Have your local shop spread your rear triangle to 126 mm, if necessary. If you have a 120-mm hub and you want to use it in a frame with 126- mm spacing, obtain the longer axle and spacers, then proceed as above.

Spoke Pattern

Spoking patterns shouldn't receive so much attention. The stiffness and longevity of a wheel is barely affected by a pattern as long as it is conventional. The accepted patterns are: 24 spoke, cross 2; 28 spoke, cross 2 or 3; 32 spoke, cross 3; 36 and 40 spoke, cross 3 or 4; and 48 spoke, cross 3, 4 or 5.

Radial (no cross) spoking looks great on front wheels and provides adequate performance, but many hub flanges can't stand the extra strain. Do not radially spoke a wheel that may see punishing service.

Touring Wheels

In the classic sense, touring includes all conceivable road and weather conditions, with or without extra baggage. Hubs need to be serviceable and have a strong rear axle. Some brands feature heat-treated axles, and these are worth the expense. Stick to low-flange hubs and 36 spokes. Why 36? Try buying a 40-spoke rim in a faraway place.

A touring rim must be able to accept wide-section tires, so choose from the second category of clincher rims above (22-mm outside width). To complement this durable menu, use 2.0-mm straight-gauge spokes with plated brass nipples in a 3-cross pattern.

Off Road

More and more paved-road touring is being done on all-terrain bikes even if they are a bit slower. As with all touring designs, ATB wheels must emphasize strength. I recommend a 3- or 4-cross pattern with 36 2.0-mm straight-gauge spokes. For true off-road hammering, rims with a 32-mm width are mandatory, but when your riding includes generous amounts of pavement the rim can be lighter, making a 22- or 28-turn width appropriate. I like the two-pair approach: One pair with 32-mm rims and full-size 2.125-inch tires, the second pair with lighter rims and narrow (down to 1.4 inch) street tires. Quick-release hubs can be used in the lighter pair. When you're set up like this, you can make the best use of your ATB.

Sport and Racing

Racing, sport riding, and fast touring can be done on narrow, 20-mm rims unless you weigh more than 200 lbs. For noncompetitive use, the tried-and-true formula is a 36-spoke, 3-cross pattern using 2.0-mm straight- gauge spokes. This robust setup makes perfect sense with a 20-mm rim, especially if you plan to commute, ride in foul weather, or do some touring.

Since fast recreational rides frequently include the speed and excitement of competition, we can take some design lessons from racers. For team use, 32-spoke wheels using a 3-cross pattern and 1.8-mm straight-gauge spokes are common. Unless you're in top- level competition, use high-pressure clinchers. Recent evidence confirms that their rolling resistance is about the same as tubulars'. At 440 to 470 grams the lightest clincher rims do weigh more, but it's a slight penalty considering that the tubular rims most teams use weigh a hefty 400 to 420 grams. On the other hand, the weight saved by using a tubular tire and a lightweight tubular rim can give you a substantial advantage if your weight or riding style doesn't endanger the wheels.

If you choose tubulars, the next important decision is between 28 and 32 spokes. In top-level racing, the vote runs about 80 percent in favor of 32 spokes. Twenty-eight spokes are most popular with light riders (130 pounds and less), time trialists, and triathletes. During the next few years the ratio will tip toward 28 spokes, perhaps to as much as 50 percent.

That doesn't mean you'll see a trend toward even fewer spokes, since 24-spoke wheels remain in the realm of the expert wheel builder and are appropriate only for special use. Still, you will even hear tales of 20- or 16-spoke wheels. Discs will get their share of publicity, too. But the cost of such exotic wheels comes in two forms: a very high purchase price and the possibility of rapid obsolescence; a much higher frequency of maintenance and risk of failure.

Tandems

With tandems, put the emphasis on brute strength. Use a solid rear axle, 700C or 27-inch rims, and 48 straight-gauge spokes per wheel. With all those spokes, rim brand becomes secondary, but use at least a 22-mm width to withstand the inevitable bashing a tandem's weight can inflict. It matters little whether the spoke pattern is 3-, 4- or 5-cross. A 5-cross wheel does have a unique look, though.

Get Ready to Build

In *Bicycling's* next issue I'll begin the instructions for wheel construction. You may be surprised at how some of the latest breakthroughs in wheel analysis and automation have affected and simplified the manual construction process.

If you want to participate, you'll need to acquire your wheel components in the coming month. You also must purchase or gain the use of a spoke wrench, truing stand, and dishing gauge. Minoura, Park, Tacx, Avocet, VAR, and Wheelsmith make consumer truing stands that cost $25 to $50. Dishing gauges for $10 to $30 are made by Wheelsmith, VAR, Park, and Minoura. At least one of these brands is probably available from your source for rims, spokes, and hubs.

