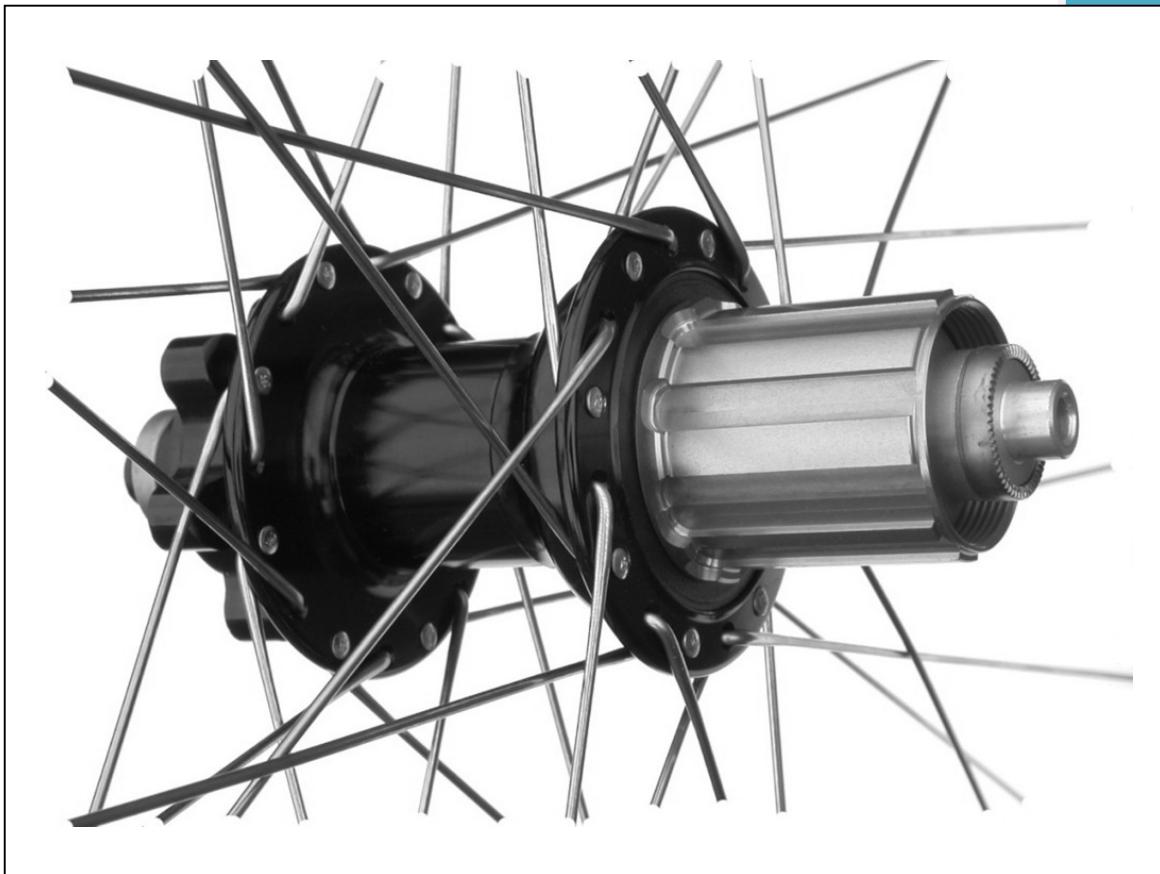


Professional Guide to Wheel Building



Roger Musson

5th
Edition

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Chapter 1

Introduction

For many people their cycle maintenance routines stop when it comes to tackling wheels. Retruing, replacing a spoke or building them is something for the experts to sort out. There is certainly a great deal of mystique surrounding the art of wheel building and this is reinforced by the reclusive life the wheel builders tend to inhabit. You rarely see these people at work, they rarely discuss their techniques in any detail, very little is written down and the cyclist can easily get the impression that wheelbuilding is a difficult skill to learn.

Building wheels is not difficult and there's certainly no artistic interpretation. Building wheels is a standard mechanical procedure of assembling and tightening spokes in the correct sequence and if you follow the procedure you'll get a perfect wheel. Building a wheel does though require patience and attention to detail if you want to build a pair of top quality wheels that will certainly be as good as and more likely better than anything you can purchase.

It's not expensive either. It's cheap to start and there are some great savings to be made once you start building a few wheels. It's very satisfying picking up a hub and rim from the closeout sale or choosing a hub from the lower end of the groupset hierarchy matched up with a similarly *ordinary* rim and knocking up some wheels that are terrific. And when your rims wear out it's a simple task of replacing the rim. But you are not doing this to save money, you are doing it because you want the best set of wheels possible all of the time and when it comes to wheels only one thing matters and that's how well they are built.

Once you have built your first wheel and are comfortable with the techniques involved you will become independent and never have to rely on the cycle shop or worry about finding a competent wheel builder. You will also have total control over the build quality and when the work is carried out and many people will become fascinated by this branch of cycle mechanics.

This book will show you how to build bicycle wheels using the methods that I use. It describes the tools and techniques and covers the design aspects that are relevant to cyclists and cycle mechanics. It is entirely suitable for people with no previous wheel building experience and for regular wheel builders who would like to see how someone else tackles the subject.

The information provided in this book is based on my wheelbuilding experiences over many years that started out building wheels for my own use, followed by owning a business that specialised in custom wheelbuilding. Part of the business activity was to sponsor several high profile professional race teams where I looked after all the wheel related issues from the initial build to ongoing servicing at race events, I also ran wheelbuilding courses and provided wheelbuilding demonstrations at numerous cycle shows. I've accumulated a lot of information and I'd like to share it with you.



Types of wheels covered

This book covers all types of wheels; road, mountain bike, BMX, etc. because all cycle wheels are built the same, once you've built one wheel you can tackle anything else.

Anyone who has knowledge of my wheelbuilding business will have noted that I concentrate on building mountain bike wheels and consequently many of the photographs in this book show mountain bike components. This is purely a commercial decision because the market for hand built road wheels is not as large as it used to be with many cyclists opting for ready built factory wheels from the likes of Mavic and many others. So I decided to stop building road wheels and gain efficiencies from reduced stock holding of road components.

I've built plenty of road wheels. My cycling background is road cycling, time trials and cyclo cross (I've raced in the [Three Peaks Cyclo Cross](#) event six times). I still build occasional road wheels for a few of the local guys but the main business focus is on mountain bike wheels since the vast majority of these are conventional standard spoked wheels which cannot be beaten, the same can be said for road wheels but the manufacturing companies are very persuasive in making you think otherwise.

The wheels covered in this book are what I call *conventional* wheels, those using standard hubs and rims with equally spaced holes and built using conventional spokes. However the principles can be applied to other types of wheels including the factory made wheelsets using obscure components.

The techniques I use

I've not been on any wheelbuilding courses, I've not been taught by anyone else. I'm an avid reader, listener, observer with a technical (and practical) engineering background. With the facilities at my disposal I can evaluate all aspects of the building process and find the techniques that I'm comfortable with from a practical and theoretical viewpoint, and also from a commercial point of view. I want to use tools and techniques that make my commercial wheelbuilding as efficient as possible whilst still making perfect wheels and I've used the same building technique over many years to build hundreds of wheels for paying customers – that's the ultimate test!

I'm not doing anything radically different to other wheelbuilders and there are plenty of very good wheelbuilders using similar techniques, your problem is finding the good builders which is why you've decided to build your own wheels.

Wherever possible the text in this book concentrates on the practical approach to building wheels and keeps away from any technical issues that would otherwise confuse a relatively straightforward process.

What I have done is show you everything I do regarding wheelbuilding and answered the questions I was asking when I started building wheels. I haven't kept back any secrets and you'll know as much as I do. If you think I haven't covered a particular aspect of building, whether in components or techniques, then it's because I do not use them. You can read many other articles on wheelbuilding and listen to many others discussing wheels but always question what you read and hear and form your own opinion and not take anything at face value.

Getting the best from this PDF

Don't be put off by the amount of information I've given you. Wheelbuilding is not difficult and I could have summarised and slimmed the book down considerably but I'm sure you wouldn't want that. You are getting the full and complete story with nothing left out.

The book is presented in a logical order and I strongly advise you read it from start to finish before homing in on the areas of particular interest. If you are new to wheel building then some sections may need reading a few times to gain a good understanding.

Reading on-screen

The diagrams in this book are drawn using CAD software and although easily readable on-screen at normal viewing resolution they can be zoomed in using your PDF reading software for greater clarity.

The colour photographs also appear clearer if viewed on-screen and can lose definition if printed black and white.

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I've not included an index because the search facility provided by your PDF reader is far superior.

Printing the book

I recommend you print the book so you have it to hand when building your wheels. It is designed to print on either US Letter or A4 paper sizes. It's not necessary to print the whole book, a suggestion would be to print the building section so you have a guide whilst building and use the PDF as an onscreen reference for the topics that may only need reading once or twice. Or print the whole lot!

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Updates

Make sure you are always using the current copy of the book. My techniques for building a wheel haven't changed for years but I sometimes make changes in the text to improve the clarity of understanding and introduce new topics to cover the latest trends in wheels and wheelbuilding.

If I make any additions to the book a free upgrade is available to all purchasers. Please see the book home page at:

www.wheelpro.co.uk/wheelbuilding/book.php

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Contact details

If you have any questions on any of the topics covered in this book please get in touch. Your questions and feedback are welcome and help improve the quality of the book in future updates.

The contact details can be found on the Wheelpro site at:

www.wheelpro.co.uk/wheelbuilding/contact.php

And finally

I hope that you are soon riding on a pair of your own hand built wheels and are not overwhelmed by the detail presented in this book. Very soon you will wonder what all the fuss was about as building wheels becomes second nature. Don't try and complicate things, keep it simple. Keep it as a hobby and don't take it any further.

Thanks for purchasing the book.

Roger Musson



Please note, this book is not free. If you are using a copy that you obtained without paying for please go to www.wheelpro.co.uk and make a purchase, it's not expensive and it will guarantee that you are using the most up to date version, plus you will be eligible for free upgrades, plus I get paid for my work!

Thanks, Roger.

Chapter 2

Components and Features

There are a number of features of the wheel and its components that are important in the wheel building process and these should be understood and identified before commencing. I'm not talking in detail about component selection, just a few wheelbuilding features that you need to be aware of.

Rim spoke hole offset

The spoke holes in the rim are usually offset alternate left and right and this is obvious on most rims. Others though will require a closer observation to reveal the offset and some rims will have no offset at all with the holes positioned centrally. It is important to identify the offset because it is significant in the lacing process since left orientated rim holes have their spokes connected to the left hub flange and vice-versa.

Look carefully on the inside of the rim at the holes either side of the valve hole (shown in black in Figure 1) and notice how there are two possibilities for a rim with offset holes. It doesn't matter which way up the rim is because the offset orientation will not change. I use the terminology *type 1* and *type 2* to describe the different hole orientations.

Rims these days are virtually all type 1's but check all the same. I have only ever seen a couple of type 2's and they were on some very old obscure rims.

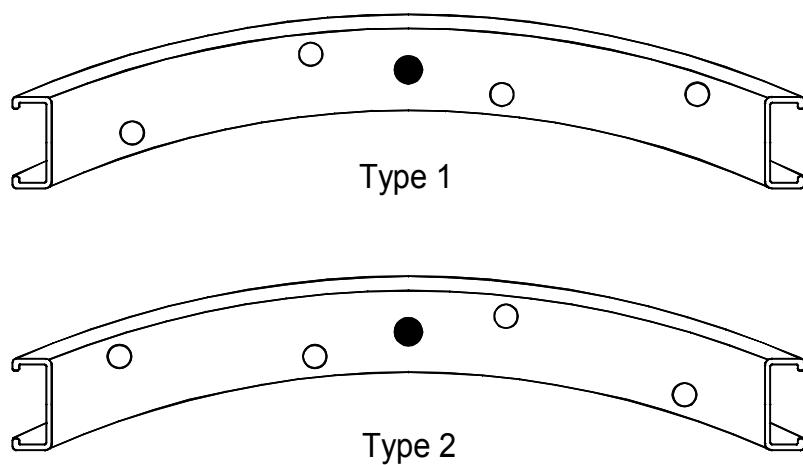
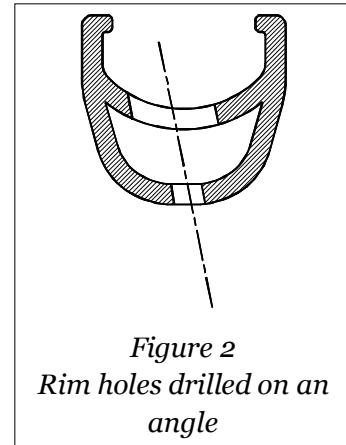


Figure 1 Rim types

The one that can catch you out is where the rim holes are drilled on an angle to allow a natural spoke line between rim and hub where the rims have the look of a type 2 but are in fact type 1. It is not advisable to look into the rim channel from the outside because the offset may appear on the opposite side to which it actually is, this is illustrated in see Figure 2.

For all rims, if you want to see the effect of the offset holes pass a spoke through the rim and attach a nipple and you will soon see the natural line as you pull on the spoke, i.e. it moves further in one direction than the other.

The rim spoke holes can be positioned asymmetrically, see the discussion on wheel dish on page 21.



Rim eyelet design

The three types of eyelets are shown in Figure 3. The rim with no eyelets has plain drilled holes through the rim, for example the Stans Notubes rims (www.notubes.com) do not use eyelets for weight saving reasons. The single eyelet design adds a simple steel collar around the spoke drilling to provide a more robust bearing surface for the spoke nipple.

The double eyelet design can be used on the deeper section rims that incorporate a box section design, the double eyelet includes a secondary collar forming a cup that completely encloses and seals the rim drilling. With the double eyelet it's a strength/durability issue because the spoke load is distributed across two faces of the rim but from your point of view it comes in handy when lacing the wheel because there is no chance of you dropping the nipple inside the rim section.

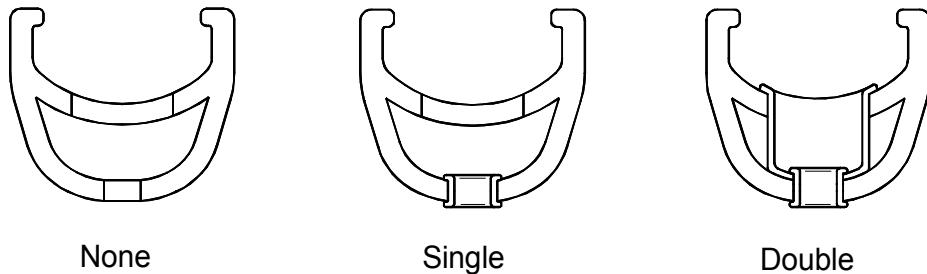


Figure 3 Rim eyelets

Choosing which eyelet design is not really a consideration for the builder, the rim manufacturer has made the choice for the particular rim and there is little difference when it comes to building either type. I've built many rims with no eyelets and they've been trouble free, both in building and in use. You can purchase washers to sit underneath the spoke nipple for use on non eyeleted rims but I've never used these. The only thing to remember is when using aluminium nipples on a non eyeleted rim is to make sure you get a good coating of oil on the nipple/rim interface to avoid any chance of friction. You oil *all* rims but make sure it's well oiled on non eyeleted rims.

Pinned rim joints

A rim starts life as a piece of aluminium extrusion which is formed into a circular shape and joined together using either a pinned or welded joint. The pinned joint rim has a couple of guide pins inserted into one end of the rim and the other end pushed flush against it. The example in Figure 4 is a Mavic pin jointed rim. I took a new rim and made two saw cuts as seen in Figure 5, held one end of the section in a vise and pulled it apart, it was a tight fit. The protruding pins in the photograph are 20mm long. The sleeve jointed rim works on a similar principle but instead of pins a small sleeve or plug is used. The pinned/sleeve joint is often regarded as a weak joint but the assumption is wrong because once built the rim is under a massive compressive force that holds the joint faces together ensuring it won't ever come apart.



Figure 4 Pin jointed rim



Figure 5

Out of curiosity I took the rim pieces and built a wheel. The rim section was initially held in place using tape to make lacing easier. I laced it up and with a small amount of tension I removed the tape. The joint faces of the cut sections were not perfectly aligned so I just pushed the section

assuming it would easily slide. It didn't, and I had to give it a hefty thump with a wooden block to align the edges. This illustrates the compressive force in the rim and even a small amount of tension puts a significant amount of compression in the rim so you'll realise that under full tension the forces are massive. As consequence the fully tensioned wheel was a solid structure and with the wheel flat on the ground I could stand with my full weight on the spokes. Did I put a tyre on and go for a downhill blast? Absolutely not! While I'm confident in its strength and certain it would be fine I stand by the warning I make in the building section on page 72. I eventually managed to separate the unpinned rim joints but it required lots of heavy stamping and strategically placed blocks of wood to give maximum leverage which is not something you would encounter when riding a bike.

You'll sometimes hear people recommend lacing a pin jointed rim so that spokes either side of the joint are pulling towards each other believing it will help pull the joint together. This makes no difference which means you lace pin jointed rims the same as any other rim.

Welded rim joints

The other type of joint is the welded joint. First a small sleeve is inserted to locate the two faces and the joint welded together. The rough weld is then cleaned up by machining and on rims destined to be used with rim brakes it's normal to machine the entire circumference of the brake surface. Sometimes the initial locating sleeve which remains in the rim comes loose and can be heard rattling around and it's nothing more than just an annoyance (looking through a spoke hole you may see the loose sleeve and place some adhesive on it to stop the rattle). Welding a rim increases the cost of the rim.

Which is best, pinned or welded? Just remember that rim manufacturers will not do anything that results in a weak rim meaning all methods of joining rims are reliable. A pinned/sleeve jointed rim will save you money.

All methods of joining result in a little extra material in the region of the joint and when a wheel is placed in the truing stand the joint will always rotate to the bottom. This out of balance is corrected when a tyre and tube are installed since the weight of the tyre valve is opposite the joint and balances everything up.

Rim compressive force

The above experiment on pin jointed rims illustrates the compressive force in the rim and like all structures there is a limit to how much force can be tolerated before something has to give. If you keep increasing the compressive force in the rim by tightening the spokes it will eventually start to buckle. Imagine the rim straightened out as a long slender strut with force applied to the ends, i.e. in compression. A larger cross section will be stronger and a shorter length will be stronger, so a 26" mountain bike rim will be stronger than a road rim. You won't be able to tighten the spokes in a mountain bike wheel sufficient to cause the rim to buckle under compression but it's certainly possible with a light road rim. I'll talk more on this in the building section. For further reading do an Internet search on *buckling of slender struts*. Here's a starter page :

www.mech.uwa.edu.au/DANotes/buckling/intro/intro.html

Hubs

Throughout this book I use the term *drive side* to describe the side of the rear hub that takes the sprockets, either cassette sprockets or threaded to take a freewheel. The *non drive side* is opposite the drive side. An alternative terminology is to use *left* and *right* where right is the drive side and comes in useful for describing front disc brake hubs where the rotor is on the left. When building a wheel be aware of the left-right orientation of the hub because with the lacing technique I describe I always start by placing spokes through the “right side” for both front and rear hubs.

Hub spoke holes

The spoke holes on opposing flanges are offset radially half a hole pitch relative to each other. Each hole on one side will have associated with it two holes on the opposite side, one to the left and one to the right. This can be seen by visually sighting across the hub and it is important when building a wheel that you can spot this, if you are still unsure then look at Figure 34 on page 44 in the wheel building section. You might find that some of the aftermarket hubs are not drilled accurately and the opposing holes are not exactly offset one half pitch and this will be noticeable when building, I'll talk more about this in the building section.