BICYCLING - FEBRUARY 1986 - Pages 90 to 92, and 98

LACING AND TENSIONING SPOKES

Part 2 of the Wheel Building Series Reveals a Foolproof Construction Plan

By Eric Hjertberg

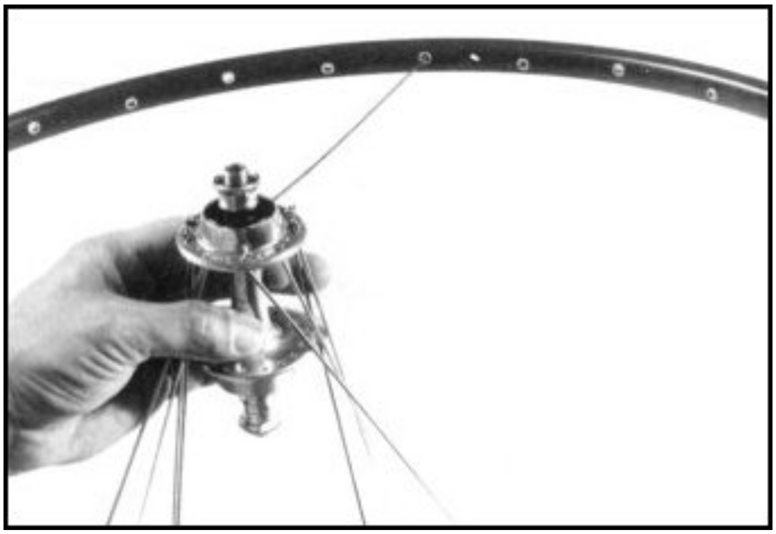
You are about to embark on one of the most satisfying yet simple tasks in the bicycle craft. Building a wheel is only a matter of lacing the spokes in a pattern that places each one correctly between hub and rim, then tensioning and truing them to achieve wheel strength and alignment. Truing will take some time to learn well, but lacing should be no problem for any first-time wheel builder who uses well-matched parts and the foolproof procedure I'll describe in this article.

Assuming you followed my advice in part one of this series (January 1986), you now have a desk top full of wheel components: a front and rear hub of decent quality, rims matched to the type of riding you're building the wheels for, and spokes of the correct length and gauge. Remember, assembly is greatly affected by the quality of the materials. Spokes that are not the same length, hubs that are twisted or eccentric, rims that are out of round or drilled erratically -- these things tremendously complicate the process. They can transform the straightforward task of wheel building into a first-class puzzle requiring years of experience to sort out. Avoid trouble by sticking to quality components.

Once you are experienced, you'll have no trouble building a wheel while watching TV or talking with friends. But for now it's best to minimize distractions. Select a location with a convenient counter top, a stool or bench that allows your knees to be at seat height, and plenty of light. Set out your components and verify that they are exactly what you need. Now gather your tools: a spoke wrench that exactly fits the nipples, a screwdriver, a truing stand, and a dishing tool. (The last 2 tools aren't mandatory -- you can make do by using a suspended or upended bicycle -- but you really should have them if you are serious about becoming a good wheel builder.) Light oil will come in handy during tensioning, and a smooth-jawed plier may be necessary to prevent an extra tight spoke from winding up.

The method that follows is only one of many successful and clever ways to assemble a wheel. It applies to "left-handed" rims (by far the most common type) and ensures that the finished wheel will be symmetrical. That is, each spoked hub flange will appear as a mirror image of its opposite. In the case of rear wheels, the "pulling" spokes will be oriented away from the derailleur when they're under tension, which minimizes damage if there should be contact during low-gear riding. In addition, the rim's valve hole will be located between parallel spokes for maximum accessibility. As a final touch, the logo on the hubs should be readable when you straddle the bike, and the rim labels should face to the right. Your first wheels deserve these features, which are minor but highly valued by experts.

For building ease, the spokes are divided into 4 equal groups. Two groups, radiating in opposite directions, are inserted into each hub flange. (At the rim, you'll notice that spokes are in parallel sets of 4, each set consisting of one spoke each from the 4 spoke groups.) Let's begin to insert and connect the first group. If you wish to coat the spoke threads with a substance that helps resist loosening by vibration -- linseed oil is the old favorite -- do it now.



For the common "left. handed" rim, the first spoke of the first group (the No. 1 spoke) is placed in the first spoke hole to the left of the valve hole.

Round One

Separate your spokes into 4 groups (9 spokes per group for the standard 36-spoke wheel). Have a seat. Hold the hub in front of you with the axle vertical. If it's the rear hub, the threaded side should be down. If it's the front hub, the logo on the center part of the hub should read from top to bottom.

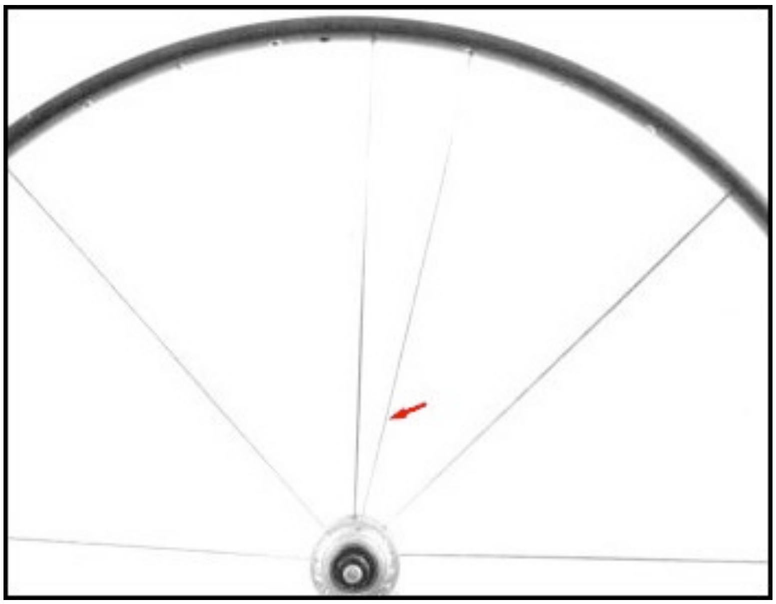
Drop 9 spokes into the top flange, putting one in every other hole. For rear hubs this will be the left flange, and it should receive the longer spokes if you are building with 2 lengths to help achieve dish.

Lay the rim on your thighs so it is horizontal. Position the valve hole opposite your stomach with the rim label upside down. Hold the hub in the center of the rim with the spokes hanging down. Select any spoke (which from now on will be referred to as the No.1 spoke) and put it through the first hole to the left of the valve hole. Attach its nipple a couple of turns.

Notice that the rim's spoke holes are slightly offset; as you are looking at the rim on your lap, one hole is a little above the imaginary center line, the next is a little below, and they alternate that way around the rim. The hole you have put the first spoke into should be offset toward the top of the rim. Top holes are intended for spokes from the top flange. If you find that the first hole to the left of the valve hole is offset toward the bottom and the first one to the right of the valve hole is toward the top, you've got a rare "right-handed" rim and must make an adjustment.*

Back to the hub, select the spoke immediately to the right of the No. 1 spoke. Leave 3 empty spoke holes to the right of the filled spoke hole in the rim (disregard the valve hole), then put the second spoke in the fourth hole. Again, this should be a hole that is slightly above the imaginary center line. Attach the nipple, then proceed to insert a spoke and its nipple into every fourth hole all the way around the rim.

** To lace a "right.banded" rim, simply insert the No. 1 spoke into the second hole to the left of the valve hole. The first spoke of the second group should be half a flange hole closer to the valve hole than the No. 1 spoke. It should attach through the hole between the valve hole and the No. 1 spoke. Then continue lacing as described.*



With the wheel flipped over, the first spoke of the second group is placed in the hub just to the right of the No. 1 spoke, which is in the bottom flange. The spoke is placed in the rim in the first spoke hole to the right of the No. 1 spoke.

Round Two

Flip the rim and hub so the unspoked flange is on top. This is the threaded side of a rear hub. Look carefully from directly above the top flange and notice that its holes do not line up with those of,the bottom flange: Prove it by dropping a spoke through a hole in the top flange -- it hits between two bottom-flange holes.

Now comes the only tricky part of lacing a wheel. You must determine which hub flange hole gets the first spoke of the second group (spoke No. 10 overall). It will be a hole above the hole used by the No. 1 spoke. Since there are 2 possibilities, drop a spoke through each hole so they rest against the bottom flange. Make sure they are vertical. One will be just to the left of the No. 1 spoke, the other just to the right. The correct spoke is the one to the right. Put this No. 10 spoke into the first rim hole to the right of the No. 1 spoke. Attach the nipple. Proceeding around the flange, skip one hub flange hole and drop in another spoke. Put it into the rim, 4 holes away from the spoke that is next to it. Proceed until all 9 spokes of the second group have been installed.

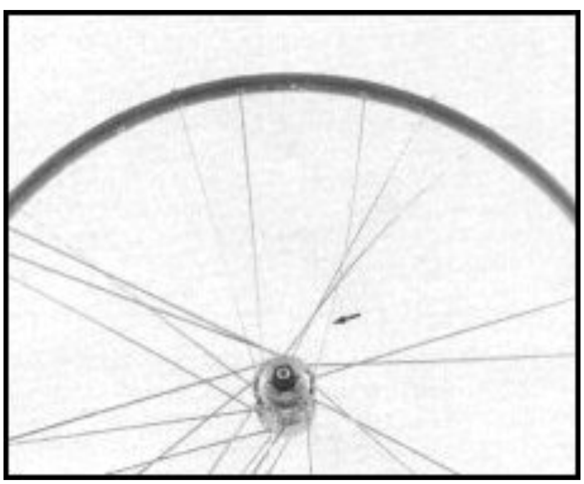
Round Three

This time, do not flip the rim. Group 3 spokes are dropped through the bottom (first) flange of the hub. Again, these will be the longer spokes if you are using 2 lengths to dish a rear wheel. Fill all the empty holes. Now hold the rim vertical so these spokes hang by their elbows. (Help them if they're tight.)

Lay the wheel on your lap with the group 3 spokes on top. Holding the rim still, twist the hub counterclockwise as far as you can. If done correctly, parallel spokes Nos. 1 and 10 will leave the rim pointing away from the valve hole, not across it.

Group 3 spokes travel to the rim in the opposite direction of the group 1 spokes sharing the upper flange. The first group 3 spoke that's installed is the one that establishes the crossing pattern. Cross 3 is the standard. This means each spoke passes over 2 spokes and then under a third before entering its rim hole. Four cross means over 3: and under 1; 2 cross is over 1 and under 1. Don't overlook the first spoke cross, which occurs right at the edge of the flange. The crossing pattern is something that must be decided when you buy spokes because it is part of determining correct spoke length.

To lace with the cross-3 pattern, select any group 3 spoke and direct it over 2 spokes and under 1. Do not cross any other spokes before putting it into the first available hole in the rim. Again, since you are working from the top flange, the correct hole will be a little above the imaginary center line. Loosely attach the nipple, then lace the next spoke. Don't worry if the spokes seem to be tight in the hub. It is a healthy sign. Tight-fitting spokes will receive plenty of support at their bend when they dig into the soft edge of the flange. That lessens the chance of them breaking.



Back on the original flange, a spoke from the third group crosses above *two spokes from the inside of the flange, then passes* under *the next inside spoke for a 3-cross pattern.*

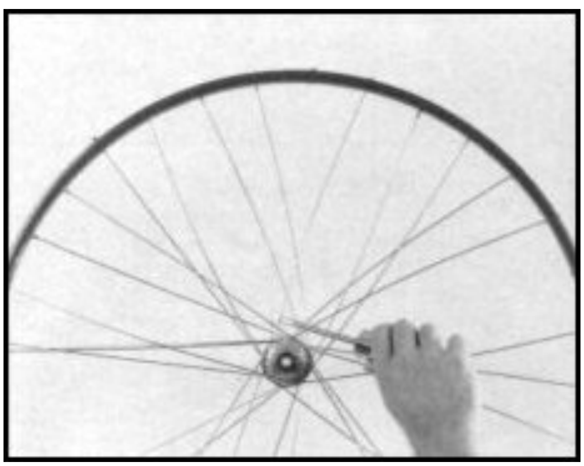
Round Four

Group 4 is a repeat of 3. Without flipping the wheel, drop the remaining spokes into the open holes in the bottom flange. Hold the wheel vertical so the loose spokes hang down, then lay the wheel over with the group 4 spokes on top. Lace each one into the rim and attach the nipple a couple of turns. If you've made an error during the lacing this will be a most confusing stage, because the group 4 spokes will seem either too short or too long to fit correctly. Sometimes it is easier to disassemble and start over than backtrack to find the mistake.