Holes on opposite flanges *can* be perfectly aligned and this is illustrated in the photograph in Figure 6 kindly supplied by reader John Shearron who obtained this hub but had trouble lacing it to a conventional rim. A spoke has been placed through the hub to show the perfect alignment. After investigation it was found that this hub is specific to a factory made wheelset using a paired spoke lacing pattern and consequently a non standard rim. This is not a hub that can be easily purchased so you are unlikely to see one unless you take one from a factory wheelset or purchase one from someone who has acquired some from a factory source. It is impossible to lace this hub to a conventional rim and I know this because I've tried. My example was a genuine manufacturing fault, a hub drilled the same as Figure 6 was given to a sponsored rider for me to build and since the wheel was intended for a next day event I had no option but to try and build it. And I really tried with all sorts of odd length spokes. Impossible. So if you encounter one of these don't even attempt to build it unless you have the rim it was designed to be used with.



Figure 6 Non offset hub holes

Hub countersunk holes

The spoke holes will usually be countersunk to accommodate the *elbow* of the spoke. Countersinking is not an important consideration on aluminium flanges since the spokes will bed themselves into the softer material regardless of any countersinking. In fact some hubs that have alternate holes countersunk would seem to prevent certain lacing patterns if you always tried to get the elbow on the countersunk side, so don't worry about it on aluminium flanges.

Hub flange thickness

The thickness of the hub flange should adequately support the spoke elbow. Very thin flanges can lead to increased spoke breakages and one solution to help prevent this is to use a small brass washer as packing between the head of the spoke and the hub flange (see Figure 7). This was common on old generation hubs often with thin steel flanges but all of today's aluminium hubs have adequate flange thickness that makes the use of washers unnecessary.

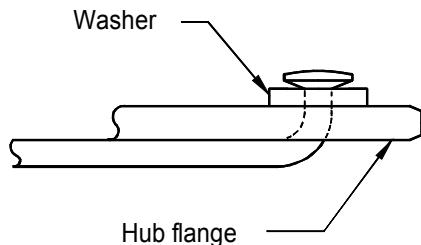


Figure 7 Using washers as packing

Downhill wheels

From this point forward I'll occasionally mention the term *downhill wheels*. If you are a road cyclist then this will need some explaining. Downhill racing is a very specialised form of off-road riding where you get taken to the top of a mountain or big hill and your descent is timed over a marked course. The courses are rough and rocky with plenty of jumps, the bikes are very sophisticated and the wheels need to be tough. I built the wheels for many downhill race teams and spent most weekends at a downhill event. Being involved with the teams gave me some unique feedback on how the wheels performed at the highest level of professional racing. I knew the bikes and wheels would be taking a beating though some very aggressive riding and after each race I would carefully examine each wheel to check the condition. They were perfect and it just confirmed my thoughts about wheelbuilding in general.



Figure 8
A downhill bike

So what's special about building a downhill wheel? Actually nothing at all, I build **all** wheels exactly the same way – whether they are for downhill racing or road time trialling. What I'm saying

is that you don't build wheels different for different applications, all that changes are the hubs and rims. Pictured in Figure 8 is Steve Jones from the Intense-Kawasaki team racing at a UK National event on a pair of my wheels.

I also go to many other cycling events to provide technical support (fixing wheels) for all the riders, so I've fixed plenty of broken and out of true wheels, I've scrutinised the building techniques (good and bad) of other wheelbuilders and I think I've seen most things that can happen to a wheel.

Spokes

Within reason, any hub and rim will do but spokes need to be the **best you can get** quality wise, so choose a recognised and trusted brand and not some manufacturer that no one has ever heard of and definitely not some unbranded spokes going cheap on the Internet. Use spokes made from stainless steel and don't be tempted by weight saving titanium spokes. Although I have no experience of using titanium spokes I understand this material is not good for spokes and compared to steel it is has lower strength, less stiffness, and more friction in the threads when tightening the nipples.

Don't assume that spokes from different manufacturers that use *stainless steel* are equal. This is not always the case because the quality and grade of the steel can be different, the manufacturing process can be different plus many other factors that can yield an apparently cheap stainless steel spoke that is half the price of another brand. It really does pay to get the best because they are easier to build with and you end up with a more reliable wheel. I'm not going into detail why cheap spokes make poor wheels – trust me on this.

Spokes are manufactured in metric units of measure for length and diameter, however you often see the diameters referred to using *standard wire gauge* terminology for example 14g (14swg). This is wrong and they should be saying 2mm. I'll let you do your own research and you'll see how the swg terminology is only an approximation of the true size.

There are dozens of different types of spoke to choose from so we'll discuss the options then narrow the field down to one or two. The common types of spokes are shown in Figure 9.

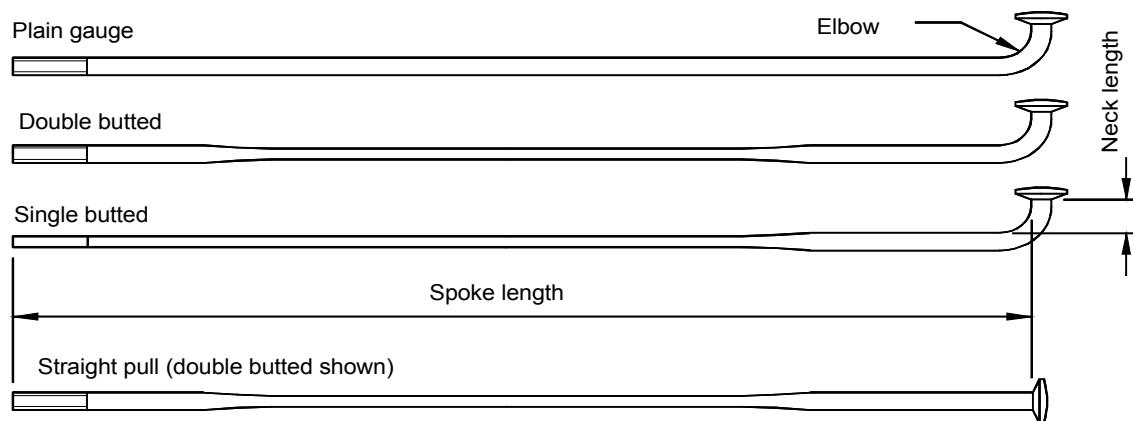


Figure 9 Spoke types (not to scale)

Plain gauge spokes have a constant diameter of along the length of the spoke, typically 2 or 1.8mm. Taking the more common 2mm plain gauge spoke, it is cheaper than a double butted spoke and is easier to build with since it is less prone to twisting during spoke tensioning. It may also look and feel stronger than a double butted spoke but if either are going to break then it will be at the spoke elbow or the spoke threads where both spokes are identical in diameter. I often hear people saying "*built with plain gauge spokes for strength*". They are not stronger and theoretically more prone to breaking at the elbow and causing stress related failures of the rims. By all means build with them but just remember that you aren't doing it for strength reasons. Modern spoke material will alleviate many of the problems associated with plain gauge spokes, but if you want the best in strength/durability then choose double butted spokes.

A double butted spoke has a central portion of a reduced diameter. The central portion is not cut or shaved but made by a forging process where the spoke goes through a pair of rollers that squeeze the metal (I believe DT use a different method of forging the central portion). The thinner central portion of the butted spoke will stretch slightly when building and the cyclic changes in tension on the spoke as you ride the bike will be absorbed within this region rather than generating high cyclic loads on the spoke elbow and threads which could result in fatigue issues – not just within the spoke but also on the hub and rim spoke interface. Fatigue is where cyclic concentrated loads cause the metal to slowly crack. The inbuilt *stretch* will also ensure the double butted spoke does not become totally unloaded as the rim deflects in use which can cause the nipple to unscrew and the spoke to loosen.

The standard double butted spoke is 2mm/1.8mm/2mm and the lightweight version is 2mm/1.5mm/2mm and a mid range version from DT is 1.8mm/1.6mm/1.8mm. The lighter versions build wheels that are just as strong as those built with standard double butted spokes and you aim to build the wheel with the same tension but you will find they twist more and are therefore more troublesome to build with especially in the longer road lengths. I wouldn't use 2/1.5/2 in road wheels because they twist too much and are difficult to tension and consequently many of the wheels you see built with these spokes are under tensioned. For a lightweight sports road wheels I've started using the DT Competition in 1.8/1.6/1.8 but if you can't obtain these it makes no difference if you use the more commonly available 2/1.8/2. Don't get taken in with weight saving because the effects are negligible (makes no difference) and other things can happen to lightweight spokes (see page 74).

Spokes *designed for heavy loads* (say the spoke manufacturers) are of the single butted type where the diameter is constant for the majority of its length at 2mm but with an increase in diameter to 2.3mm towards the spoke elbow (the DT Alpine is actually triple butted 2.3-1.8-2.0). If using these large diameter spokes make sure they pass through the spoke holes in the hub. Ideally the hub hole diameter should be a little larger than normal, for example if you look at the specifications for DT hubs designed for standard 2mm spokes they have a hole diameter of 2.5mm whereas those designed for 2.3mm spokes have a 2.8mm hole diameter. These larger spokes are **not** a cure for spoke breakages, good building technique solves spoke breakages. The standard double butted spoke is more than adequate and consequently I've never used these large single butted spokes.

The straight pull spoke is becoming popular on factory built wheels where claims for additional strength are often made. However all you will be hearing is *sales and marketing speak* because they offer no advantage over standard spokes. The straight pull design is not a cure for spoke breakages either since they are just as susceptible to fatigue failure as conventional spokes. Hubs must be specifically designed to take the straight pull spoke and since you cannot readily purchase these or the spokes there is no point in contemplating using them.

There is nothing special in the manufacturing process of straight pull spokes, in fact they are easier to make because they just take them off the spoke making machine one stage early before they receive the thump that bends over the elbow (making spokes is quite a brutal process with lots of thumping and banging).

Spokes come in cross sectional profiles other than round, typically the flat bladed spoke although it's debatable whether the aero effects make any real difference. A standard flat bladed spoke is typically 3mm wide and unlikely to pass through the holes in a normal hub so check before using them, hubs for these spokes are generally not available. The 3mm bladed spokes have now been largely superseded by the lightweight bladed spokes such as the CX-Ray from Sapim and the Aerospeed and Aerolight from DT where the cross section is 0.9mm x 2.3mm (1.2mm x 2.3mm Aerospeed) which pass through standard drilled hubs. They are *very* expensive and twist very easily when building (I have a tool to help with this, more later in the tool section). I would never put lightweight bladed spokes in mountain bike wheels because they will make zero difference in aero effect or wheel strength. Marketing claims (for example Sapim) refer to additional strength for the lightweight bladed spokes but they only endure more cycles on the fatigue testing machine which does not correspond to wheel strength and even the increased fatigue life has no bearing in the real world. On road race wheels the difference in aero performance is negligible but is noticed by some top road racers, but I cannot tell any difference.

Spokes last a long time and providing you take care of them when building and limit any damage to them when using the wheel the spokes can be re-used many times and will easily outlast many rims. And neither do you *retire* your spokes after they've done a certain mileage. As far as spokes go, if they are still in one piece then keep using them because they will be in perfect condition. There is a proviso here; I only reuse spokes if the original wheelbuild was my own (more about this on page 79)

So what do I use? You've probably guessed by now that it's the standard double butted spoke, certainly in my own personal wheels, team issue wheels and the vast majority of customer wheels. Some people ask for the lighter double butted spokes for lightweight mountain bike wheels and I build a few with CX-Ray spokes for the road racing guys. I try and stay with one manufacturer and use DT spokes. I couldn't use several manufacturers because I would be increasing my already large stock holding where my main spoke is the *DT Competition* in 1mm increments and the *DT Revolution* in 2mm increments both spokes in silver and black— imagine duplicating those sizes with say *Sapim Race* and *Sapim Laser* (other excellent spokes).

The main problem for the new wheel builder is getting the correct length spokes and this is discussed in more detail later in the book.



Figure 10
Sapim straight pull spokes

Spoke threads

Spoke threads are not cut, they are rolled where the thread is forged into the bare spoke. You can see this because the thread diameter is slightly greater than the spoke body diameter as the threads have bulged out slightly, for example on a 2mm diameter spoke the outside diameter of the thread measures 2.18mm (on the ones I measured). Forging the thread makes it stronger and less prone to fatigue failure. Some people like to obtain the appropriate spoke lengths by cutting their own thread into a trimmed down spoke. This is not good because you are using a metal removal cutting process and not a forging one resulting in fatigue issues with the spoke. Some very expensive tools are available for rolling the threads but either way it's difficult to do because stainless steel is a tough material. Cutting and threading is also a laborious job so take the easy route and buy your spokes at the correct length and in doing so get a better spoke.

If you are using spokes with a 1.8mm thread make sure you are supplied with 1.8mm threaded nipples. The 1.8mm spoke thread has the same pitch as the 2mm thread which means a 2mm nipple will screw onto a 1.8mm thread albeit with a loose fit and if you build with the wrong nipple the wheel will have poor reliability. Both nipples look identical but a 1.8mm nipple will not screw onto a 2mm spoke.

Inside and outside spokes

Inside spokes have their elbows on the inside of the hub flange and outside spokes on the outside shown in Figure 11. A feature of the outside spokes is the excessive bows these spokes take when connected between the hub and rim. This can be seen by taking a hub and passing a spoke through to the outside then pulling the threaded end gently inwards towards the hub centre line. These bows that appear to pull straight when the spoke is tensioned are detrimental to the spokes life and will be catered for at the building stage (aligning the spokes). Try the same with an inside spoke and notice how these can easily swing into the central position with little or no bowing.

Wherever possible you lace all the inside spokes first then lace the outside ones. This reduces the amount of spoke tangles when placing the spokes and will be better appreciated when you start lacing wheels.

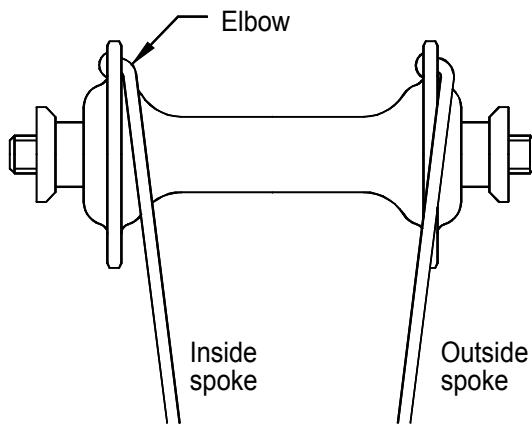


Figure 11 Inside and Outside spokes

Spoke orientation

You should be able to identify two distinct spoke orientations in a cross laced wheel, spokes that radiate backwards (pulling) and spokes that radiate forwards (pushing) as shown in Figure 12. The name given to these is unimportant and you will often hear other terms to describe them. Rather than worry about what they are called just make sure you can spot them.

It becomes more significant in the building process where you have the option of placing the pulling spokes on the outside of the hub flange or on the inside. It is also one of the observations you will make when examining other people's wheels (the other habit you are guaranteed to form is to give their spokes a gentle squeeze to see how tight they are).

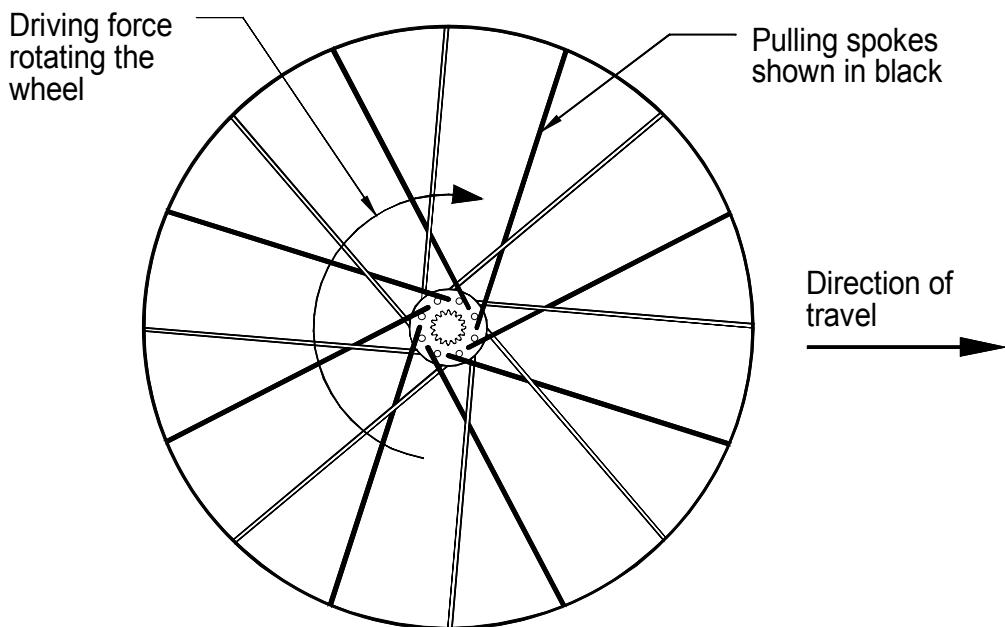


Figure 12 Pulling spokes

Nipples

Brass nipples will come as standard with the spokes and are the best choice for all wheels. They are made from brass and nickel plated to give the silver finish. For purely cosmetic purposes some manufacturers will produce a black finish brass nipple. Standard nipples have an overall length of 12mm but on thicker rims they may not protrude enough through the rim to get the wrench on and for this condition the longer 14mm and 16mm nipples exist, an example of using longer nipples is when building Mavic UST rims (page 68) where I use a 14mm nipple. Brass nipples are tough enough to be re used several times.

An alternative to brass are aluminium nipples and wrongly called *alloy* (brass is a better example of an alloy because brass is made from copper + zinc). When using aluminium nipples it is advisable to use a wrench that grips on four sides of the nipple to avoid rounding the corners of the

nipple and also prevent shearing it (snap by twisting). You should tighten the aluminium nipple to the same tension you would use for the brass nipple. Yes you will save a few grams in weight but you won't notice any difference when riding but they do allow you the option of different colours. If you purchase a box of 72 DT Competition spokes in black they are issued with silver aluminium nipples as standard but you are not obliged to use them and purchasing additional brass nipples is not an expensive option.

If you are not sure whether you have brass or aluminium then call in at your local postal office and borrow their scales. For 12mm nipples, 32 brass nipples weigh 30g and 32 aluminium nipples weigh 10g.

When doing race support and fixing other people's wheels I've seen aluminium nipples that have failed where the nipple heads have snapped off, or the nipple flats were completely destroyed due to someone's previous clumsy attempt at building or fixing the wheel making it impossible to locate the spoke wrench. People have often brought poorly built wheels to me for truing and the aluminium nipples were completely frozen to the spokes making any adjustment impossible. Poor building technique, in particular lack of oiling the spoke threads and rim-nipple interface cause the most problems with aluminium nipples.

Aluminium nipples are perfectly okay for road race and MTB cross country wheels and I've built hundreds of them with no reported problems but given a choice I always use brass nipples because I know they'll stay in good condition for many years and can be re-used when swapping out a damaged or worn out rim.

DT Swiss make a self locking nipple called the *Proloc* which has pre-applied adhesive on the nipple threads in order to prevent the nipple unscrewing. However if you build your wheels correctly then ordinary nipples will not unscrew and consequently I have never used Proloc nipples and will refuse to use them even if a customer requests them.

Wheel trueness

The three aspects of a true wheel are shown in Figure 13. The wheel shown is a perfect wheel with no errors. In reality this is very difficult, if not impossible to achieve and a certain amount of error is inevitable, this is discussed in more detail in wheel tolerances on page 62.