Tensioning

When all spokes are attached, sit back and admire your handiwork. You've just laced a wheel as well as any pro. Now mount it in a truing stand and put a drop of light lubricant between each nipple and the rim. (Avoid sulphur-bearing oils, because sulphur will degrade the brass from which most nipples are made.) Tighten every nipple with a screwdriver until only the last spoke thread is visible. If your spokes are a little short, it may be necessary to leave several threads showing at this stage -- make sure it's the same number for each spoke. For safety's sake, the nipples must be screwed on a minimum of 8 full turns when you've finished tensioning.

Now that each spoke is adjusted to the same length as its neighbors, it's time to bend the spokes near their elbow so they fully conform to their direction. Do it by inserting a stout screwdriver shaft between two spokes, just under one of the crosses. Once in this triangle, lever the screwdriver so the handle end rests against the outside spoke and the blade end presses against the inside spoke. A gentle push will bend them into conformity. Go around the wheel "setting in" pairs. This procedure stabilizes the wheel by doing immediately what normally occurs during miles of riding. The life of each spoke is enhanced because each elbow bends less after it conforms to its path. Otherwise, it constantly tries to recover its original shape during riding and fatigues more quickly.



Use a screwdriver to seat inside spokes and gently bend outside spokes to conform to the hub flange.

Next Month

Success in wheel building depends to a great extent on the initial lacing and length-evening steps just described. Perform them carefully and the wheel can seem to fall into place. That's important, because when you're done, every spoke will bear a tension approaching 300 lbs. Compressive force in the rim will be measured in *tons.* Your decorative wire sculptures will be capable of high speeds, sharp cornering, and rapid decelerations.

In the next installment you will discover a simplified method of truing. By approaching this potentially confounding process in a new and scientific way, you will be able to produce even stronger and more reliable wheels.

BICYCLING - MARCH 1986 - Pages111 to 115

TTRUING BY TENSION

Part 3 of the Wheel Building Series Makes the Hardest Part Easy

By Eric Hjertberg

Don't be fooled by perfect trueness, apprentice Wheel Wizards. That's how you want your wheels to turn out, of course, but it isn't the whole story. Not by a long shot. Uniformly tensioned spokes, which ensure that your wheels *stay* perfectly true, are even more important.

In the January issue we selected our wheel components. In February, we laced the spokes into the hub and rim. Now it's time to tighten those spokes in a way that produces a wheel that's not only round and straight (i.e., true), but strong and reliable. I promise that it won't take a trip to Oz to pull this one off.

Uniform spoke tension is a wheel's most important asset. Even the best rims and spokes can't make up for incorrect tension, and trueness without uniform tension is short-lived. Traditional building methods emphasize spoke corrections based upon visual straightness, with tension occupying a mysterious background role. At Wheelsmith, our long-standing interest in spoke tension has developed a building method that monitors and balances tension as it produces straightness.

It may sound like this must take a lot of extra time, but it doesn't. Rather than prolonging construction, my method creates wheels that are easier and quicker to finish, and they're more likely to stay true. They are also more resistant to spoke breakage because the load is shared more evenly among the spokes.

These are the 4 steps of what I call the tension method:

1. Start by creating "ground zero." This is a perfectly true, low-tension state that serves as a foundation for further tightening.
2. Add tension in small, equal "layers" (1/4 or 1/2 turn per nipple each time around the wheel).
3. Following each layer of tension increase, correct roundness and side-to-side errors with tension balancing and visual evaluation.
4. Avoid overstressing the finished wheel with any sort of physical force.

Ground Zero

Mount your loosely laced wheel in a truing stand. Starting from the valve hole (as you should for all appropriate procedures so you know when you've finished one complete trip around the rim), put a drop of light oil where each nipple comes through the rim. This helps nipples turn with uniform friction as spoke tension mounts.

Tighten the nipples until 2 threads on each spoke are visible. The spokes should still feel relaxed when you squeeze pairs together.

Next, tighten each nipple one more half-turn. If the spokes are still relaxed, do another round of half turns. After several half-turn advances, spokes will start to feel snug. Then stop tightening. In this lowest tension condition, truing is easier than at any other time.

Most good rims do not need adjustments at the joint (seam), but occasionally one will. If you merely see a gap at the joint, ignore it. As the forces generated by tightening spokes increase, the rim will probably be drawn together. If the seam is disjointed, try gently squeezing it in a smooth-jawed vise. By all means do not overcorrect -- a joint area that's narrower than the rim means interrupted, weak braking. If the rim is out of round in the joint area, it may be helpful to bend it gently over a 2-by-4, holding the rim on either side. Only experience can help you determine which joints to lever and how much force to use. If you are uncertain, continue truing and perhaps spoke tension will make the correction.

Before adding any more tension, the wheel must be as true as you want the finished wheel. This is the principle of ground zero. By providing a perfectly true base, the wheel will be ready for the tension to come. New, undamaged rims should allow spokes to be uniformly tight. Such equality is the basis of an excellent wheel. (And this is why used, bent rims make such poor candidates for rebuilding; in order to be in true at ground zero, spoke tension must be unequal.) Another factor in favor of the ground zero approach is that a wheel is much more easily manipulated at low spoke tension than high spoke tension.

Attack side-to-side play first. Imagine that the uppermost section of the rim is a helium-filled balloon restrained by guy wires (the spokes). Its position can be precisely adjusted by changing the lengths of the wires. If the rim is too far to the right, then slacken the spokes from the right and tighten those from the left. Work in 1/4 turns and try to make equal changes to right and left spokes. If you add and subtract the same number of tensioning turns, you will bring the wheel into side-to-side true without disturbing its up-and-down true (roundness).

Hold each spoke lightly so you can feel if it twists as you turn the nipple. If it does twist, turn the nipple slightly past the desired point and then back to it, so the spoke is no longer twisted. Always work on the largest error first. After each correction, spin the wheel to find which error is still largest. Sometimes you will return to the same error; other times your attention will be directed to another section.

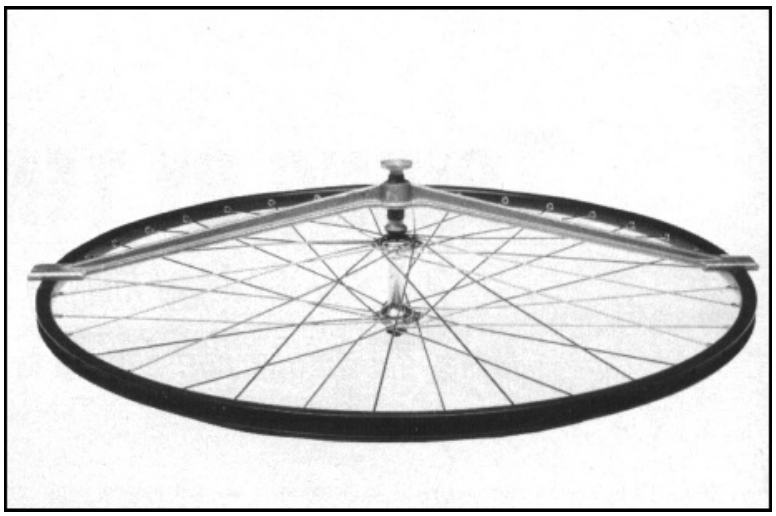
Continue making 1/4-turn corrections. Aim at the center of each error. If the wobble spans 4 spokes, the middle 2 are the ones to adjust. Eventually, the rim will spin straighter.

Once the side-to-side trueness is within 1/8 inch all the way around, try improving roundness. A section of rim can be moved down toward the hub or away from it by tightening or loosening the spokes that go to that section.

Spin the wheel slowly and watch for the largest high spot. Tighten the left and right spokes at the center of the high spot 1/2 turn each. If the high spot is long, go to the next two spokes in each direction and tighten them 1/4 turn. Spin the wheel and find the high spot again. (It might be in the same place.) Make another set of half-turn and/or 1/4-turn corrections, balancing right and left changes so as not to spoil side-to-side trueness. When you encounter a significant low spot, use the same technique but *loosen* the spokes. Never loosen to the point where they become slack.

If loose spokes do occur, check those from the same flange on either side of the slack pair. They may be so tight that the others don't have to be tensioned to keep the rim round. Remember, any given spot on the rim is affected by many spokes. Spokes that have too little or too much tension need to share their load with their neighbors.

Once roundness is within 1/16 inch or so, go back to trueness. After trueness is improved, switch back to roundness. Keep alternating to bring the wheel to the straightness you desire.



When both ends and the middle of the dishing gauge touch evenly on each side of the wheel, the rim is correctly centered.

Now check the wheel's dish. The rim must be centered between the hub axle locknuts. This means the rim will be centered between the hub flanges of a front wheel, but will be offset toward the freewheel-side flange of a rear wheel. You can check for proper dish by mounting the wheel in your bike. It should center in the frame and between the brake pads. But a much more precise way is to use a dishing gauge. Apply it to one side of the wheel so the adjustable center piece contacts the axle locknut and the arms rest on the rim. (See photo.) Then put the gauge on the opposite side of the wheel. If it fits the same way, the wheel is in perfect dish. If not, you must make a correction.

Draw the rim to the right or left by uniformly tightening *all* the spokes on the corresponding side. Most errors are best approached with 1/4 turns.

Rear wheels are a bit more complicated than fronts because the rim is offset or "dished" toward the freewheel side. As mentioned last issue, dishing can be accomplished by using shorter spokes on the freewheel side, or by using a uniform length but tightening those on the freewheel side several additional turns. Once the dishing gauge tells you the rim is centered between the axle locknuts, be careful -- further work on the spokes, if done equally to both sides, will put the wheel out of dish. The reason is that spokes from the freewheel-side flange approach the rim at a more vertical angle. Tightening (or loosening) them won't move the rim laterally as much as the same number of turns to the other side.

Most builders approach the situation by applying extra turns on the freewheel side during ground zero work. This overdishes the wheel so that during the next step, tension layering, equal turns around the wheel will bring it back into correct dish.

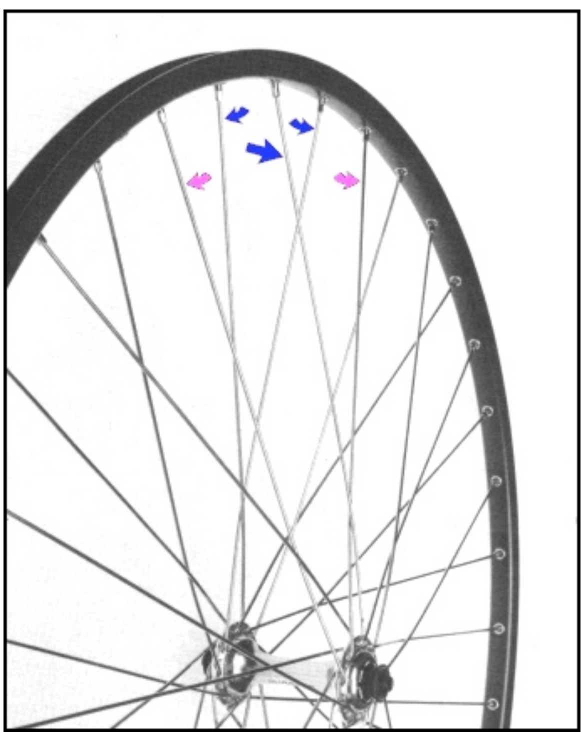
Once trueness, roundness and dishing are correct, you've accomplished ground zero and are 80 percent finished. Any extra time spent achieving this state, especially when you are learning, is well worth it.