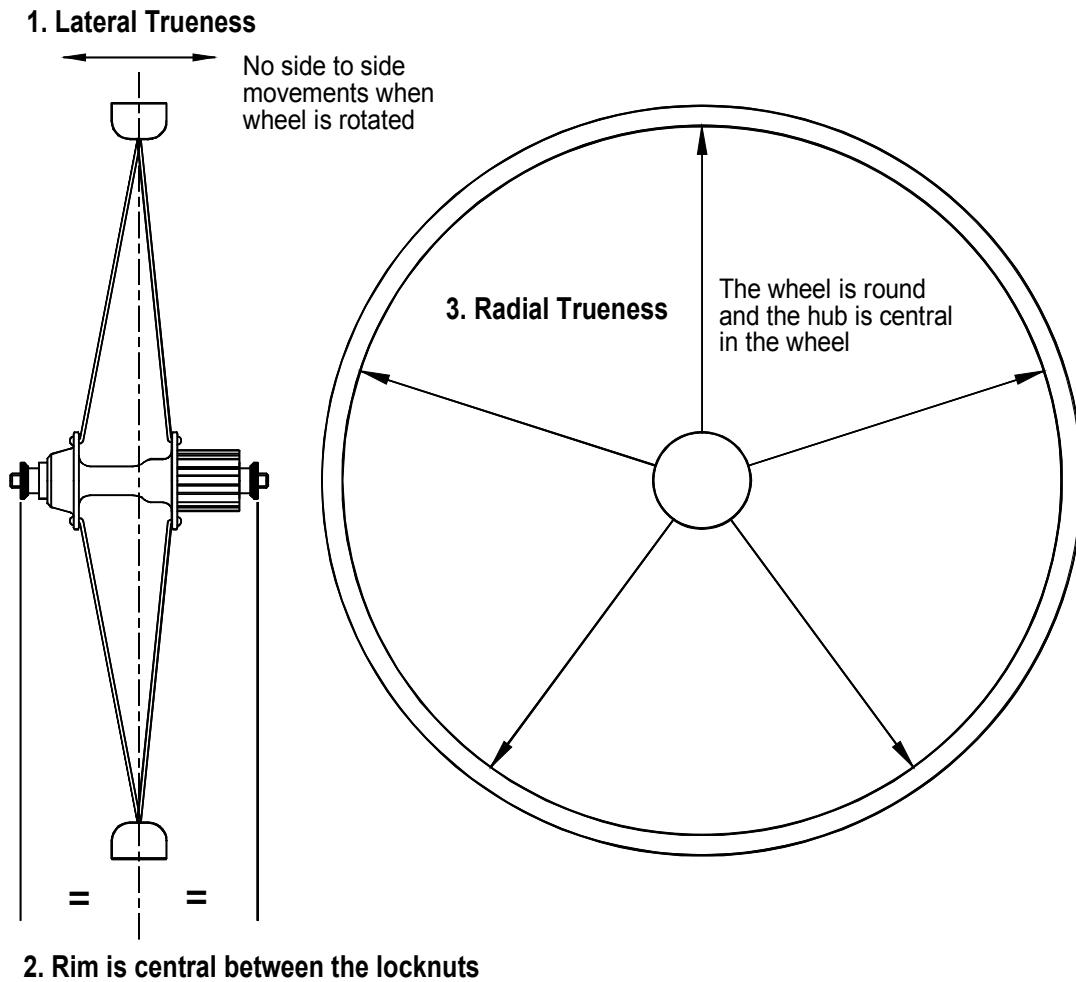


Figure 13 A true wheel

Wheel dish

Wheels are built central between the hub locknuts and **not** central between the hub flanges illustrated in Figure 13 which is a dished rear wheel. This ensures the rim aligns correctly with other components of the bike such as the frame and rim brakes. If the wheel is not built central it will be noticeable when swapping different wheels in the frame since you will be continually readjusting the position of the brakes, that is for bikes that use rim brakes since wheel dish does not affect the position of disc rotors. A wheel with a large amount of dish error could cause the tyre to foul the frame. If the wheel appears to be running too close to one side don't assume it's a dishing error, it could be the wheel is misaligned in the fork/frame dropout. Checking the dish is easy enough, see page 33 in the tools section.

Central between the *locknuts* is a term you'll often hear and is derived from hub designs using locknuts either side of the hub to position and secure the hub axle. Locknuts are still found on hubs from Shimano but many hubs particularly those with cartridge bearings and bolt through axles use designs without locknuts. So more correctly I should be saying central between the hub faces that locate on the fork and frame dropouts, however throughout this book I'll be using the term *locknut*.

Wheel dish is apparent on rear hubs that take a freewheel where the flange on the freewheel side is moved over towards the left to make room for the sprockets. Wheel dish describes this non symmetrical state and a feature associated with dish is the reduced spoke tension in the non drive (left side) spokes. The lower tensioned side will still be adequately tight enough to stop the nipples unscrewing and you will only encounter a problem if you modify a hub such that it builds with extreme dish. The front hub is symmetrical by design and so produces a dishless wheel. The exception being front hubs that take a disc brake where these wheels build with a little dish to accommodate the disc rotor and spokes on the opposite side to the disc rotor will have a slightly lower tension.

The hub design dictates the amount of dish and relative spoke tensions and you will find more dish on a 130mm road wheel than a 135mm mountain bike wheel. There's not a lot you can do about dish, your job is to build the rim central between the locknuts and accept the resulting dish. The hub manufacturer has designed the hub so that the dish will not effect on the performance of the wheel. Problems will occur if you modify a hub, for example fitting a wider 8/9/10 speed cassette body onto a hub that was originally designed for a narrower 7 speed one. This is often contemplated by people with old road bikes using narrower hubs and frames who want to upgrade their gears and still use the narrower hub and frame. Fitting a wider cassette body will also require changing the axle end spacers and in this example the resulting wheel will have extreme dish that will have a detrimental effect on the reliability of the wheel. I do not recommend modifying the hub and its axle spacing (and by association its geometry) in any way.

A technique to reduce dish is to use a rim that has asymmetrically drilled spoke holes where the holes are positioned more towards the non drive side (front non disc side). This effectively reduces the steepness of the angle the drive side spokes take from the hub to the rim. They are not common but do exist, however there is nothing wrong with normal rims and if there was a problem with them we'd all know about it by now.



Offset frames and dishless wheels

Offset frames are not common but do exist on a few downhill race bikes where the frame manufacturer has designed a non standard rear geometry that requires a dishless or semi dishless wheel. The resulting wheel has the rim centred more towards the left and more central between the hub flanges rather than central between the hub ends and helps make a stronger rear wheel. This only applies to rear wheels and the frame manufacturer will specify the amount of offset the frame has, for example the manual for the Specialized Demo 8 frame states:

Rear hub spacing: 135mm (6mm drive side offset)

Those who fail to read the manual and build a normal wheel often wonder why the rim is positioned wrong i.e. over towards the drive side, or don't realise it and ride around on a misaligned wheel and losing the benefit of a stronger wheel (had it been correctly built with reduced dish according to the specification).

This is how I would build one of these wheels, for example a frame with 6mm offset. On the drive side axle put a mark or identify a position 6mm inwards from the locknut face, then make a 6mm thick spacer and when you come to check the dish place it on the end of the **non** drive side locknut.

For correct dish the dishing tool should touch the end of the spacer and when the tool is transferred to the other side it should reach the 6mm mark. Your final check is when you place the wheel in the frame and the wheel ends up in the right place i.e. sitting plumb in the centre of the bike.

For calculating spoke lengths for offset frames use the online calculator at

www.wheelpro.co.uk/spokecalc

Put the value of the frame offset in the entry “Rim offset”. When you calculate a spoke table see how the hub flange offsets are modified with left and right distances being very similar (when using 6mm).

150mm rear hubs

Modern downhill bikes now use 150mm rear hubs in conjunction with a standard frame geometry and if the hub design has correctly spaced flanges it naturally builds an almost dishless wheel by default when building it central between the hub ends. Some hub manufacturers don't take advantage of the wider hub and move the left flange out resulting in a normal dished wheel. When looking at rear 150mm hub specifications see how some manufacturers have the centre to left and right flange dimensions almost the same, i.e. dishless.

Chapter 3

Tools

Specialised tools and truing stands are by no means compulsory but will certainly make things easier. Fortunately they are few in number so it is worthwhile obtaining them particularly if you are building complete wheels.

Professional wheel builders are **not** equipped with obscure or exotic tools that make wheel building a simple task and many that I know (myself included) are equipped with an extremely basic no frills toolset comprising those listed below. The tools are not complicated and descriptions are given for making most of them yourself. As you will see, I made quite a few of my own, not as a cost cutting exercise but because it was just a natural thing for me to do and I'm sure you have often said yourself "*well, I could make one of them*". Another benefit of making your own tools is that you can make them to your exact requirements and as a result I consider the tools I made myself to be better than the purchased variety.

Spoke wrench

Spoke wrenches come in various sizes so make sure yours is correct for the nipples you are using. The *across the flats* dimension of the nipple is the critical dimension and the wrench must be a good fit to avoid rounding the corners of the nipple as it tightens. There are essentially two standard sizes, those for European/USA nipples (Sapim, DT, ACI etc) and those for the slightly larger nipples found on Far Eastern wheels.

Many designs for the spoke wrench exist and it comes down to personal preference. Since they are relatively cheap it is advisable to have at least two wrenches because, being small, they are often misplaced at the most inconvenient time.

I always use the standard Spokey wrench, the red one for Euro/US sized nipples and occasionally the yellow one with slightly larger jaws for when someone brings me a wheel to fix that uses the Far Eastern variety of nipples. Spokey also make a *Pro* version but I've never tried one so I guess that makes me an amateur! I even have a red Spokey on my key ring.

For new builders the biggest mistake is turning the wrench the wrong way. One trick I do with my wheelbuilding students is to use a marker pen and place a black mark on one of the wings of the Spokey (see the photograph) such that pressing the mark is the direction for tightening the nipple.



Figure 14 The Spokey

Wheel truing stand

The purpose of the truing stand is to support the wheel and allow it to rotate relative to two fixed reference points, one to check for lateral trueness, and one for radial trueness. A truing stand will become a necessity if you do a lot of work with wheels. Truing stands can be purchased, some are very expensive but that doesn't guarantee they are good and the lower cost ones tend to flex and are unstable. I am a professional wheelbuilder, I can buy *any* truing stand I want regardless of price, if there was something that would make my life easier and make building wheels easier I would have bought it, however there's nothing out there that I find suitable.

If you do decide to purchase a truing stand then it's fine by me because I'd say in the professional world the vast majority of mechanics will be using the high-end stands from the likes of Park Tools. One thing's for sure, a good wheelbuilder will be able to build a wheel using whatever truing stand is available to them, from the very basic to the very complex.

In my amateur days the sole purpose of wheelbuilding was to make the occasional reliable wheel for myself. The first wheels were built using the bike as the truing stand and I could put up with the inconvenience because you only build a wheel every now and again since good wheels last a long time. Once I started building wheels more regularly (I had more bikes and built a few wheels for friends) a better stand was required.

Back then I worked in mechanical engineering and being a very practical design orientated person with access to plenty of metal and tooling it never crossed my mind to buy a wheel truing stand and having studied the available truing stands I designed my own that bore little resemblance to anything in the shops. Rather than use the obvious metal as the material I decided to use wood because it could be fashioned into a very elegant design and would make a very solid, rigid stand. For you, a benefit of wood is that it's easy to get hold of and easy to work with. The same design with a few modifications is what I currently use for all my professional building because I can't find anything better.

I see other stands out there full of knobs, dials and levers and I've even tried them but my wooden stand is the one for me. When I attend cycle shows – usually with a component manufacturer I am obliged to use their stand. On one occasion I went to a race and hitched a ride in the Hope Technology support truck and somehow I forgot to load my truing stand, at the race weekend I borrowed a high-end stand from another mechanic and built and fixed wheels for two days with it and I hated it! So I've had many days away from my personal stand and on each occasion couldn't wait to get back to using my own.

Making your own truing stand

I take your point that it does seem quite awkward that you need to build a truing stand in order to build a wheel. Investing a little time making the one shown here will ensure you have the best stand available and it will cost less than anything you can purchase. The plans are shown in Figure 15. Everything is made from 20mm thick wood, I use MDF which is a good choice although other types of wood will be suitable. Make two of each piece except where shown. The 3mm black plastic can be obtained from a sign maker (check out their scrap bin). If you have no woodworking tools then I'm sure you can find some local hobbyist who will make it for you and a small engineering workshop will soon make the steel jaws and it will still be cheaper than a store-bought stand.

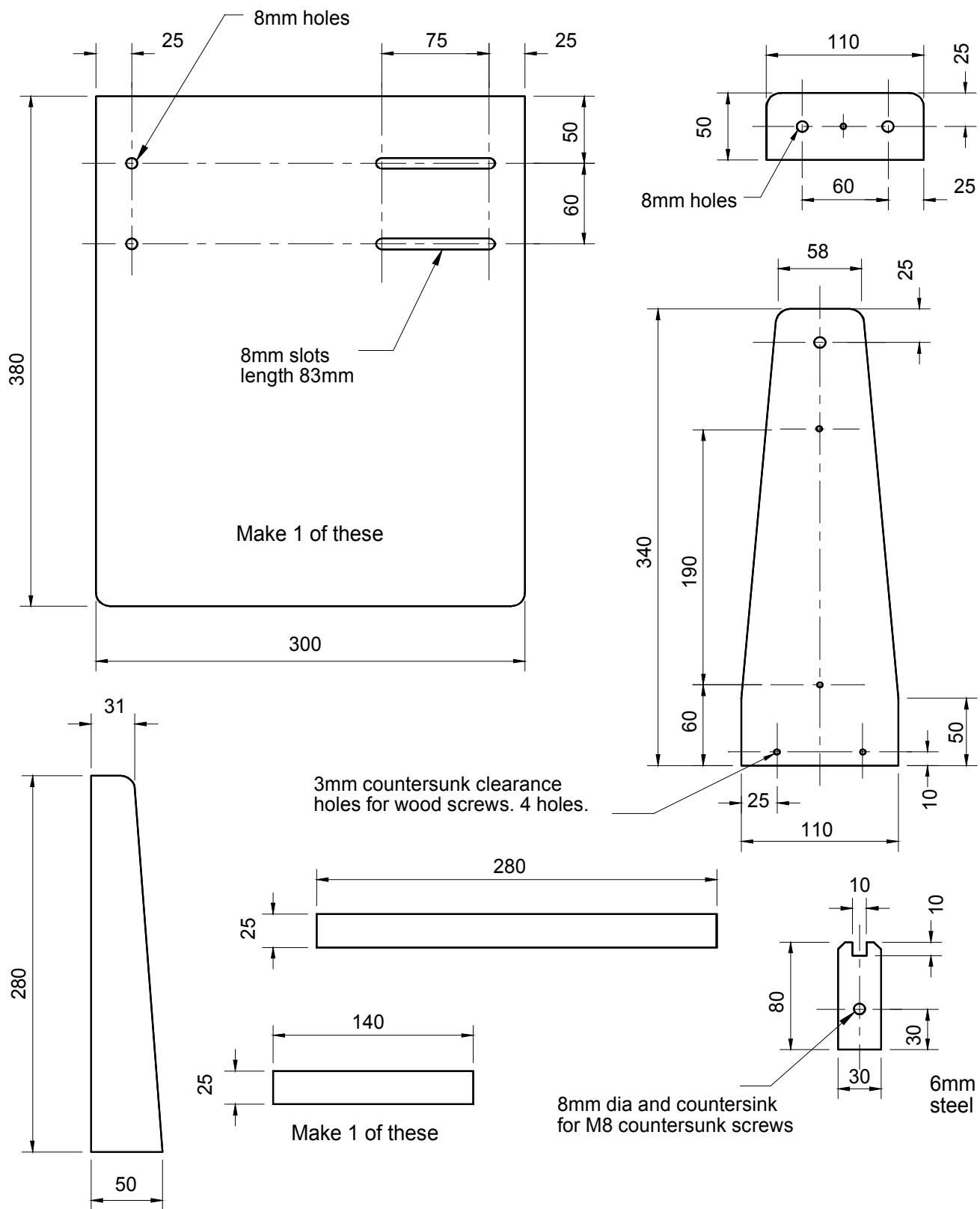


Figure 15 Truing stand plans

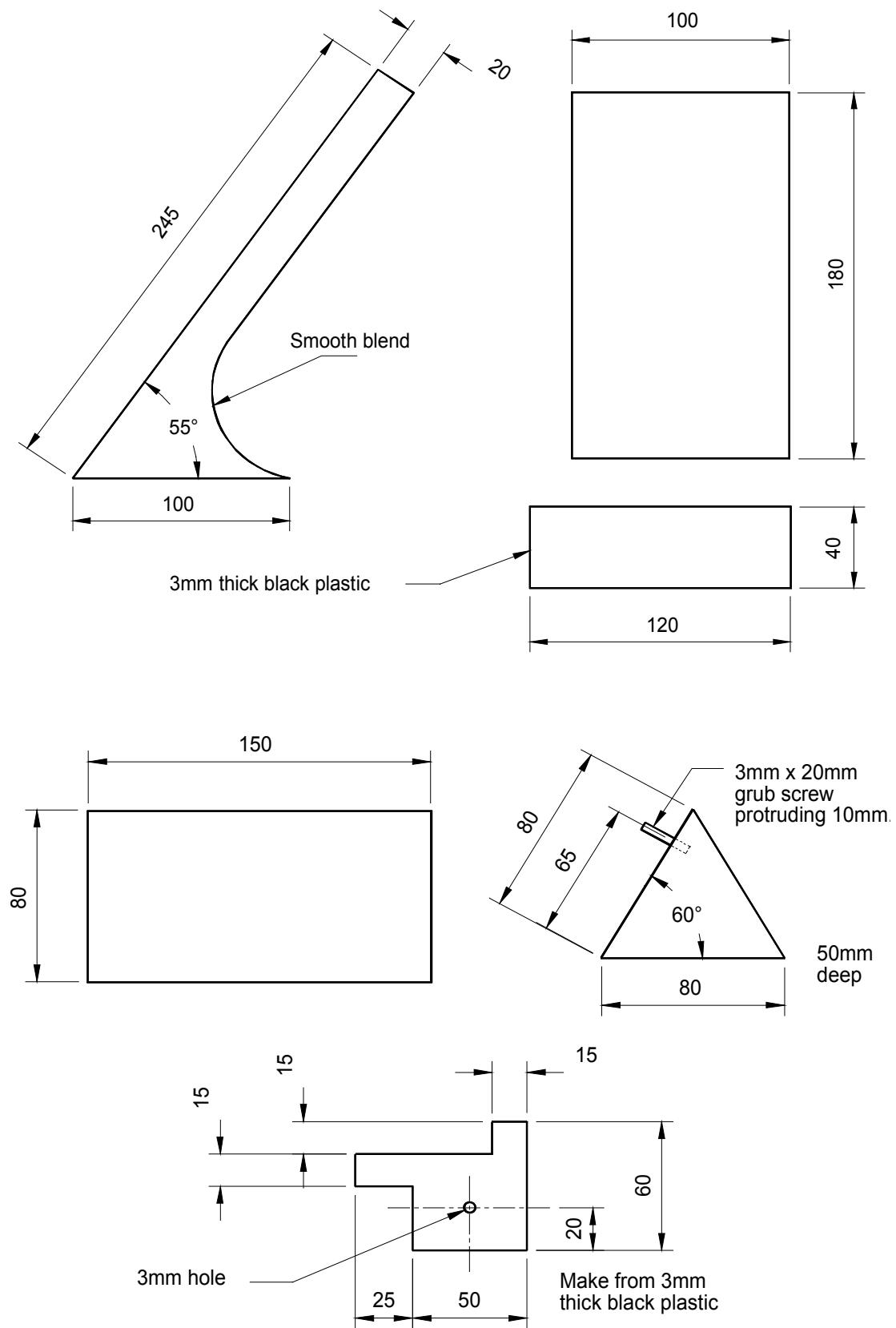


Figure 16 Radial and lateral gauges



Figure 17 My truing stand



Figure 18 Hub width adjustment

Here you can see the adjustable side of the stand and how it accommodates different hub widths. The support slides against a guide block (the 140 x 25 piece in Figure 15) onto which I place marks for the different hub widths.