Tension Layering

Now you must add tension to the wheel. Depending on your experience, the increase each time around may be as small as 1/2 turn per nipple or as much as 2 turns. In general, smaller increases are easier to monitor and more appropriate for lighter rims. Inspect for roundness; a lightweight rim's roundness is a good indicator of spoke tightness. When the rim is round, tension is more even and side-to-side adjustments are quicker and less likely to spoil roundness.

Keep adding tension and checking trueness, roundness, and dishing.

For rear wheels, add tension to only one side of the wheel at a time, trying to maintain a little overdish. This means more turns on the freewheel side than the left side. As tension builds, it becomes almost impossible to pull the rim to the right by increasing tension on the already tight, vertical freewheel-side spokes, but it's easy to pull the rim to the left. Finish tensioning, truing, and dishing mainly with left-side spokes.



An example of tension balancing: If this right-side spoke needs to pull the rim to the right, but it's already too tight and creating a "low" spot, loosen the spoke and its 2 neighbors from the left side (blue arrows) and tighten the 2 nearest spokes on the right side (red arrows).

Tension Balancing

Side-to-side corrections are more effective when they complement the tension level that already exists in the spokes in question. For example, suppose you observe a wobble in a 4-spoke region. Before making changes, pluck each of the 4 spokes to see which is tightest (highest note) and which is loosest (lowest note). Try to improve the trueness by loosening the tightest spoke(s) or tightening the loosest spoke(s). Observe rim wobble to find the spot for correction, but let tension (by plucking) help determine which spokes to adjust.

Try to visualize how adjustments for side-to-side trueness can affect roundness. Toward the end of the truing process, it's often possible to tighten or loosen a single spoke to move everything in the right direction.

What if you reach a contradictory situation? Suppose there's a spoke that needs to be tensioned for trueness but loosened for roundness. Unless the rim is defective, spoke tension in the immediate vicinity is unbalanced. Pluck at least 6 spokes to either side of the one in question. Mark those that are too tight or too loose. You'll probably see a pattern of imbalance that can be corrected without making the wheel go out of true.

Truing a wheel by tone is a strange idea to many builders, who depend primarily on visual cues and let tension distribution take its own course. Learning to balance tension is like opening a new set of eyes. Given practice, wheels become easier and faster to true.

After each straightening and balancing sequence, add more tension. Since you started from a solid ground zero, roundness should become increasingly stable as tension mounts. Continue adding small layers of tension and patient corrections until the wheel feels as tight as a known good wheel of similar design. If suddenly the wheel starts becoming less true or round, or it's difficult to tighten spokes without rounding off the corners of the nipples, stop! You're venturing beyond maximum desirable tension. Loosen each spoke a full turn or so before trying to finish the wheel. Also, keep an eye on the rim, not just spokes, to spot overtensioning. Some rims give distinct signs, such as puckering at the nipple, to indicate maximum tension.

Do not try to make too many corrections at full tension. (You shouldn't have to if you've done the job right.) A fully tightened wheel resists change, which is why it is so durable on the road.

Avoid Overstressing

A tension-balanced wheel is remarkably stable. It does not need the prestressing or overstressing often applied to lesser-built wheels. Stressing tries to prevent 2 types of problems. One is the stretching of parts during building and use, which changes the trueness of the wheel. The second is spoke windup created during tightening, which produces an artificially correct tension level. When wound-up spokes untwist and release their extra tension, they ping the first time the wheel is ridden. In effect, that's the sound of the wheel going out of true.

Windup can be minimized by lubricating the spoke threads and by compensating with the spoke wrench. (See above.) You can also mark one side of each spoke with a felt-tip pen to see when it turns. Some builders grip the spokes with smooth-jawed pliers.

If spokes are prevented from winding up, potentially dangerous methods of releasing stress are unnecessary. These include bouncing the wheel on the floor, or laying it on its side, grabbing the rim at 3 and 9 o'clock, and vigorously pushing down. This is a popular technique, but it's best reserved for straightening bent rims, not building new ones. Surviving a massive side load might be a sign of strength, but it might also weaken or ruin a wheel.

Final Check

Now that your wheel is straight, centered, fully tensioned and free of hidden stresses, you might be inclined to slap on tires and hit the road. *Stop!* Before putting your safety on the line, seek the advice of an experienced builder. This may be a local shop mechanic or a bike club member. If you have followed my procedures carefully, your wheels are probably as safe as those built by any professional. But your learning curve will be enhanced and your safety improved by double checking your work.

It probably took you between 2 and 3 hours to build each wheel. After gaining the experience of another 6 pairs for yourself and your friends, you should find that time cut in half. The professional develops speed from repetition and familiarity with his or her favorite components. On a good day the pro may take only 30 minutes to fashion an outstanding wheel, although 45 to 60 minutes is the norm.

So now you know -- wheel building is not a form of magic as some would have you believe. As usual in cycling, the real magic is in the riding itself, when your hand-built wheels help the miles roll by.

Next month I'll conclude this series with some tips and procedures for wheel maintenance and repair.