It is shown in the 100mm position for a front hub. The settings relate to the hub width across the locknuts where the common settings are:

100 – Front hubs

110 – 20mm through axle front hubs

127 – Old style road hubs rear (7 speed)

130 – Road hubs rear (8,9,10 speed)

135 – Mountain bike hubs rear

150 – Downhill rear hubs

Painting the truing stand white or using white laminated MDF makes for a clear bright working zone and gives excellent contrast when used in conjunction with the black reference plates on the lateral and radial gauges.

Your stand doesn't need to be as fancy as this, the upright legs do not need to be tapered, that's just cosmetic and parallel sides are fine. I'm sure some rough sawn lumber nailed together will work just as well. I just want to inspire you to make your own stand because the ones you can purchase are nothing special.

To assemble the truing stand you will need the following hardware:

Item	Quantity
M8 Hexagon head screw x 50mm long	4
M8 Countersunk head screw x 35mm long	2
M8 Flat washers	10
M8 Nuts	2
M8 Wingnuts	4
3mm Countersunk head wood screws	16

The wingnuts make it easier to adjust the width of the stand and also make it easier to disassemble it for flat-pack storage. They can be substituted for M8 nuts if you want.

Two separate gauges are placed on the base and positioned against the wheel rim to check lateral and radial trueness. The weight of the gauges is sufficient to keep them in place and this is helped by using a non-slip material or in my example small rubber buttons on the underside. I always use separate gauges for checking lateral and radial trueness, i.e. check and adjust in one direction, then swap over gauges and check the other direction. This method is fast to use especially when compared to the cumbersome task of using the screws and levers found on shop-bought stands.

Another benefit of the wooden stand is that part of the wheelbuilding procedure requires balancing the spoke tensions by plucking the spokes and the wooden stand gives a more precise sound due to the better resonance of the wooden frame whereas metal stands produce a heavily damped dull sound.

The wheels this stand can build

The stand is suitable for all wheel diameters from BMX to road wheels and all hub widths from 100mm to 150mm. Hub axles can be solid, quick release, and mountain bike front 15 and 20mm through-axle hubs, and 12 and 15mm bolt through rear mountain bike hubs.

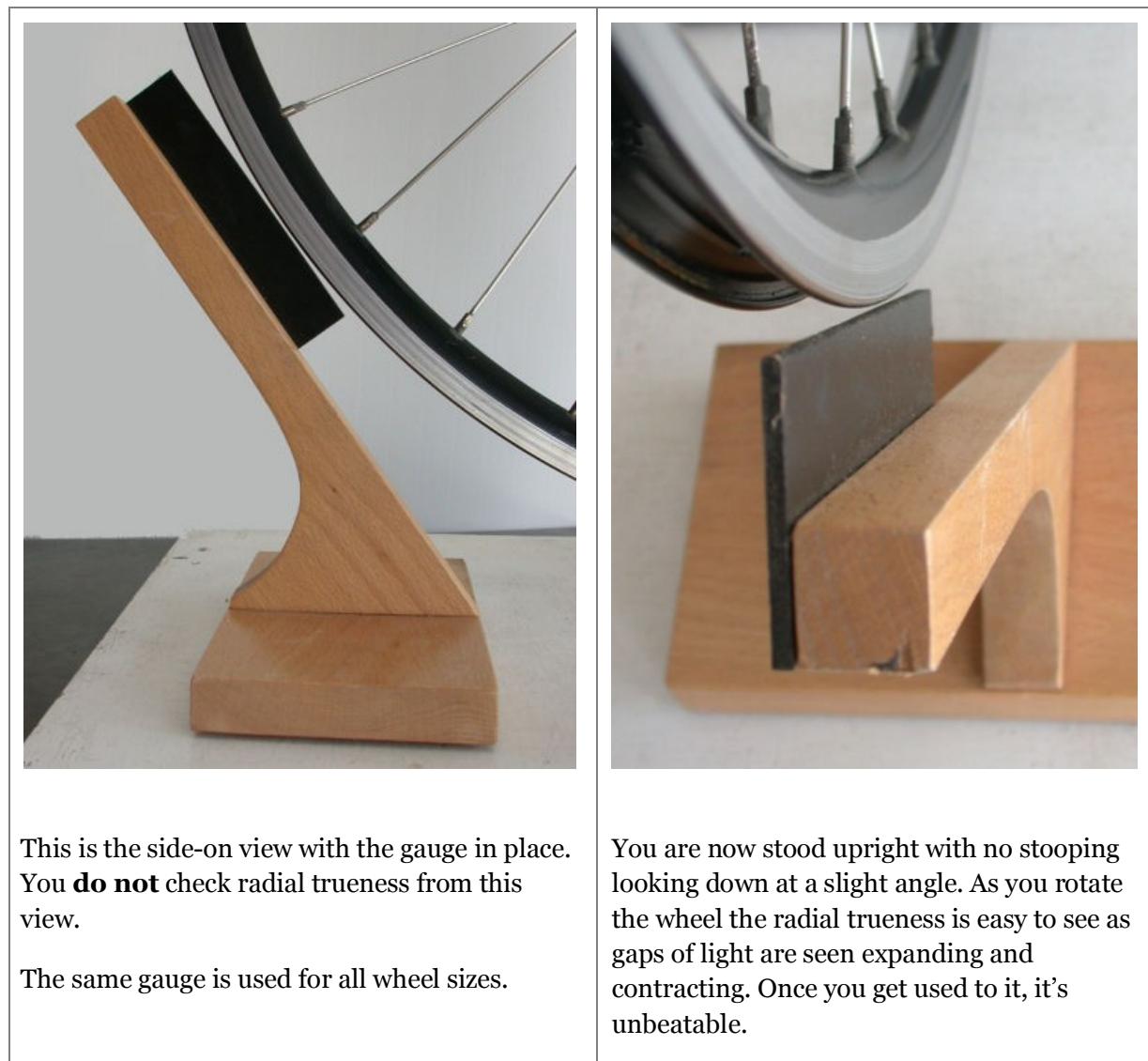
Checking lateral trueness

In the photograph note the lateral trueness gauge. I always make checks from this side so there is no need to have a similar profile on the other side. Instead, on that side I have a protruding reference that I use to check lateral trueness when a tyre is on the rim, the shape becomes more obvious when you try it yourself when you check a wheel with a tyre on. This gauge is **only used** to check lateral trueness.

The stand in the photograph is shown with a 26" mountain bike wheel in it. The wheel is secured in the jaws using the hub skewers. If I were to replace it with a larger diameter road bike wheel then all I need to do is move the gauge a fraction back making it very fast to use when dealing with lots of different size wheels with and without tyres on. Just pop the wheel in and position the reference – easy.

Checking radial trueness

The conventional way for checking radial trueness is to use a flat bar (or similar) underneath the rim but I find it not as accurate and slow to use. After much thought I devised a unique method for checking radial trueness shown in use in Figure 19. It is extremely easy and fast to use and I couldn't imagine not using one. Some builders have made one of my radial gauges to use in conjunction with their purchased truing stand.



This is the side-on view with the gauge in place.
You **do not** check radial trueness from this view.

The same gauge is used for all wheel sizes.

You are now stood upright with no stooping looking down at a slight angle. As you rotate the wheel the radial trueness is easy to see as gaps of light are seen expanding and contracting. Once you get used to it, it's unbeatable.

Figure 19 Checking radial trueness

Front 20mm and 15mm through axle MTB hubs

To hold these in the truing stand use a front quick release skewer. The skewer does not need to be central through the hub, let the skewer rest in the bottom of the stand jaws and let the hub rest on the skewer rod and lightly clamp. The hub should spin freely and all the axle designs I've used can be located this way. This technique for holding 20mm hubs is only applicable to my stand or similar ones that feature broad flat jaws for the hub faces to rest against.

If the hub does not spin freely then you need to purchase some 20mm truing stand adapters that look similar to the ones shown below. Just do a web search on *20mm truing stand adapter* and use a rear quick release skewer through the adapters to hold the hub in the truing stand.



Figure 20 20mm hub located in truing stand



Figure 21 20mm adapters

Rear 12mm and 15mm through axle MTB hubs

For 135mm wide hubs use a standard 135mm rear quick release skewer using the same technique shown above. For 150mm wide hubs the rear skewer is too short. You can use your 150mm frame fixing bolt but you'll need to modify the truing stand jaws to locate the larger diameter axle. An alternative is to purchase a piece of M8 threaded rod from a hardware store, cut to length and use a couple of wing nuts and washers.

Wheel dishing gauge

Wheels are built with the rim lying central between the hub locknuts and you check this by using a dishing gauge. The gauge is placed on one side of the wheel and the indicator positioned so that it just touches the outer edge of the hub locknut, it is then placed on the other side of the wheel and the indicator should reach the same position relative to the other locknut if the rim is central.

Some wheel truing stands incorporate a mechanism that automatically checks the dish as you build the wheel. Even if you have one of these stands you should always check the dish with a separate dishing gauge because it's more accurate.

I use a dishing gauge that I purchased many years ago because I thought the Park Tools gauge (code WAG-1) was a good design. Looking on the Park Tools website it would appear that it's now unavailable.

Dishing gauges are easy to make and you'll gain little by purchasing one. I'd say my old Park WAG-1 is slightly quicker to use but remember I have commercial considerations and build lots of wheels so your decision making process will be different.

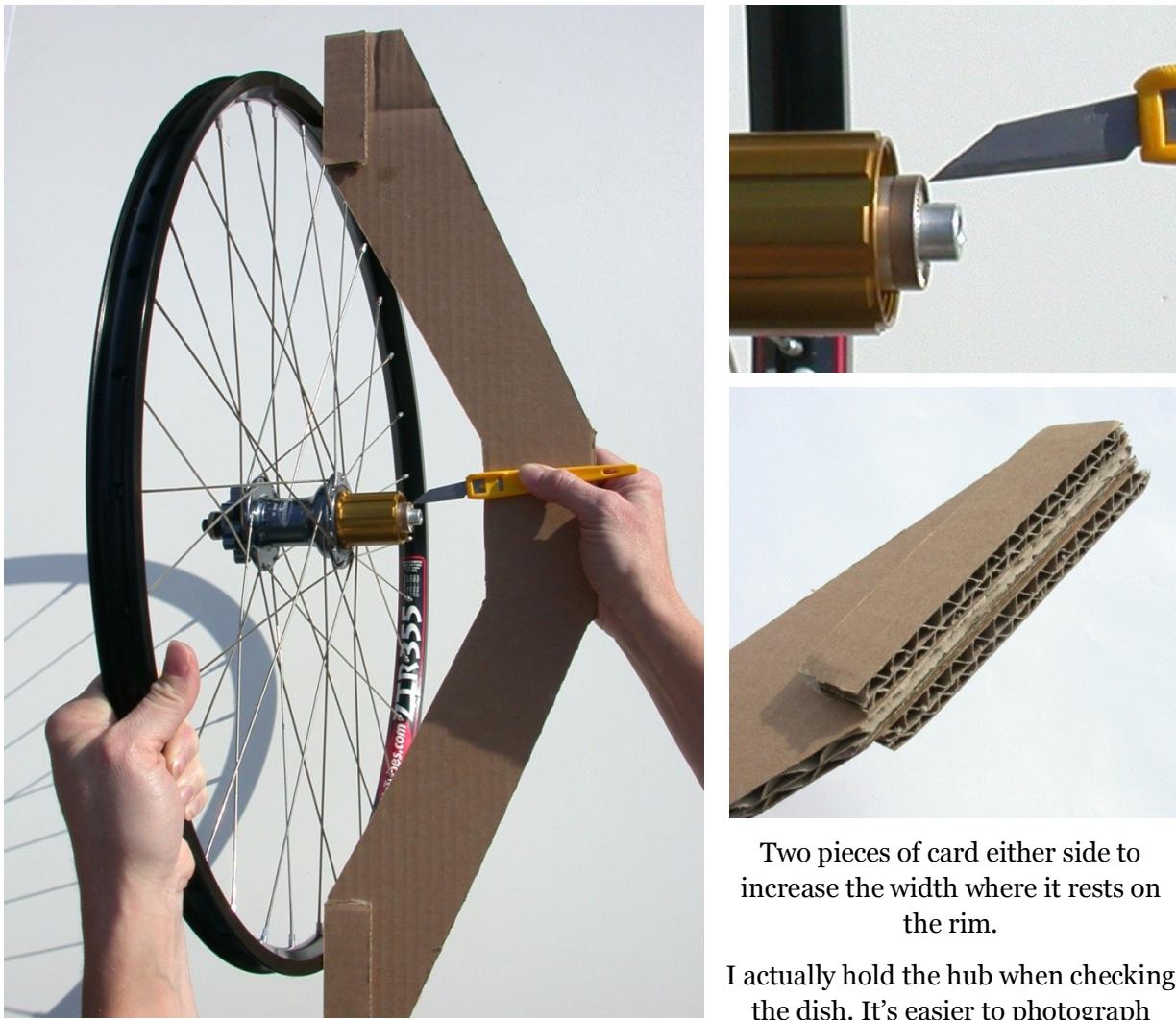
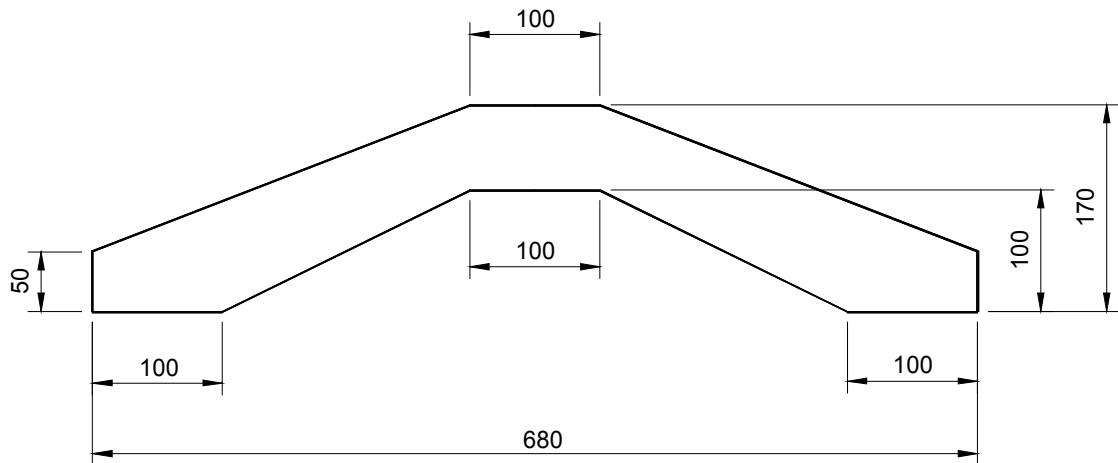
The design of a dishing gauge is simple and I suggest you make one out of corrugated cardboard. The details are shown in Figure 23. There's no need for an elaborate indicator, you hold something thin against it with your thumb to act as the indicator and you can easily hold the grip as you transfer the gauge to the opposite side of the wheel. In the photo on the next page I've used a small craft knife. I actually use a cardboard dishing tool when building BMX wheels because my Park dishing gauge is too big.

This cardboard design will work, it will be 100% accurate and it will cost nothing! In the future you may even decide to make something similar out of wood, the principles will be just the same.

The wide angle lens and camera angle makes the rim in Figure 22 look bowed.



Figure 22
Wheel dishing gauge



Two pieces of card either side to increase the width where it rests on the rim.

I actually hold the hub when checking the dish. It's easier to photograph whilst holding the rim.

Figure 23 Cardboard dishing tool

The nipple driver

Using a nipple driver makes building the wheel easier and faster.

The nipple driver is an indispensable tool and I never build a wheel without it. After lacing the wheel this tool enables you to quickly screw down all the nipples to the same thread engagement making the wheel virtually true radially (i.e. round) with little thought and no effort. The blade of the nipple driver is placed in the slot in the nipple and briskly rotated via the action of the cranked shaft. As you turn the nipple the top of the spoke releases the blade and the blade spins freely with no further turning of the nipple.

The nipple driver is a simple tool to make and a drawing is shown in Figure 25. Make the cranked blade from an old screw driver. A good idea is to purchase a cheap screwdriver because the softer material will be easier to bend, a high quality screw driver will be made from tougher steel and you will not be able to bend it unless you heat it up. Remove the screw driver handle to reveal the complete blade, file the end profile and bend it in two places to form the cranked shape as shown. Purchase a standard file handle available from any good hardware store or engineering supplier and drill it out so that the blade is inserted with a loose fit and spins freely.

There's no need to provide an elaborate method for securing the blade in the handle, you hold both handle and blade with one hand when locating the tool then the pressure exerted whilst turning keeps it firmly in place. The procedure becomes intuitive and fast after a short time. If you are struggling to see how this tool works then make one and try it out.

You can buy these tools but they are not that good. They may look nice and high tech but they don't work as well as the one described here. I find the proportions of the cranked profile are all wrong and the length of the point on the blade too short. If you purchase a nipple driver then you must ensure the point is 3mm and if it's not you are advised to modify it. Using too short a point will tighten the nipples too much in the early stage of building.

Some wheelbuilders use a power drill with a straight bit (as opposed to cranked) using the same end profile as shown for the nipple driver but I never use a power drill and always use the nipple driver shown here. The hand tool gives me more control and gives better feedback on how the nipple is tightening, plus I find it just as fast as the power drill and it never lets me down when doing race service out in a field.



Figure 24 The nipple driver

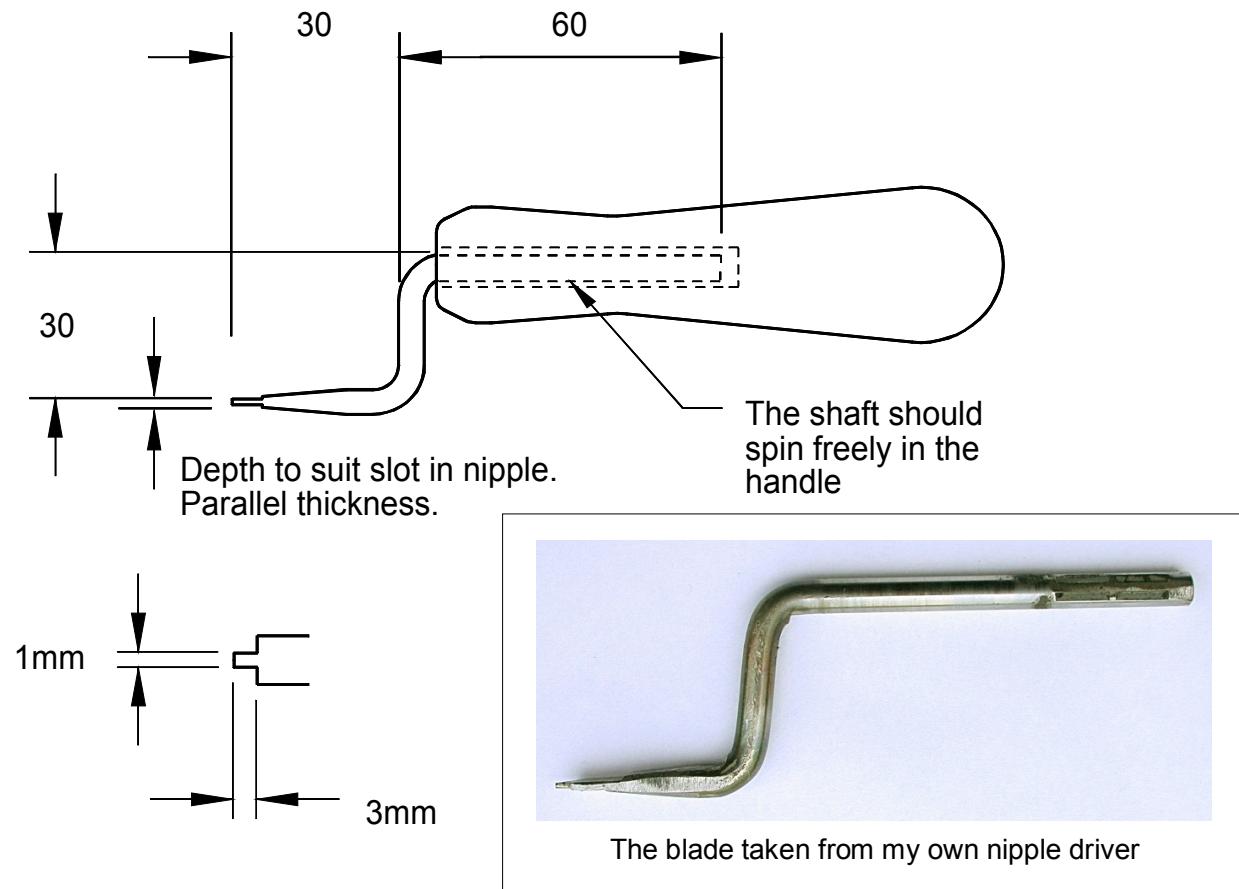


Figure 25 The nipple driver dimensions

Leather gloves

You'll need a pair of leather gloves in the latter stages of wheelbuilding where you need to grasp and squeeze the spokes (I'll explain why in the building section).