BICYCLING - APRIL 1986 - Pages 136 to 139

WHEEL CARE AND REPAIR

Part 4 - How to Help Your New Wheels Roll On and On

By Eric Hjertberg

This fourth and final part of the wheel-building series is your insurance. It will help you protect the time and money you've invested in creating a fine set of wheels (or just the money if you opted to buy instead of build). We'll see how to keep new wheels rolling smoothly, and how to fix some problems you might run into.

A well-maintained wheel saves money because it should last longer than one that's regularly allowed to deteriorate until it must be repaired. When a problem is caught and fixed early, the risk of permanent damage is lessened.

A wheel that's round and true rides smoothly and brakes safely. Dented or bent rims can cause brakes to grab, which impairs stopping efficiency and can cause skids that damage tires.

Finally, nobody likes to have a mechanical problem interrupt a ride. A wheel inspection takes little time, and minor repairs can be made within minutes right in the garage.

Routine Maintenance

Once a month, take the time to evaluate your wheels' condition. Remove them from the bike, then use a soft brush and soapy water to scrub the tires and rims. Rinse well and wipe dry with an old towel. Under a strong light, inspect the tread for pieces of glass, gravel, a thorn, etc., which could work through and cause a puncture. Then check the sidewalls for casing bruises or small cuts.

Wipe off the spokes and hub. Use solvent on the corner of a rag to loosen any foreign material. Some people choose kerosene, which leaves a very light residue, while others prefer a product that evaporates completely, such as the nonflammable paint preparation solvent available at automotive stores. Whatever your choice, do not allow the solvent (or the soapy water) to get into the hub bearings. And always keep solvent away from tires.

If any brake pad residue has built up on the rim, remove it with steel wool and wipe the surface clean.

After everything is clean and dry, inspect the following:

Hub - A loose or bent axle can make the rim seem out of true. Look directly into the end of the axle and rotate it from the other side (and then reverse sides). If it oscillates, it's bent and should be replaced. Turn the axle and wiggle it back and forth to check for excessive play or tightness; adjust the cones if necessary.* If the axle seems properly adjusted but feels rough when you turn it, open the hub for an inspection. There may be internal damage, or it might just need cleaning and lubrication.

Rim - Look carefully around the spoke holes for signs of cracks or bulging. If an area looks suspicious, tag the spoke(s) with a piece of tape for the next step. Watch for *dents,* which spread the rim's sidewalls and usually create a flat spot on its circumference, and *bends,* which make the rim out of true. Both conditions diminish riding comfort and stopping ability.

Spokes - Check for spokes that are broken or have vibrated loose by squeezing pairs together. Never leave a broken spoke free to snag something and cause more damage or an accident. If you can't replace it right away, unscrew it from the nipple and remove it from the wheel, or weave it securely through other spokes so the end is inside the wheel.

Check trueness by spinning the wheel in the frame or truing stand. This visual inspection will tell you a lot; so will spoke tension.

**Quick-release hubs should have some play in the axle bearings when the quick-release isn't tightened. How much? Experiment by placing a wheel in the frame and lightly tightening the quick-release. You should be able to feel some side-to-side play at the rim, but this should disappear when the quick-release is fully tightened. During wheel truing however, adjust out all play until you're done, then put it back in.*

Tension Detection

The March article discussed the importance of equalizing spoke tension during construction. This is crucial to the life of a wheel, and equal tension is just as important during wheel maintenance. As we say at Wheelsmith, don't just be a wheel truer, be a tension detective. If the wheel is trued without regard to maintaining equal spoke tension, there will be problems down the road.

Start at the valve hole and work around the wheel, squeezing pairs of spokes to check relative tightness. (See photo 1.) You can audibly confirm your findings by tapping each spoke lightly with a screwdriver shaft and listening for odd notes. Tag the spokes that feel different or ring noticeably higher or lower. I know a builder who keeps color-coded alligator clips for this purpose -- red for tight spokes, blue for loose ones.

This check of spoke tension should be performed twice a month, or about twice as often as your wheel cleaning and inspection.

Truing

If there is no wheel damage but the rim is wobbling, the repair is simple. Before you begin truing, put a small drop of penetrating oil into each nipple where the spoke enters (unless a thread preparation compound was used during wheel construction). Also put a drop where each nipple comes through the rim. This lubrication reduces friction that can bind nipples and produce false tension.

A wobble that develops in a new wheel is often caused by just one or 2 spokes that were wound up or not quite seated in the hub. Feel for spokes that are looser than their neighbors. The fewer spokes you involve in retruing, the faster and better your repair will be. Tag tight and loose spokes, and see if there's a way to true the wheel by equalizing their tension.

When a spoke is damaged or broken, the rim will be out of true at that spot. Unless the wheel is brand new, remove the tire so you can replace the nipple as well as the spoke. An old nipple may bind on new threads, making you think the spoke is tighter than it is. Remember to weave the spoke's final cross. If this bends the spoke a bit, straighten it before threading it into the nipple. Next, tighten the spoke until its tension equals those surrounding it (front wheel) or those going to the same hub flange (rear wheel). This should result in almost perfect trueness if the wheel was properly built.

Let's say, however, that the wheel remains out of true and/or round, or the wheel was almost true *before* you replaced the damaged spokes. This means the rim is bent. As mentioned in previous articles, a bent rim makes it difficult to achieve balanced spoke tension, which is the key to long-lasting trueness. If the wobble isn't too bad, try loosening all spokes 2 or 3 turns, 1/2 turn at a time, to return to a Ground Zero tension level.