The gloves need to be substantial and the best ones I find are from gardening shops called *heavy duty pruning gloves* – the ones for pruning prickly bushes. They are made from canvass and reinforced on the palms and fingers with thick leather and surprisingly they are very cheap.

Here you see one of mine, note the markings across the palm and fingers made from the spokes.



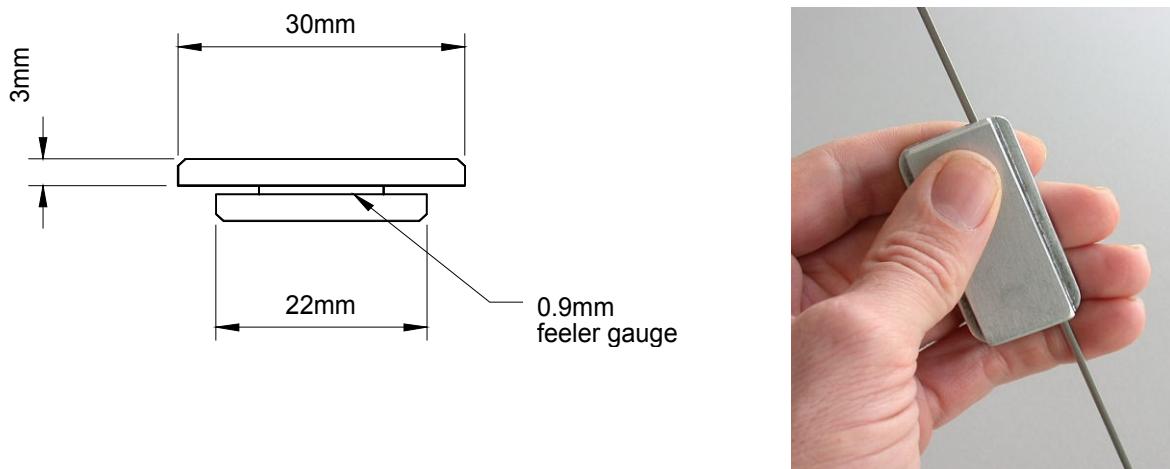
Figure 26 Gloves

Bladed spoke tool

The Sapim CX-Ray and DT Aerolight spokes are very thin bladed spokes with a cross section of 2.3mm x 0.9mm and when building they twist very easily making tensioning them difficult. Sapim and DT supply a tool for holding the spoke in place while tensioning, they work okay but I found them a little clumsy to use so I designed my own.

It's a tricky one to make and I am only describing it here since it's a tool I regularly use. The cross sectional profile is shown in Figure 27, with a depth of 50mm, the drawing shown is for bladed spokes having a thickness of 0.9mm, for other thicknesses of spoke modify the 0.9mm dimension. I used a piece of 0.9mm feeler gauge (actually two at 0.45mm each) sandwiched between two pieces of aluminium plate. Initially it was bonded together using a high strength industrial adhesive but the joint failed after a few months so a friend who works in the aerospace industry took it away and had it riveted together. You can also drill a couple of holes and use small bolts to hold it together. The stepped design is important because it makes locating the tool on the spoke very easy.

To quickly make a bladed spoke holding tool take a piece of metal or hard plastic and make a thin saw cut into it.



*Figure 27 My bladed spoke tool design.
Photographed holding a Sapim CX-Ray spoke.*

Nipple holder

If you look on the websites of Sapim and DT you will see they supply a small tool called a *nipple holder* to help placing the nipples into deeper section rims. I tried one but found it cumbersome and preferred to slice the plastic portion of a cotton bud at an angle. Push it into the slotted end of the nipple and you can easily place the nipple into the rim then grasp the protruding nipple and pull it off the holder ready for using the nipple driver.

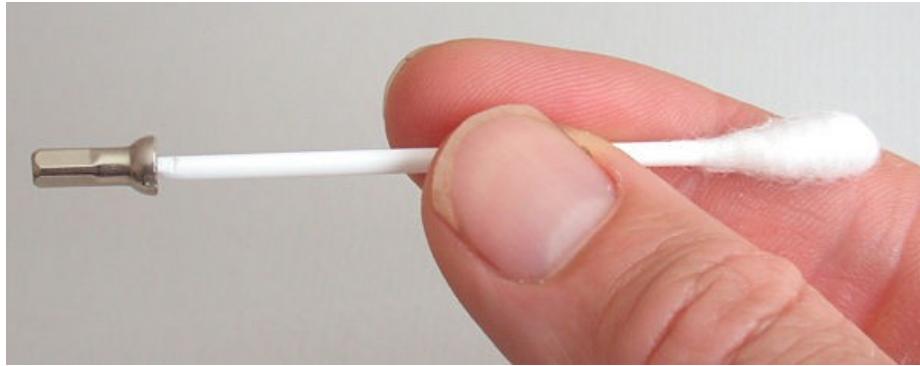


Figure 28 Nipple holder

Tensiometer

A tensiometer measures the spoke tension and shown in Figure 29 is my DT tensiometer. It lightly clamps onto the spoke and measures the spoke deflection from a load applied via a calibrated spring. The measurement is then cross referenced against conversion charts supplied by DT to show the actual spoke tension in Newtons. Why use a tensiometer?

- There is an acceptable tension range for building a reliable wheel and some builders like to measure the tension to ensure they are within this range. In reality obtaining the correct tension can be accomplished without one and I'll show you how in the building section.
- Some builders like to measure the tension to ensure all spokes are tensioned to the same value. Using a tensiometer to do this is time consuming and it's easier and much faster (and just as accurate) to use the spoke plucking method that I'll describe.
- The rim manufacturers like to specify numeric spoke tension limits for their rims and you need a tensiometer to check that your spokes are within their limits. I'm not sure what they base their figures on and whether there's any scientific basis at all but their figures are always well below what the rim can withstand.

Some points you need to be aware of:

- The best and very expensive tensiometers are only accurate to +/-10% and lower cost tensiometers are even less accurate.
- Manufacturing tolerances of the spokes mean the diameter may vary from batch to batch. I've seen DT Competition spokes (diameter 1.8mm) measuring 1.75mm and if you are using the conversion charts assuming it's a 1.8mm it throws a significant error in the tension measurements. For example I built a wheel and I was sure it was plenty tight enough yet the tensiometer said it was still low. I then measured the spoke diameter with a micrometer and the spokes were smaller than the assumed diameter – hence the discrepancy.

In all my years as a professional builder leading up to 2007 I never used a tensiometer. In 2007 I started building on Stans ZTR rims (www.notubes.com) and they specify low tension limits for their extra lightweight rims that they say should be adhered to. I've spoken to them and they seem

to be knowledgeable on the subject so I build to their specifications and had to buy a tensiometer. Shown below is a tension reading of 1.27mm using DT Revolution spokes which equates to 1000N – a little more than the 95Kg that Stan wants but that particular wheel has been raced hard and is perfect.



Figure 29 DT Tensiometer

Out of curiosity I took a tensiometer to a wheel I'd built without the use of one (using the building techniques shown later in this book). It just told me that the tension was fine and the spoke tensions were equal. So in summary – you don't need one but I've no objections if you want to try one.

Chain whip

Although not a wheelbuilding tool a chain whip is a tool I use often when removing rear cassette sprockets. I made my own out of a piece of 3mm x 25mm steel with an overall length of 300mm plus a piece of old chain.

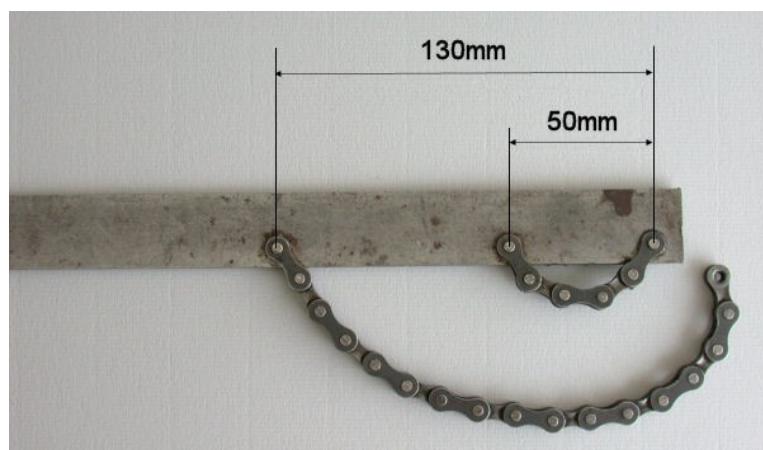


Figure 30 The chain whip

Chapter 4

Building

This section will show you how to build a rear wheel using 32 spokes arranged 3 cross. This configuration accounts for 95% of all the wheels I build. In the Design Section I'll show you how to adapt this procedure for many other standard cross laced wheels.

Your BIG advantage over the commercial wheel builder is that you have no time constraints so use your time to make a good job of the wheel. Never race against the clock to see how fast you can build a wheel because the quality will surely suffer.

Determine your spoke lengths

Determine the correct spoke lengths, this is covered in detail in the Spoke length section. This is an **important** part of the wheel building process because the correct length spokes will make building the wheel much easier. It is harder to build a wheel using short spokes because you will be struggling with tight spokes too early in the building process. You can get away with spokes that are too long but in the finished wheel they must not protrude more than 2mm above the top surface of the nipple.

Our rear wheel will require two lengths; the drive side spokes typically 1 or 2mm shorter although the geometry of some disc brake rear hubs results in the same spoke length either side but the text here assumes 2 different lengths. Take 16 of each and clearly segregate them, preferably into two containers, one marked **Drive** the other **Non drive**. Alternatively place them on well separated sheets of paper marked drive and non drive. If you accidentally mix these up or choose a spoke from the wrong pile during lacing you will encounter major problems that will only surface much later on in the build process in which case it is often quicker to disassemble and start again rather than try and find the problem spokes.

Measure your components

If you haven't already done this while determining your spoke lengths then do it now. I'll explain why it's necessary in the Spoke Length section, you'll be glad that you did measure them – maybe not now but certainly in the future. Please see measuring rim diameters on page 101 and hubs on page 103. Write down your hub and rim measurements plus the spoke lengths you are using and keep your notes somewhere safe.

Oil the spoke threads

The purpose of the oil is to reduce friction and allow the nipple to be tightened to achieve the correct tension in the spoke; the oil will not subsequently cause the nipple to work loose. Correct spoke tension will prevent the nipples working loose but we do not increase the spoke tension just to keep the nipples in place. A key fact to remember is that a tight wheel is a strong wheel and the tension ensures the nipples stay in place making it reliable as well as strong.

Components assembled completely dry will be difficult to bring to the correct tension, the wrench will be hard to turn and be accompanied by screeching sounds and in severe conditions you will shear the nipple or damage it so that it could later fail when the wheel is used.

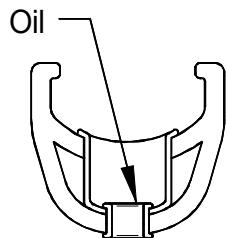
The oil I use is standard motor engine oil.

Don't use any vegetable based oils or other fats because although they allow the wheel to be built the oil/fat will decompose over time and the spoke nipples are likely to get stuck making re-truing difficult.

I am not opposed to using adhesives, I do not recommend them because it encourages sloppy building and low tensioned wheels relying on the adhesive to *try* and sort out any potential problems. If you run out of your favourite glue you will have no confidence to build without it and the job stops. Your wheels will be built with oil but at the end of this section I'll talk a little more about adhesives.

Pour some of your oil into a container such as the cap off a bottle. Take each bundle of spokes in turn and tap the spoke threads on the bench to get them all level and dip them into the oil about 2mm, then tap them on a rag to remove the excess oil. You just want them *lightly* coating and not swimming in oil which is messy.

Oil the rim eyelets



Always lubricate the inside of the eyelets on all rims, those with eyelets and those with no eyelets. This need only be a light wipe with a cotton bud with a little oil on it. Wipe around the top surface and the inner sides of the spoke hole barrel.

If you do not oil the rim you will never be able to tighten the nipples sufficiently due to the high friction at the nipple/rim interface.

If you want to practise lacing up (then dismantling) the wheel a few times then leave the oil off the rim and spokes to keep things clean. Only apply the oil when you aim to complete the wheel.

The above steps were all preparatory and from now on the actual building will start. I always stand up when building a wheel but I know a few people who sit down. I also like the room to be quiet. The choice is yours.

Lacing the Wheel

Lacing is the task of assembling the spokes in the wheel using the correct pattern and positioning them correctly relative to the valve hole.

The lacing procedure for a rear wheel is now shown in 9 steps using simplified diagrams. A mark ● on the hub centre indicates that you are looking on the drive side (the side that takes the sprockets) and all the wheel diagrams are viewed from this side.

After completing each step take a good look at your wheel and relate it to the diagram and understand the logical progression. Make sure it is correct before moving to the next stage, a mistake made early on will cause major problems as you try to complete the latter stages of the lacing process. You'll soon know if you are lacing it wrong because spokes will not go where they ought to and the symmetry of the wheel is lost.

Look at your rim and check if the rim holes are offset (refer to Figure 1 on page 9). If the offset is type 1 or there is no offset then use the lacing procedure as written. If your rim is the less common type 2 then there are just two slight modifications and these are clearly shown in the text. Note, the drawings relate to an offset rim of type 1.

When lacing, the nipples should only be attached a couple of turns just to hold them on the spokes.

The diagrams in steps 3 to 5 are drawn semi 3 dimensional. After much thought and evaluating other means of representing the wheel I believe this to be the best method.

If reading the pdf on-screen you can zoom in for additional clarity.

Lacing step 1

Take 8 drive side spokes and place them through the drive side flange of the hub from the outside using alternate holes. If the hub has alternate countersunk holes ensure the first spoke is placed so that the elbow rests on the countersunk side. You might want to read the discussion on aligning the hub label with the rim valve hole on page 66.

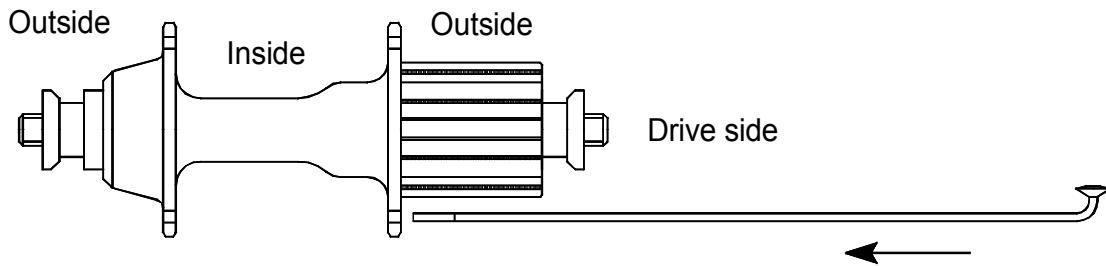


Figure 31 Lacing step 1

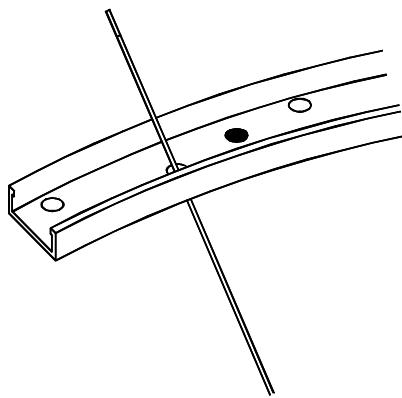
Lacing step 2

Figure 32 Lacing step 2

If the rim has a manufacturers label then it is good practice to ensure it is readable when looking on the drive side so turn the rim over if necessary.

Place a spoke through the rim hole to the left of the valve hole (shown here as the black circle) and attach a nipple.

Type 2 rims place a spoke through the 2nd left rim hole.

It is important to get this first spoke correct because it determines the placement of all other spokes in the wheel and ensures that the valve hole ends up in the correct position.

Lacing step 3

Place the next 7 spokes in every 4th rim hole.

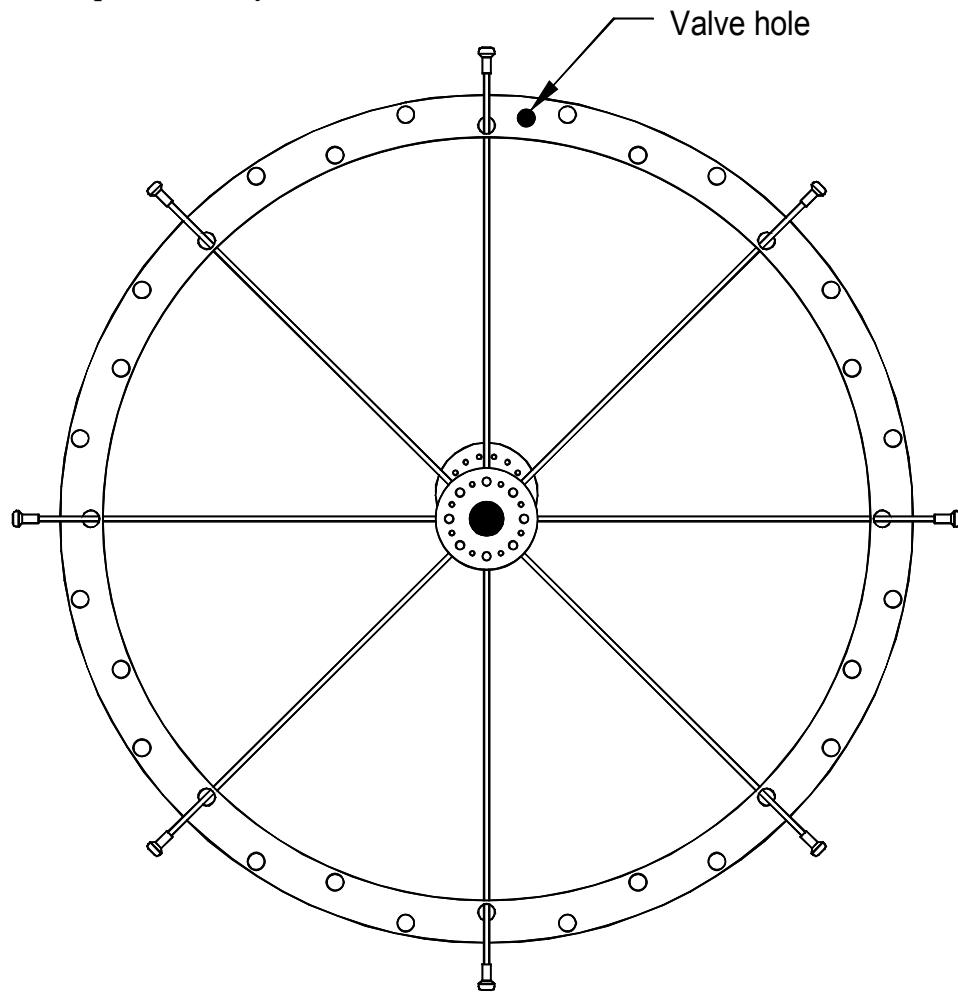


Figure 33 Lacing step 3

Lacing step 4

Look at a spoke on the drive side (any spoke will do) and note the hole where it passes through the hub. Using this hole sight across the hub and notice how the holes on the opposite flange are offset slightly, there is one hole either side.

Select the hole to the **left**.

Take a spoke from your box marked **non drive** and pass it through this hole from the **outside**.

Type 2 rims, select the hole to the right

Place this spoke in the rim to the **left** of the spoke used for sighting purposes and attach a nipple.

Type 2 rims, place to the right

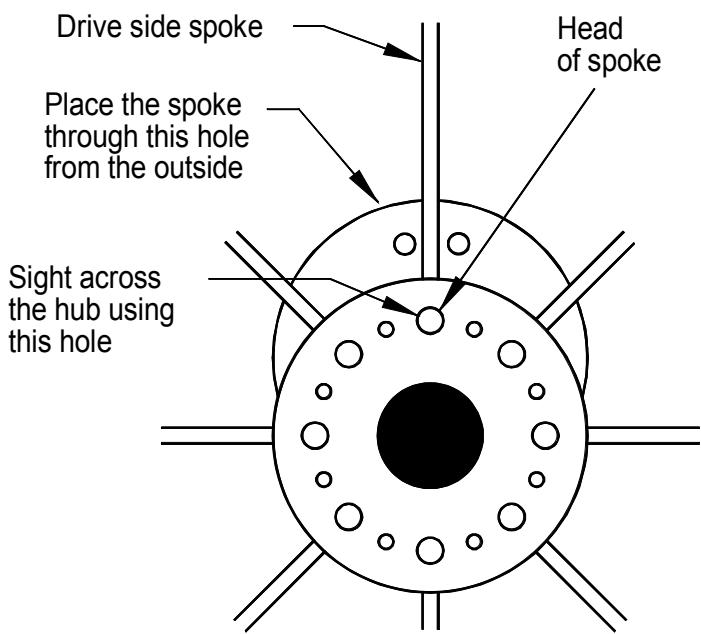


Figure 34
The first spoke on the opposite side

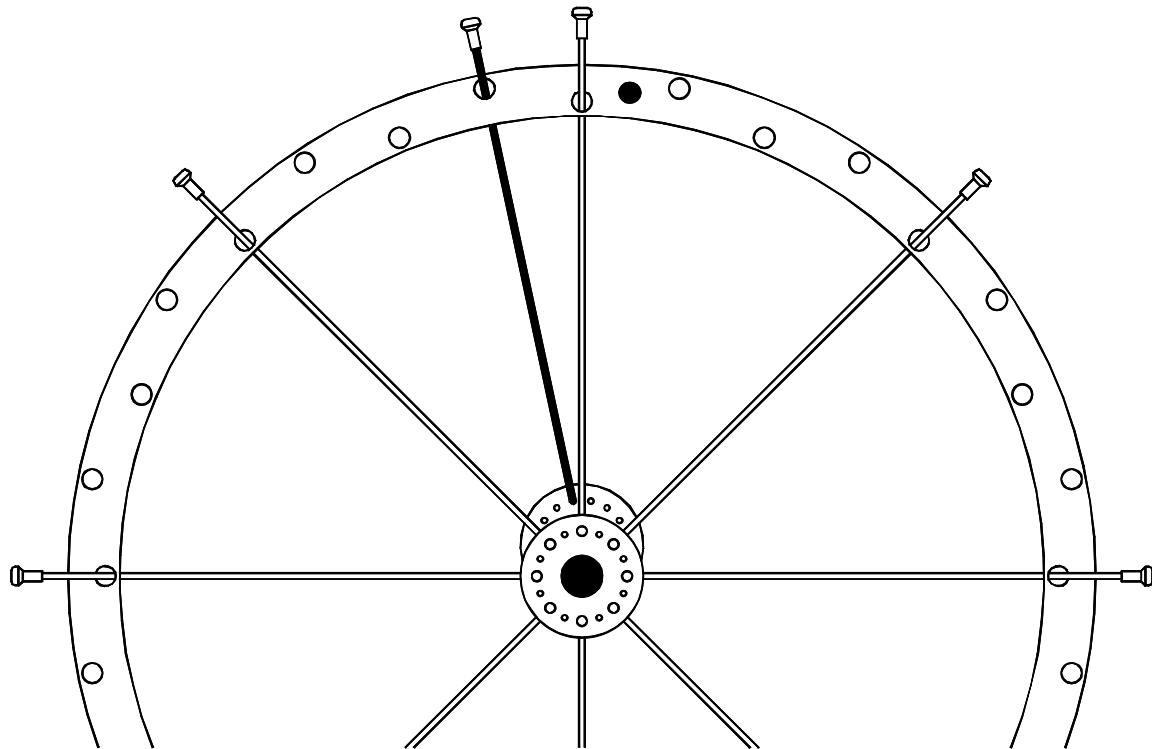


Figure 35 Lacing step 4

Lacing step 5

Continue on the opposite side with 7 more spokes. There is no need to sight anymore, the spokes are placed through alternate holes in the hub and placed in the rim every 4th hole, these spokes are shown in black in Figure 36. I hold the wheel flat looking on the opposite side and drop these 7 spokes in through the hub then with the wheel upright place them very quickly adjacent to a drive side spoke. The second set of spokes are now in and both sets lie on the inside of the hub.

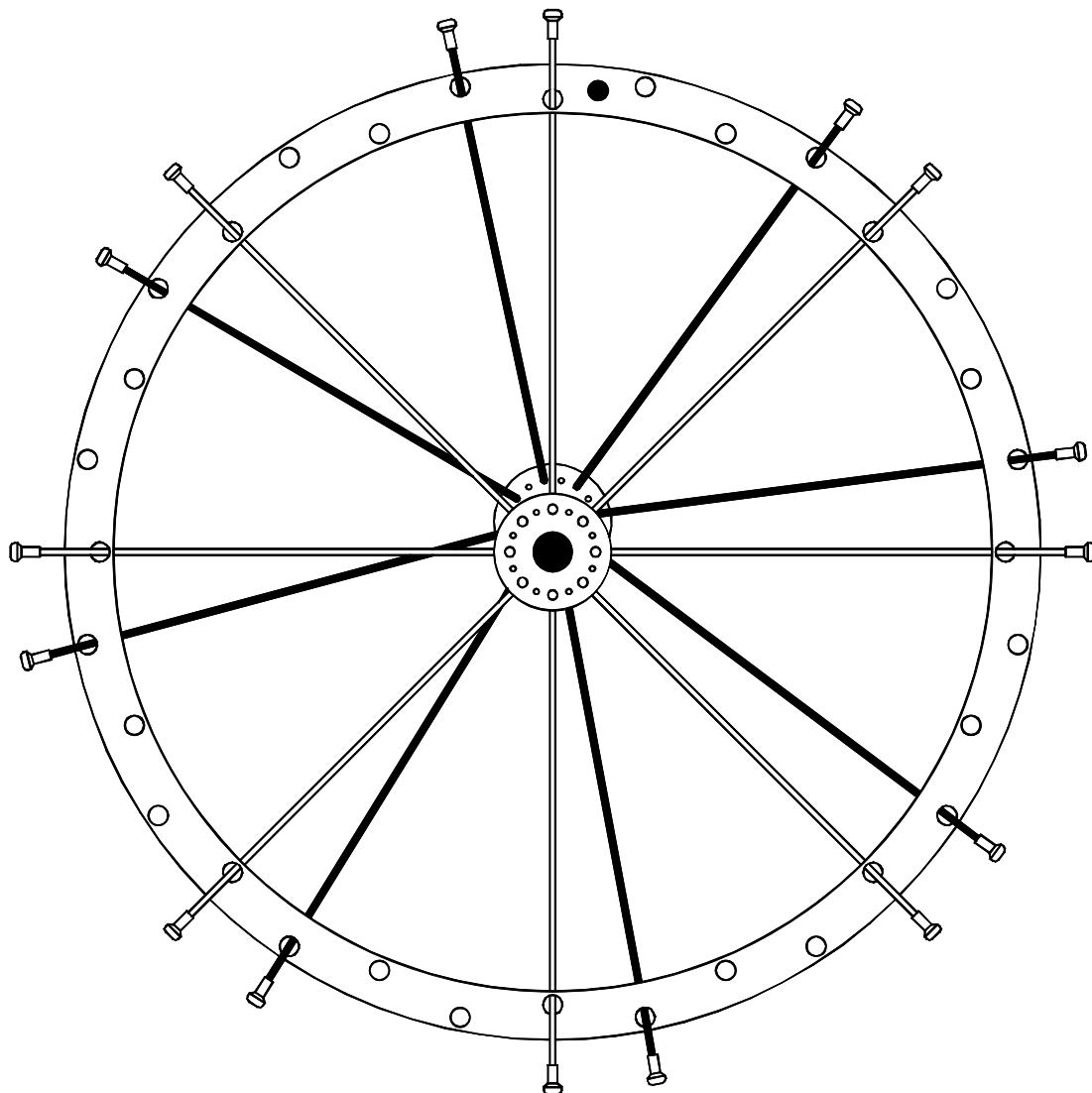


Figure 36 Lacing step 5

The following diagrams now show a more realistic side view of the wheel. For clarity only the spokes in the drive side are shown.

Lacing step 6

Grip the hub flange and rotate in the direction shown. The two spokes adjacent to the valve hole will slope away from it (note, the diagram only shows the drive side spoke).

If the spokes are a good fit in the hub then it may be difficult to rotate so rest the wheel upright on the work bench and use both hands either side to rotate the hub, you may even have to start the spokes moving tangentially by pushing each spoke in turn close to the elbow. Alternately the spokes may be a relatively free fit in the hub and it will not hold its rotated position in which case you will have to carry out this exercise again whilst starting step 7.

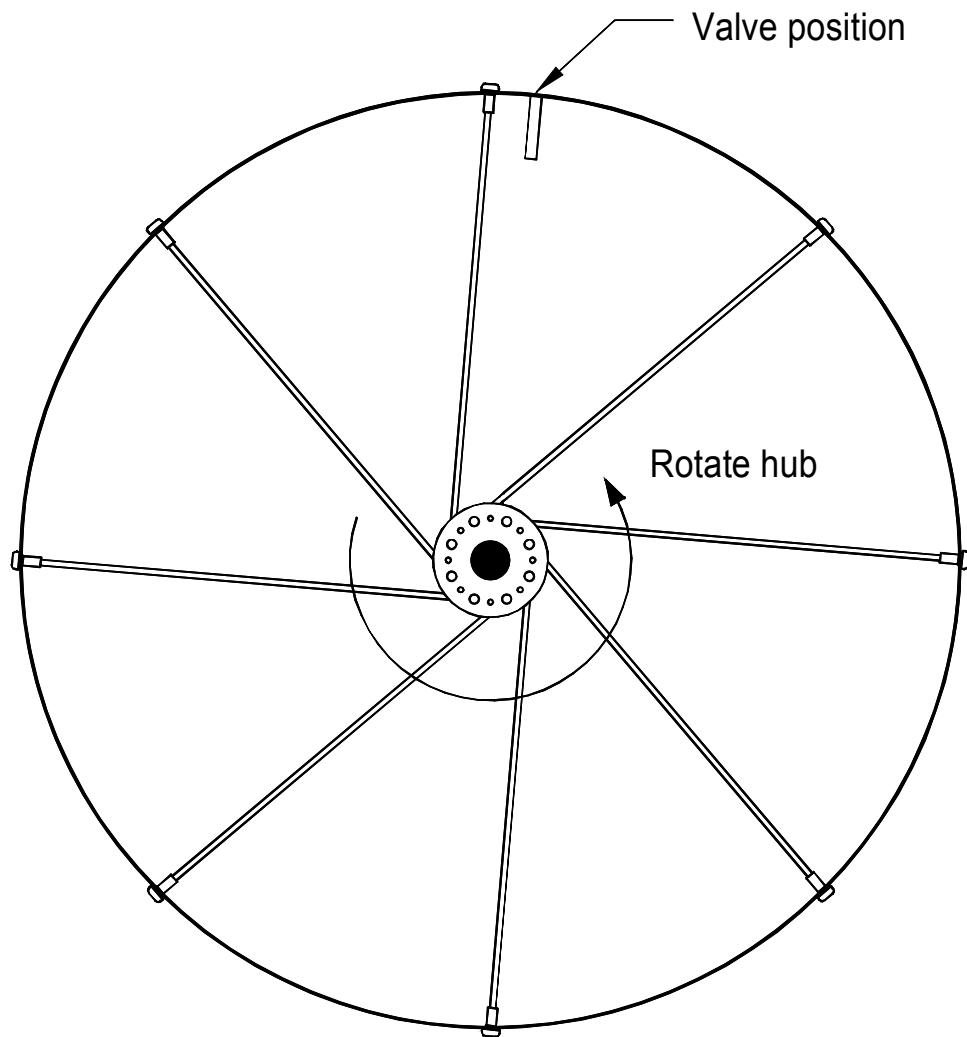


Figure 37 Lacing step 6

Lacing step 7

Take a drive side spoke and pass it through the hub from the inside of the drive side to the outside, any hole will do.

This spoke (shown in black) will radiate back to the rim in the opposite direction to those already placed. Since it is a 3 cross wheel it will cross 3 other spokes before entering the rim (see below).

Pass the spoke *over* spokes 1 and 2 and weave it *under* spoke 3. In order to weave, the spoke must be flexed very gently, be careful not to kink the spoke or scratch the rim surface with the threaded end of the spoke.

There are two options for placing the spoke in the rim but it must go through the hole which is central between the two other spokes on the same side (see Figure 39). It should easily reach the rim, if it doesn't reach, or goes too far through then check you have made the correct number of crossings.

It will be necessary to use the nipple driver to attach the nipple. First weave the spoke and position it near the rim hole then place the nipple into the rim and give it a couple of turns with the nipple driver as you bring the spoke towards the nipple.

With deeper section rims that do not have double eyelets be careful not to drop the nipple into the rim box section because it can be awkward to get out. If you have difficulty placing the nipples in this type of rim then use the nipple holder shown on page 37.

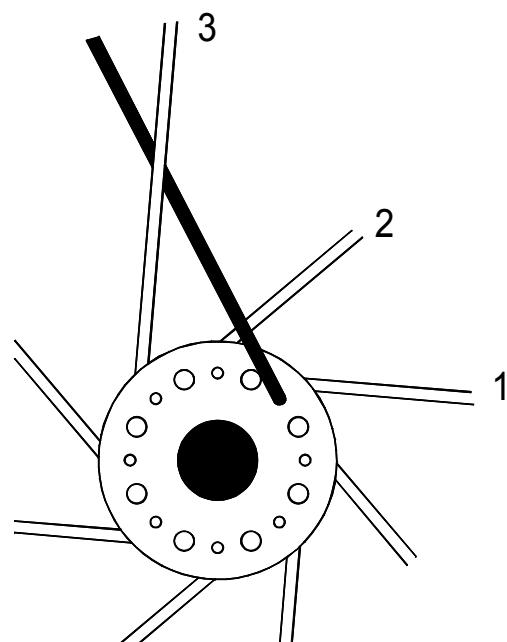


Figure 38

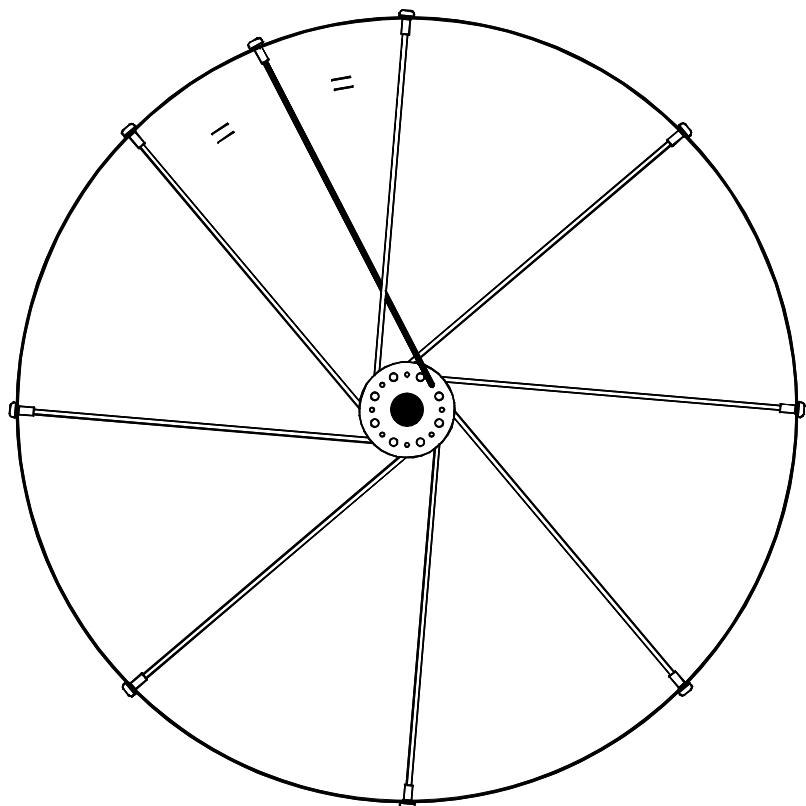


Figure 39 Lacing step 7

Lacing step 8

Continue on the drive with the remaining 7 spokes (I normally put all 8 spokes into the hub when starting Step 7), weaving each spoke *over, over, under and in*, again using the nipple driver to attach the nipple. The 3rd set of spokes are now in.