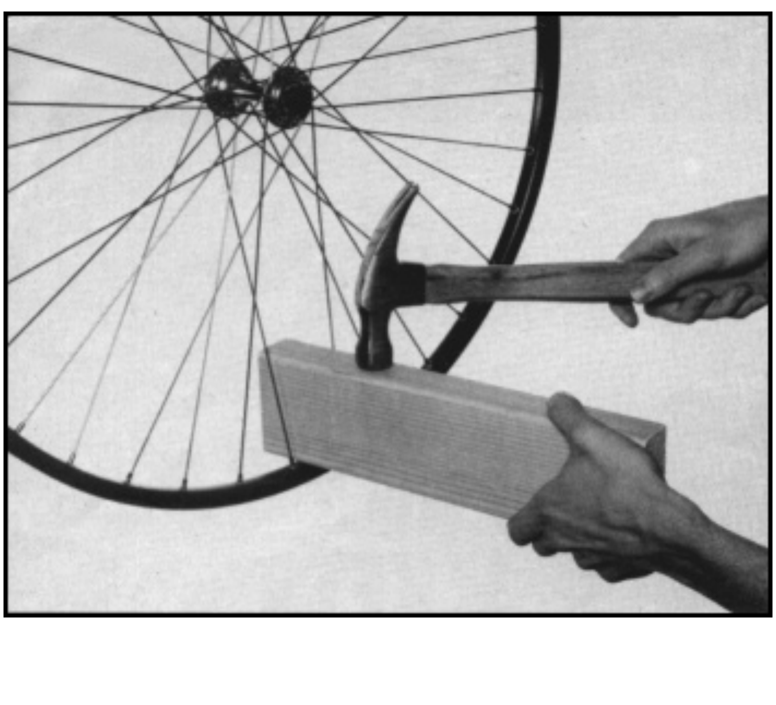
Then retighten to equalize spoke tension around the problem spoke(s). With experience you'll be able to tell whether the tension distribution is equal enough for the wheel to stay true. If it isn't, you have 2 choices: try to repair the rim, or replace it.

Dents

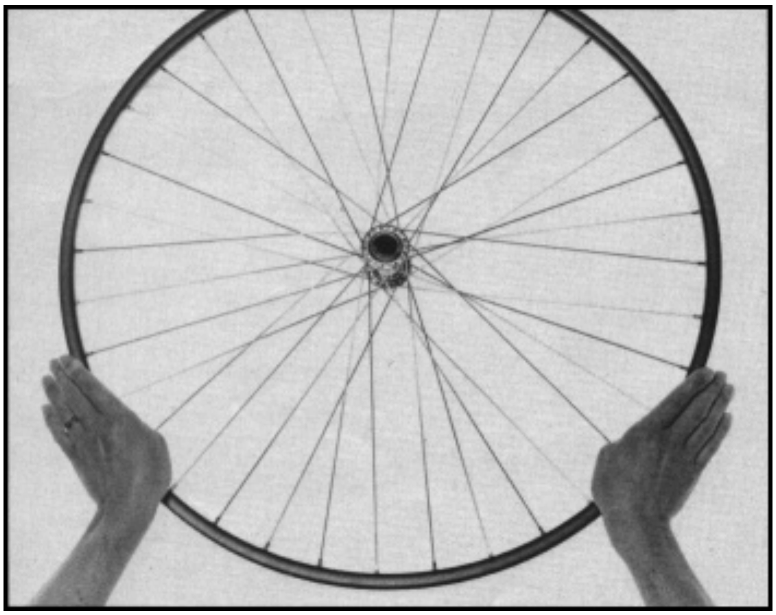
Dents occur when tires are underinflated and you hit railroad tracks, curbs, potholes, etc. This widens the rim and causes the pads to grab during braking. Press the dented section in with a smooth-jawed vise, proceeding very carefully. You can also use pliers if they're large enough to hold 2 pieces of flat metal against the sides of the rim to protect it. Don't press too far. Although a section of rim that's too narrow is better than one that's too wide, it's still not good. Smooth over any nicks or deep scratches with medium sandpaper (120-180 grit).

Flat Spots

If the flat spot that almost always accompanies a dent is apparent as you ride, you probably won't be able to remove it by adjusting spoke tension. You'll have to unbend the rim. Start by unscrewing nipples several turns in about an 8-spoke region of the flat spot, then fully loosen the 2 spokes at the center. Suspend the rim with the flat spot centered on a round, secure object such as the anvil of a vise, and pull down. (See photo 2.) If you need more room, unscrew and push aside the 2 center spokes. Slowly increase force until you feel the rim give, then retighten the spokes and true the flat section.



An alternative method requires a helper to hold the wheel (prepared the same way) with the flat section down. Place a piece of 2x4, preferably rounded to fit the rim, on top of the flat section. Strike the wood with a hammer, progressing from light strokes to heavier ones until the rim is once again curved. (See photo 3.) Inspect the metal for cracks or wrinkles; their presence means it's time for a new rim. Rebuild, tension, and true the wheel. If spoke tension in the repaired section is about equal to that of the rest of the wheel, you'll probably get a fair amount of additional service from the rim.



Bends

A bent rim looks like it's out of true, but truing it makes some spokes very tight, others very loose. Even if the rim becomes straight enough to ride, it won't stay that way very long.

To straighten a bend, reduce the spoke tension of however many *pairs* of spokes are necessary to span the bad area. Then place the wheel flat on a hard floor with the bent section closest to you and the bowed side down. (See photo 4.) With your hands about 10 inches to either side of the bend, press down on the rim until you feel it give. Check to make sure you haven't pushed in the lip of a clincher rim (you may be able to bend it back with pliers) and look for cracks or wrinkles. Then retension and true the wheel.

One bend can be remedied this way if it isn't too large. On the other hand, if a crash leaves a wheel with the contour of a potato chip, the rim must be replaced.

Remember, the goal in all these repairs is to recreate balanced spoke tension in the wheel, not just make it visually true again. That's the key to ensuring that well-built wheels will continue to provide safe and reliable performance.