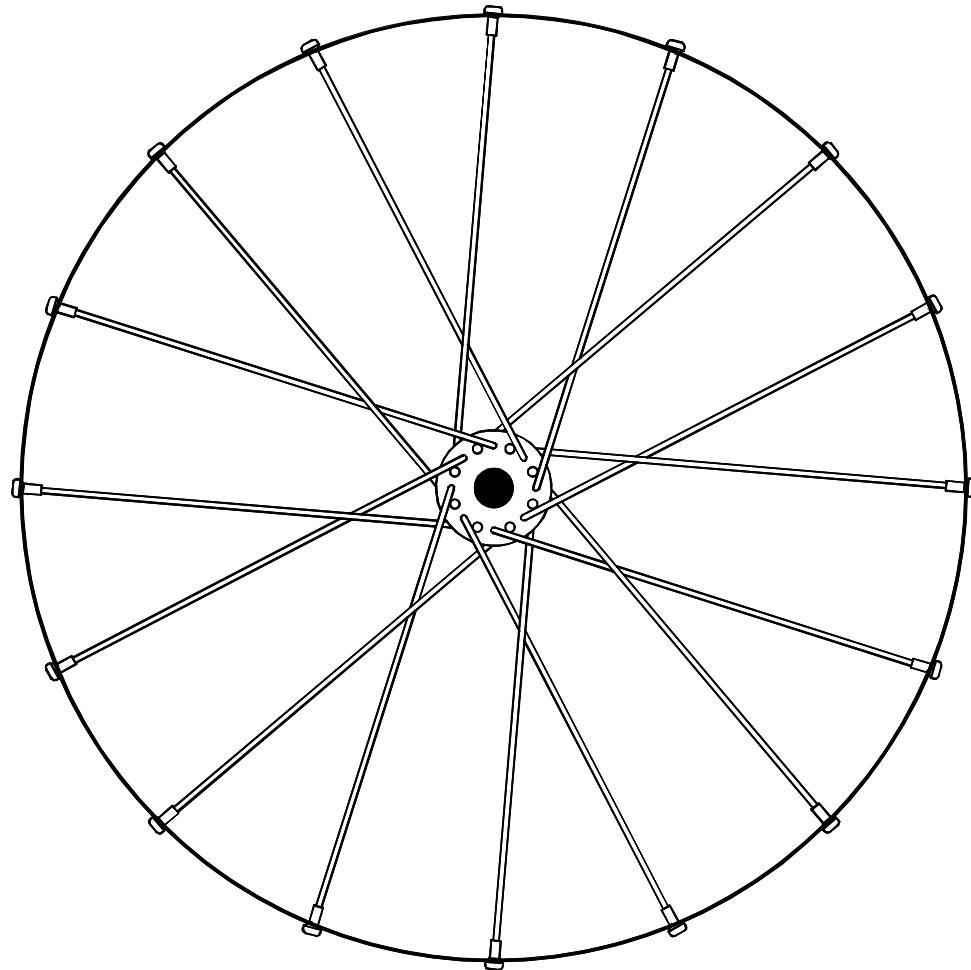


Figure 40 Lacing step 8

If you are struggling placing the last few spokes then :

- The hub may not be fully rotated, in which case try rotating it more.
- Some of the nipples on other spokes may not be seated in the rim.
- A mistake has been made in the preceding lacing.
- It is possible that the spokes are excessively short.

At this stage all the spokes should still be relatively loose.

Lacing step 9

Complete the opposite side of the wheel in the same manner by inserting 8 spokes through the inside. Rotate each spoke back to the rim in the opposite direction to those already placed remembering to weave the spoke. Now there is only one rim hole available to take the spoke.

The 4th set of spokes are now in and the diagram below shows the wheel with the full complement of spokes in both sides. At this stage the spokes in *your* wheel will be loose and bowed and will not look exactly like the diagram below.

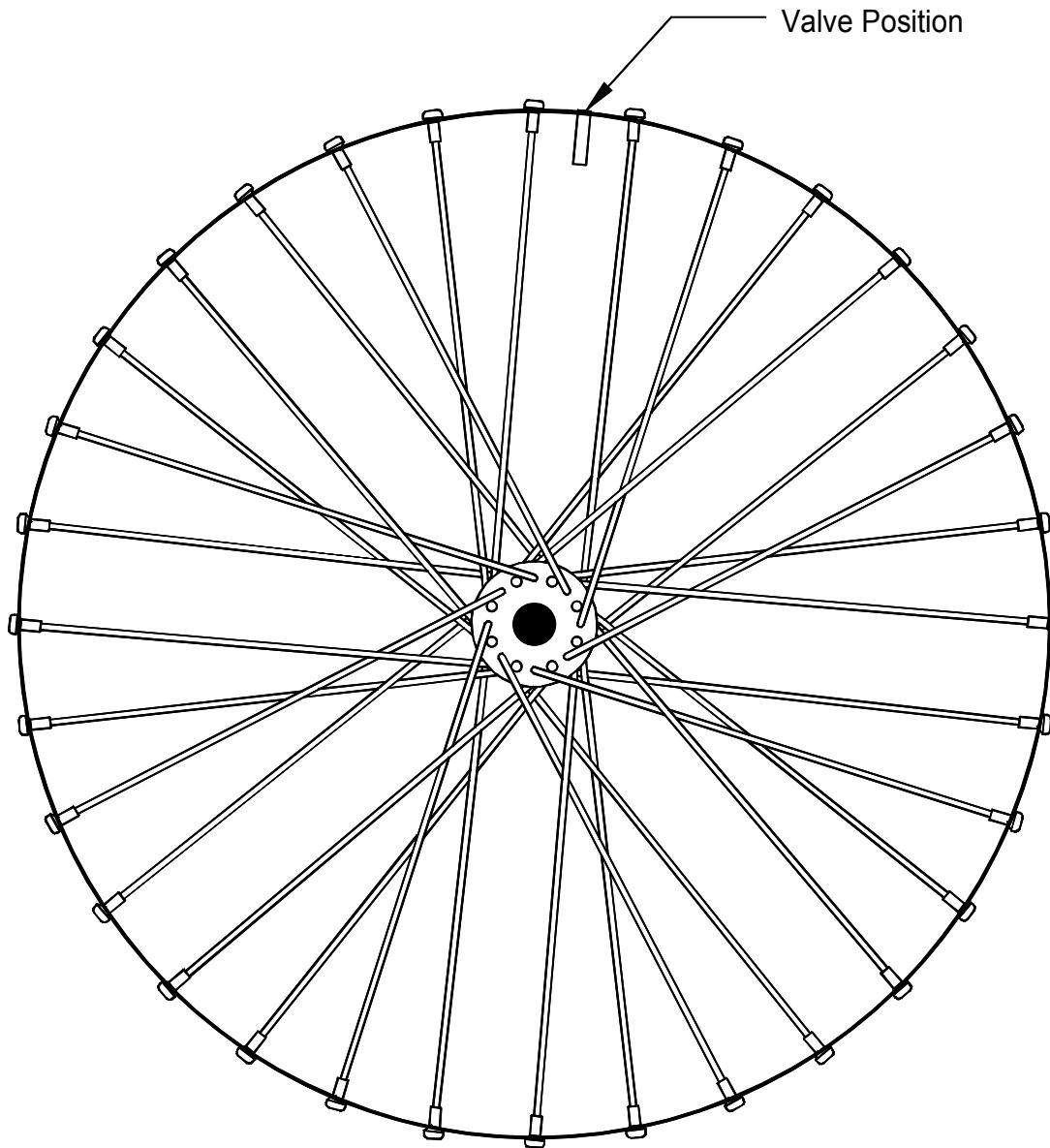


Figure 41 The fully laced wheel

Check your wheel

- It should have a regular even pattern; the triangles formed at the spoke crossings should be the same size.
- All the spokes should be uniformly loose with no individual tight ones.
- All the spokes should be weaved.
- The valve hole will lie between two almost parallel spokes (to allow easy attachment of the pump).
- If the rim holes are staggered then the spokes should be connected to the correct hub side.
- If you decided to align the hub label with the valve hole then discover it doesn't then it's not a big issue and can be left as is. It's up to you if you want to start again.

Notes on lacing

1. The front wheel is laced in a similar fashion. Remember to get the rim label correct ensuring it's readable from the drive side, this may seem trivial but is good practice and shows attention to detail. On road wheels it's not just a case of flipping the built wheel over because the spoke orientation at the hub will change, it will go from type A to type B in Figure 64 on page 89.
2. If the outside spokes were laced first (as opposed to the inside spokes as described) or a complete side laced first you will get tangling problems when placing the remainder of the spokes which slows up the lacing process.
3. The 32 hole 3 cross wheel laced here is just one example from a family of standard crossed wheels. It is easy to adapt the procedure for any number of drillings e.g. 48, 40, 36, 28, 24, and for other cross patterns such as 2 and 4 cross. I'll deal with standard crossed wheels in the Design Section.
4. In *Lacing step 3* the spokes in the standard crossed wheel are always placed every 4th hole irrespective of the number of holes or cross pattern. This is because the spokes are arranged in groups of four i.e. two forward and two backward orientated spokes and is why the available drillings are always divisible by 4.

At this stage, particularly if you are new to wheel building you may want to dismantle the wheel and re lace it for practice without looking at the book. Make sure you keep the drive side and non drive side spokes separate since they are different lengths.

Completing the wheel

The rim is flat and round to start with and by tightening the spokes the same amount it will remain flat and round with the hub central in the wheel, and if we get our spoke lengths correct the dish will be very close too. Then all that is required is a bit of fine-tuning to finish the wheel.

... and that's how we build them so easily.

Things will get very messy if you don't understand what I've written in the above box and is why many new wheelbuilders arrive at the fine-tuning stage with an egg shaped wheel that looks like a potato chip and spend the rest of the week *fine-tuning it* and getting in an even deeper mess.

It is of course easier if you are starting with a brand new rim which should be flat and round to start with and I recommend you start with a new rim for your first wheel. Previously used rims may not be so perfect and will sometimes require more effort to get the wheel finished. A used hub will not pose any problems.

It will help if your hub bearings are correctly adjusted, even a small amount of side to side movement will make delicate truing difficult because the wheel will wobble about in the truing stand making it harder to identify lateral trueness discrepancies.

You will also need some tape, paper based tape such as decorators masking tape is best because it adheres to the spoke well.

Completing the wheel is described in 8 steps. Each step is a logical progression, if you wish to take a break from building then complete the current step and resume at the same stage when you get back.

The wheel is now placed in the truing stand.

1. Take up the slack

*You are attempting to take up sufficient slack so that the spokes are not loose, they should have a little tension in them but **they should not be tight**.*

Use the nipple driver to screw down all the nipples equally to the same position. I normally apply a little pressure to the side of the spoke with my fingers so that it enters the rim at 90 degrees allowing the driver blade to release more precisely. The main problem new builders have is keeping the wheel radially true (i.e. round) and I cannot over emphasise the use of the nipple driver. I have **never** built a wheel without the nipple driver and you have no excuse for not making this simple tool (page 35).

With the correct length spokes you will be able to screw down each nipple so that the nipple driver disengages easily.

If the spokes are too short you will not be able to tighten them all equally and will start struggling with the last few nipples. If the spokes start to tighten up before the nipple driver releases engagement do not try to force it because you will be tightening the spokes too much at this stage. If it's marginal and you've only got a few left to go then complete step 2 below and it will release a little tension and help you in tightening the remainder of the spokes. If the spokes are obviously too short then mark where you are up to and use the wrench to back off all *previous* nipples two turns. Continue with the nipple driver on the remaining nipples but remember to use the wrench to back those off the same amount to ensure all nipples are at the same engagement.

If the spokes sizes were correct then the spokes at this stage will still be loose so continue tightening them with the spoke wrench.

For new builders the biggest mistake is turning the wrench the wrong way and this is easily done on a few nipples and often without realising it. If you make this mistake the wheel starts going out of shape, it loses its roundness and gets some severe side to side wobbles which can be very disheartening for the new builder, so each time you use the wrench carefully consider which way to turn it. To help you, see my tip for using the Spokey on page 24.

When using the wrench make adjustments a little at a time until you become familiar with the building process and can use your judgement to make larger adjustments when you can recognise the situation that warrants it. A small adjustment is one quarter turn of the wrench (or one eighth when finishing the final truing), a large adjustment is 1 - 2 turns.

At this stage I usually make a quick check on the wheel dish and remove any large dishing errors whilst taking up the slack. See Step 7 on page 56.

Starting at the valve hole use the wrench to tighten each nipple one turn, go completely around the wheel and repeat if necessary. It should only need one or two turns at most, any more and the spokes are a little long. At all times use the valve hole as a reference point and always go completely around the wheel, you may want to clearly mark the valve hole with some tape because it's easy to miss it and start another revolution. The natural hand and finger action of using the wrench yields one half a turn and this is my basic unit of measure so if I were tightening the nipple one full turn I would consciously count "one – two" in my mind.

Have a piece of tape handy ready to mark **the next spoke to tighten** if you are interrupted midway or drop the spoke wrench (and also remember how many turns you were giving it). If you lose your position you are in big trouble. I always have a couple of pieces of tape stuck on the truing stand ready to grab and place on the spoke (for me it is usually the phone ringing or someone calling in the shop that causes me to stop). That's why I prefer paper masking tape because it's easier to rip a piece off the roll when required immediately.

2. Align the spokes

The previous stage will have removed the looseness from the spokes and there will be just sufficient tension for the spokes to point in a direct line between hub and rim.

You will notice that the spokes on the *outside* of the hub flange tend to bow slightly outwards away from the hub before taking a line towards the rim. The amount of bowing depends on how good a fit the spoke elbow is in the hub, the tighter the fit the more the spoke will bow.

If the spokes had been over tightened in the previous stage then the spokes would have been pulled straight with no apparent misalignment. Some people build this way and don't bother manually aligning the spokes, others insist that manual alignment increases the fatigue life of the spoke. I manually align. I also find it makes tensioning easier because you are not working against the natural spring of the spoke.

Take each *outside* spoke in turn and press on the spoke close to the elbow with your thumb so that the spoke takes a straight line to the rim. You are physically bending it a little extra at the elbow. This bending does not cause any problem to the spoke (remember making a spoke is brutal process and what you are doing here is mild in comparison). Sight along the spoke to make sure it is straight.

Take more care if the outside spokes slightly touch the heads of the inside spokes, in this condition it is possible to form a secondary bend in the spoke by pivoting on the other spoke head as you press down the spoke. Also be careful not to pivot on the edge of the hub flange as this too will put an undesirable kink in the spoke close to the elbow.

The *inside* spokes usually have sufficient angular movement to take a straight path to the rim without any modifications but check all the same.

The above discussion only applies to new spokes. If you are reusing old spokes and replacing them the same way they were removed from the hub then they will already have the correct alignment and will require no modifications.

Once aligned, the spokes will lose a little tension.

3. Take up all of the slack

Tighten the nipples again, half a turn at a time, and always one complete revolution of the wheel. Feedback from the wrench will tell you when the spokes are starting to tighten when a slight resistance to turning is noticed although the nipples can still be turned freely. This stage may only require an additional one or two turns of the wrench. **Do not over tighten.**

At this stage the spokes will make a tone when plucked close to the nipple.

4. Improve the lateral trueness

If the spokes were tightened equally as described previously the lateral trueness will be reasonable but no doubt could be improved. It is always better to work with a wheel that has good lateral trueness since the radial trueness is easier to identify and there is also the benefit of seeing the wheel taking shape. It doesn't need to be absolutely perfect at this stage but it helps if you get it fairly close rather than trying to correct large errors later.

Spin the wheel in the truing stand and position the reference point close to the side of the rim. Identify any local discrepancies where the rim touches or moves away from the reference point and examine the spokes in the immediate vicinity. Slight variations in spoke tensions will be causing the out of true. Identify a zone of out of trueness and home in on this area. The out of trueness is likely to be caused by only one or two spokes in the region.

Use tone to determine the relative tensions between adjacent spokes, tighter spokes have a higher pitched sound and looser spokes give a rather dull note when plucked, if you have no finger nails then use a guitar plectrum or something similar. On the rear wheel the drive side spokes will be tighter because of the dishing effect so for rear wheels only compare spoke tone on the same side. The same goes for disc brake front wheels, compare the tone on each side separately.

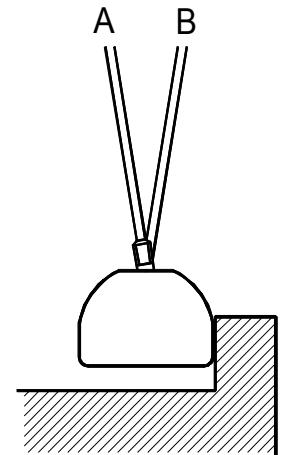
Using tone as the guide slacken any tight spokes and tighten the loose ones, keep the adjustments to half a turn or less because the rim will move easily at this stage. Tightening a spoke will pull the rim towards the appropriate side and slackening the spoke will allow the rim to move away. If all appear to be the same tension then loosen slightly the spokes on one side and tighten the opposite side.

In this example the wheel spins freely except at the position shown here where the side of the rim touches the reference point. Use tone to check the tension of the spokes in this region then use one of the following actions to correct the out of true :

- i) A spoke on side A may require tightening.
- ii) A spoke on side B may require loosening.
- iii) A combination of the above.

Note, if there is a gap (instead of the rim touching) then spoke B would require tightening or spoke A slackening etc.

More than one spoke may need adjusting to correct an out of true region where the region spans several spokes.



Now that the wheel is laterally true you aim to keep it that way and after each of the following steps you will check and adjust the lateral trueness and **always** use tone to identify the exact spoke(s) to adjust – **no guesswork**, get the exact one(s).

5. Adjust the radial trueness

Obtaining a radially true wheel is considered one of the more tricky aspects of wheel building. The rim must be round with no low spots or high spots. If you have been careful in the previous stages then the radial trueness will not be far out, if it's more than 2 mm out of round then take more care next time.

Use the lateral trueness gauge (page 31) and place it on the outside edge of the rim. Turn the wheel slowly looking for high spots where the rim touches the gauge. Spokes in this region will require tightening to pull the rim closer towards the hub thus reducing the high spot. It's better to attack the high spots because correcting them requires tightening, i.e. we are still moving towards the finished wheel rather than backing off spokes at this stage. Remember to feather out the tightening towards the edges of the region i.e. reduce the amount of tightening as you approach the outer edges of the high spot. When adjusting spokes on a rear wheel tighten the drive side spokes slightly more to maintain lateral trueness (due to the difference in spoke angles on the drive/non drive sides).

Now look for low spots where there is a gap between the rim and reference point, spokes in this region will need loosening a little, again make sure to feather the adjustment.

In all cases make adjustments a little at a time, each time checking the rest of the wheel since adjustments in one region can cause radial movements in other regions of the wheel. Be careful not to make the spokes too tight because it makes things difficult and you can end up with dozens of tiny bumps that are impossible to get out.

The region around the rim joint may not be perfectly round due to the manufacturing process used in making the rim. On rims that are joined by welding an otherwise good and round rim may have a little material removed (or added) in the welded region causing a false error which can be disregarded because the important tyre seating region will be perfectly round. Rims that are pinned may not butt up squarely and leave a little high spot. You can try to improve it but if it requires overly tight or loose spokes compared to adjacent spokes then it's much better to try and maintain similar spoke tensions and tolerate a small localised radial error which will not be noticeable when riding the bike. After adjusting the radial trueness re-check and adjust the lateral trueness.

As you turn the wheel be aware that the truing stand will exaggerate the out of trueness. Closer examination may reveal it to be satisfactory and this is described later in *wheel tolerances* on page 62.

6. Equalise the spoke tensions

At all times in the wheel building process you are endeavouring to keep things equal and in balance and this is particularly important with spoke tensions because it helps prevent them coming loose when the wheel is used. It is possible to produce a nicely true wheel but with spoke tensions all over the place, a few low tension spokes could be compensated for by a few overly tight ones and when the wheel is used those loose ones will become looser and the trueness you thought you had will soon disappear after a few rides.

Starting at the valve hole pluck a few spokes on the *same side* to gauge the average tone since each side has a different tension and consequently a different tone. Even on dishless fronts I still do one side at a time because it's less complicated this way.

Although the wheel is currently laterally true some spokes may be making a bigger contribution whilst others are not pulling their weight. If you find a slack spoke you'll no doubt find the immediate neighbouring spokes are tighter than average. So tighten it a little, but to maintain lateral trueness and balance the tensions one or both of the neighbouring spokes will need slackening a little. Similarly, if you find a tight spoke then back it off a little and tighten one or both of its neighbours. *The neighbouring spokes are on the same side of the wheel and not the immediate neighbours which are from the opposite side.*

An annoying situation occurs when the spoke hole drillings in opposing hub flanges are not offset exactly one half a hole pitch (see Figure 34 on page 44) due to inaccurate drilling of the hub. You'll soon notice this when you do the initial check because there will be a consistent tight-slack-tight-slack going all around the wheel. It just makes balancing the tensions takes a little longer.

It will take at least two passes around the wheel to equalise the tensions. The adjustments made here are of the order of fractions of a turn of the wrench. It is unlikely you will get the pitch identical but you can get them all pretty close.

Check and adjust the lateral trueness which should not have moved that much. Always use tone to identify the spokes to adjust when doing truing operations so that when the wheel is finished you end up with all the spokes to the same tension which is a key factor in producing a reliable wheel.

You will check for equalised spoke tensions perhaps once or twice again, first after you complete the initial stressing of the wheel and then as you approach the final tension in the latter stages of building the wheel.

7. Check the wheel dish

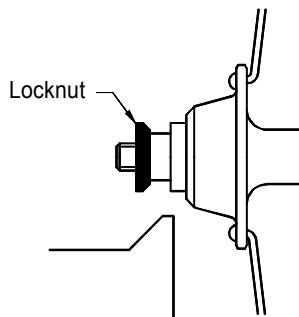
The wheel dish should be checked regularly from now on. This will ensure the rim in the finished wheel is central between the locknuts and it applies to both front and rear wheels.

When checking the wheel dish for the first time some error will be noticed and the amount for a dished wheel (rear or disc brake front) is closely related to the spoke lengths used. Since we cannot get spoke lengths in fractions of a millimetre to suit the theoretical lengths required some dishing error is to be expected. If the spokes were near to the ideal length then the dish will be perhaps 5mm out (or closer). If you had to compromise when selecting your spokes and one side was 1 or 2mm different from the ideal length then the dish will be out a lot more.

If I knew I was building with spokes that were too long on one side then I would compensate for this when taking up the slack when using the wrench in Step 1 (page 51), i.e. the long side would get more turns than the other side, or if they were short then they wouldn't get as much. I often do a quick check on dish prior to starting Step 1 and make compensations as I take out the initial slack. You don't want to be fixing large dishing errors when the spokes are tight, try to do your *fixing* earlier if you are using less than ideal spoke lengths. If you believe your spoke lengths to be correct and have a large dish error then make sure they went into the correct side when lacing the wheel.

Take your dishing tool and check the wheel. If the locknut protrudes further on one side than the other then spokes on that side will need tightening to pull the rim over and push the axle back, see Figure 42. This takes some getting used to and there is the real danger of adjusting the wrong side. It doesn't need much tightening to correct dishing errors, start with half a turn and you will be surprised how far the rim will move. Correcting small dishing errors will often require a fraction of a turn and you can easily over correct.

The standard symmetrical front wheel with the same length spokes either side should be very close if you have tightened all the spokes equally but it can easily wander to one side requiring a small adjustment to correct it.



The gauge was first placed on the opposite side of the wheel and adjusted so that it just touched the outside edge of the locknut. It is now shown here on the other side of the wheel and the diagram shows how this wheel is over dished. The spokes on this side will require tightening.

Figure 42 Correcting dishing error

Maintaining dish : Once the dish has been corrected which is quite easy at this stage when the spokes are not too tight you must be careful because the dish can very easily go out again as you continue to bring the wheel up to its final tension.

Maintaining dish on the rear wheel (or front disc brake wheel) is not as simple as going around tightening all the spokes the same amount, spokes on the drive side (or front disc, rotor side) require slightly more to maintain the dish because of the steeper angle of these spokes. When tensioning a dished wheel it is therefore better to go around the wheel in two passes, first go around the *drive side* spokes say half a turn then the *non drive* side spokes a fraction less.

At this stage I consider the wheel to be in a state of balance, it is true (radial and lateral), has equal spoke tensions and the dish is correct. All that is required is to tighten the spokes to achieve the correct spoke tension whilst maintaining dish and trueness.

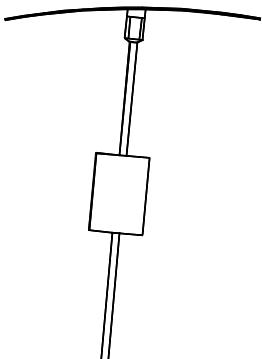
8. Final tensioning

This last stage is concerned with finishing off the wheel by bringing the spokes to their final tension. Before starting the final stage of completing the wheel it is necessary to understand two importance aspects in the wheel building process:

- i) Spoke twist.
- ii) Stressing the wheel.

i) Spoke twist

As you turn the wrench the nipple should tighten itself on the spoke threads but even with lubricated threads there is still sufficient friction to cause the spoke to twist as well as tighten. The amount of twist is dependent on the type of spokes being used and how tight they currently are. Slender butted spokes will twist more than the plain gauge one which is fairly resistant to twisting and as all spokes become tighter they will twist more. You need to be aware if the spokes are twisting so you can compensate for it when tightening them and release any twist that would otherwise remain in the spoke. Leaving spokes twisted in a finished wheel is not good practice, they will untwist when the wheel is used (with a pinging sound) and the thread engagement will change resulting in the wheel losing some lateral trueness.



The way to check for spoke twist is by placing a piece of tape along the spoke at a position as close to the rim as possible without interfering with the wrench forming a flag.

Figure 43 Checking for spoke twist

Before turning the wrench make a mental note of the original position of your tape flag and notice if it starts rotating in the same direction as you turn the wrench. This shows that the spoke is twisting rather than the nipple tightening. When the flag stops rotating there is sufficient torsional resistance in the spoke to cause the nipple to turn (relative to the spoke) and thus tighten the spoke. At this point you can then turn the wrench the required amount to tighten the spoke. Release any spoke twist by turning the wrench in the opposite direction until the flag returns to its original position. It is not necessary to tape every spoke since the spokes will react similarly but since it is easy to do replace the flag every couple of spokes to monitor the twist. The tighter drive side spokes will twist more.

If you are using bladed or other profiled spokes then spoke twist is easily visible and it is even more important that you un-twist any spokes to maintain their correct orientation otherwise any aerodynamic benefits will be wasted. Thin bladed spokes such as the Sapim CX-Ray twist very easily and require a special tool to physically prevent them from twisting whilst you tighten them (see page 37) and without using this tool they will be impossible to tighten.

In the previous building stages there will be very little spoke twist due to the lower tension in the spokes but look out for it in the final tensioning stage. If you suspect your spokes already have some residual twist in them you can use the tape flag to return them to the neutral position i.e. when the flag rotates equal amounts one way then the other as you turn the wrench back and forward.

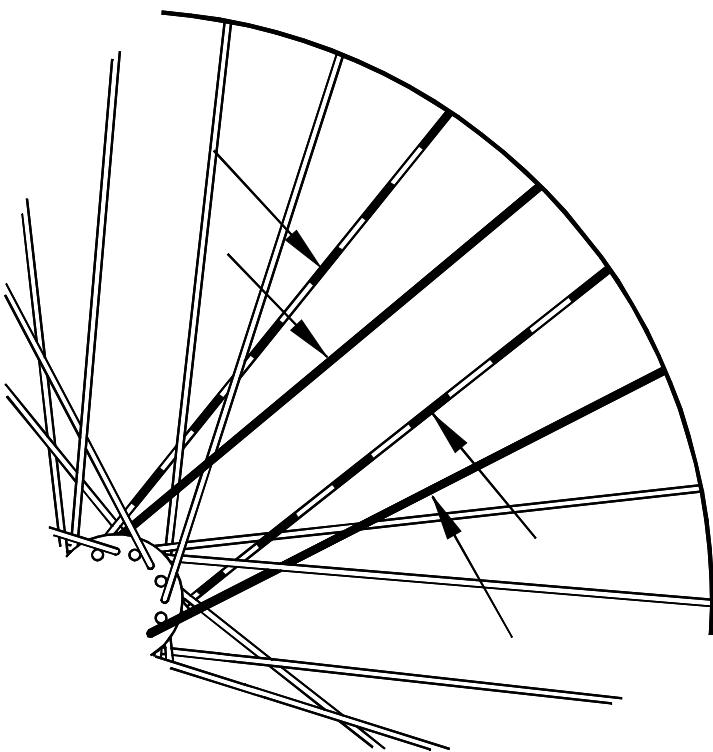
ii) Stressing the wheel (spokes)

All the methods used for stressing a wheel momentarily increase the tension in the spokes. Applying a stress to the wheel makes sure the nipples and spoke elbows are firmly seated in the rim and hub and more importantly the procedure has a beneficial effect of reducing fatigue failures at the spoke elbows.

Stressing the wheel is not a once off operation and should be used several times during building. Although not required during the building stages already described it will be necessary during the next stages as you start the final tensioning of the wheel. After the first stressing operation the wheel will probably lose some of its lateral trueness which will need correcting and then further stressing operations will cause little or no out of trueness as the wheel nears completion.

To stress the wheel first remove it from the truing stand then grasp two pairs of parallel spokes and give them a firm squeeze together as shown in Figure 44 going all round the wheel squeezing in groups of four, you'll need your gloves to protect your hands (page 36).

This technique applies a lot of force to the spoke elbows which enables a superior stressing operation. Don't worry, you will not break or damage any of the spokes unless they were faulty spokes or old spokes previously damaged so don't look into the rim channel or point the wheel at someone else when stressing the spokes.



Choose the two almost parallel spokes on either side of the wheel and firmly squeeze both pairs together simultaneously at midpoint, then move around the wheel from group to group until you complete the wheel, i.e. 8 separate squeezes on a 32 spoke wheel.

Note, the near side pair are shown in black, far side pair shown dashed.

Figure 44 Stress relieving two pairs of parallel spokes

The other method to stress the spokes is to place the wheel flat on a hard surface and press down on the rim diameter with your hands at several different places before turning the wheel over and repeating the process. You are advised to rest the hub on a block of wood that is bored out so the hub rests on the hub flange since pressing on the axle could damage hubs with cartridge bearings, cup and cone bearings will be okay because they are designed for axial loads. I'm describing it here because I expect you believe this is a required operation but it's purely optional. You are stressing the *upper* spokes in the region where your hands are which become tighter during this operation. The lower spokes lose tension and any residual twist in them is released and you will hear a tinkling sound as they unwind (but they should have little or no twist in them if you have tightened the spokes correctly and compensated for the spoke twist). Many people attribute the tinkling sound to the stresses being relieved and take comfort when they hear it. I'll sometimes use this method in addition to the previous squeezing technique just to see what happens to the trueness. I'll squeeze several times during a build and only rim-press once right at the end of the build. There's some debate about which is the best technique, Mavic goes for this pushing on the rim and other highly respected builders (Jobst Brandt) squeeze. I'm a squeezer.

Complete the final tensioning

How tight should the spokes be and do you require different tensions for different end uses e.g. touring, racing and off road? It is obvious there should be sufficient tension to prevent the nipples from working loose and it is also important to note that tighter spokes make a stronger wheel. You will not obtain a softer ride by using lower tensioned spokes the only effect being a less strong wheel, so for *all* wheels there is only **one** tension and it's tight.

There is a decent margin between sufficiently tight and theoretically the tightest the spokes can be and as long as you drop into this zone you will have a good reliable wheel.

The term *tight* though is ambiguous and difficult to define easily. You cannot use tone to quantify tension because tone only identifies relative differences in tension between spokes on the *same wheel* i.e. one spoke is tighter than or slacker than the other, there is no correlation between the sound it makes and whether it is sufficiently tight, plus different sizes and types of spokes make different sounds. Neither should you be guided by the resistance in turning the spoke wrench since this is influenced by many factors such as friction in the components (e.g. aluminium or brass nipples), type of rim eyelets, the size of the wrench and the available leverage and how strong you are.

For example the lowest tensioned wheels I build use lightweight Notubes ZTR rims with a recommended tension of 95kg (930N) and all other rims I build are 130kg (1250N) and each wheel performs fine.

The best place to start when judging the correct tension is to examine a similar wheel you know to be good and reliable and compare the spoke tension to the one being built (similar means the same number and type of spokes - plain gauge or butted, and a similar type of rim).

To help you build up your own knowledge and understanding always take the opportunity to check the spokes in other people's wheels but do not assume those wheels are correct since it is always easier (and quicker) to build a wheel with spokes at a lower tension and you will come across many examples of these. When doing race tech support the vast majority of wheels I see are under tensioned poorly built wheels, yet even with low tension they perform their function well but are prone to going out of true.

It's better to deflate the tyre on your reference wheel since an inflated tyre reduces the spoke tension slightly. Choose a pair of almost parallel spokes on the reference wheel (on the same side) and flex them at mid point and make a comparison with your own wheel. Do not compare the tone of the spokes to those in the comparison wheel, this tells you nothing unless it's a brand new wheel (no sound deadening grime on it) of the same specification. As you build more wheels you just get to know what is tight and what is slack. Note also that the relative spoke tension is different for the front, rear and rear drive side and also both sides of a front disc hub, so only compare like with like.

Can they be too tight – yes, but it's not the spoke that is the limiting factor because spokes have an easy life in the wheel and do not reach anywhere near their limits of tension (assuming you are using good quality spokes). The limiting factor is the rim that is subjected to extremely high compressive forces and it can only take so much before it starts to lose its shape.

When talking about the rims compressive limit it does not mean the spokes are pulling out of the rim because that won't happen. That's why simple pin jointed rims are strong, it's the compressive force that holds the joint solidly together and why a welded joint offers no benefit to strength. See my discussion on rim compressive force on page 12.

As you tighten and stress the wheel there should be little change in lateral trueness. If it goes significantly out of true after stressing in the latter stages of final tensioning then it's likely the spokes are too tight and the rim has reached its compressive limit. In this case it is wrong to correct it by further tightening so back off all spokes half a turn then make minor adjustments to finish the wheel.

The main variable here is the type of rim, the narrower section larger diameter road rims cannot take as much tension as a smaller diameter mountain bike rim, similarly a rim with a larger cross section such as aero rims can take higher spoke tensions. You will never buckle a mountain bike rim through spoke tightening because they are just too strong. On a mountain bike rim the spoke twist is a good way of judging when to stop and if a well lubricated spoke twists a third of a turn then it's pointless going further, on a road rim watch out for the lateral trueness as your indicator.

A special tool exists for measuring the spoke tension, please see my discussion on *tensiometers* on page 38. When using a tensiometer you check the spoke tension in the tighter side of the wheel and the other side just happens to be whatever it is in order to ensure the correct wheel dish. The most important feature of a reliable wheel is *equal spoke tension* and this is easily achieved without a tensiometer.

For the same rim the spokes in a 32 spoke wheel will be tighter than those in a 36 because the total tension in the wheel will still be the same but distributed over less spokes in the 32 spoked wheel and hence they are tighter.

You need to keep going around the wheel tightening each spoke half a turn until you consider the wheel is sufficiently tight, be very mindful of spoke twist. With each rotation of the wheel and after each stressing operation always check and adjust the lateral trueness and check the dish.

As you tighten or stress the spokes do not look into the rim channel. A spoke that breaks can fly out of the rim and hit you or someone else in the eye.

The radial trueness is not going to wander any great deal and it should maintain the accuracy you achieved in the previous stage, if necessary make any small adjustments to radial trueness before you approach the final tension. If there are large errors in radial trueness then this is not the stage for fixing them, in fact it will not be possible to. Once the spokes are approaching their correct tension then it will be too difficult to correct any large errors (radial, lateral or dish) in which case it is necessary to slacken off all the spokes a little and start the tightening process again.

The last adjustment to lateral trueness will just require a fraction of a turn on the occasional spoke.

The wheel is finished.

The stages for building the wheel are summarised on page 110 and will serve as a reminder when building future wheels since you may be tempted to skip the detail presented in this section and miss out a vital operation.

Wheel tolerances

It should always be your aim to build perfectly true wheels every time, but for new wheel builders and even for experienced builders like myself a wheel with zero errors is impossible to achieve. I know some people brag about how true they get a new wheel but my stock answer is “give it to me and I’ll ride it for 100 miles, then we’ll place it back in the truing stand to see how true it is”.

So how good must they be? As with all manufactured items there are acceptable errors or tolerances. A wheel that is built to a tolerance and stays within tolerance is far superior to one that is perfect in the truing stand but goes significantly out of true after being ridden a short distance and needs constant attention.

When viewed in the truing stand or using the dishing gauge any errors will always appear greatly exaggerated as your eye homes in on massive zones of light between the wheel and reference points. Careful measurements will show that you are often dealing with very small dimensions and

with a tyre on and the wheel placed in the bike the errors will be insignificant and will certainly go unnoticed by the rider.

The following measurements are a guide to good trueness, as you become more proficient in wheel building you will continually try to improve on these: lateral trueness 0.2mm, radial trueness 0.5mm, dish 1mm (difficult to measure so use a visual assessment). With dish the 1mm error is distributed 0.5mm either side which is insignificant and is far more accurate than the likely error in the bike frame and dropout alignment.

Optionally, use feeler gauges (obtainable from engineering suppliers) to measure the gap between the reference points and the rim when checking lateral and radial trueness. Once your eye is in tune then a visual inspection will suffice, if it looks true then it will be true. I used feeler gauges once, just to see what a 0.1mm gap looked like and from then on is was just a visual inspection.

The vast majority of rims (purchased new) can be easily built to these tolerances or better. Some rims will be more difficult to build and an example is the lightweight mountain bike rims from Notubes. They take longer to build and I never get them as perfect as I'm accustomed to but as a built wheel they perform extremely well.

This leads to the general question, am I being too much of a perfectionist. It's always good to set your standards high and this had to be the case when building mountain bike wheels before disc brakes became popular. With rim brakes they *had* to run true (and stay true) otherwise even the tiniest amount of grit on the rim would result in an annoying grinding sound as it scraped past an out of true region. The same situation is found on close running brake blocks on road wheels. The advent of disc brakes means a wheel can run out of true without any noticeable effect but that's not an excuse for sloppy building. So my advice is to build them true and see how true they remain, that's the sign of a good builder.

How long should it take

There's no answer to this because it takes as long as it takes to get a good reliable wheel. You are aiming to build a wheel that you are satisfied with. If you build a wheel that meets your requirements then you have a quality wheel and the time it took to build is not important. My advantage is that I know when to stop, I know when no more effort will make the wheel any better, but that comes with experience that you will start to gain. Plus I've had lots of practice and know how to build a wheel without consulting a book every few minutes and I *never* turn the wrench the wrong way. Don't be impressed by anyone who boasts about how fast they can build a wheel because there's a good chance they are building poor wheels that require time consuming maintenance to keep them running.

Re-tensioning wheels

Once built you should never have to touch your wheel again which means you **never have to re-tension it** after a few rides. Re-tensioning wheels is folklore and perpetuated by discussions on the Internet. There may be some value in re-tensioning wheels but this only applies to wheels built by other people, particularly from discount wheelbuilders because it's easier and quicker (cheaper) for them to build at substandard tension, plus they may not appreciate what goes into a well built wheel and as a result the wheels may be too slack. I'm not going to describe how to correct a wheel

built elsewhere but if you understand the building techniques previously described you will be able to correct any faults. In summary and assuming they've got the spoke lengths correct (if they were too long you have little chance on tightening them more) you will equalise the spoke tensions, stress relieve the wheel, correct the trueness then tighten to the correct tension. All this additional effort is normally found in a well built wheel and is why they cost just a little more, however you can't see this hidden detail and the most important factor for people buying wheels is price. With a choice of apparently identical wheels (using the same components) they will buy the cheaper option and are conditioned into thinking it needs re-tensioning then they pay someone to do it! I have never re-tensioned any of my wheels.

Testing your wheel

So barring any accident damage the wheel will stay as good as the day it was built to the day the rim wears out through natural wear and tear. However, in your early wheelbuilding days I propose the following test routine.

For each newly built wheel you should adopt a standard test routine that will enable you to monitor your progress as a wheel builder. The further you get down the test regime the better the wheel builder you are likely to be. At each stage you should check the lateral trueness because it will serve as a useful indicator of the general state of the wheel. A typical standard test would be :

1. The first few pedal strokes.

If you hear a tinkling sound then the spokes had some twist in them that should have been released in the building process. The spokes should not make a sound. The sound comes from movement of the nipple at the rim interface or within the spoke threads. That movement will likely change the nipple thread engagement and cause the wheel to lose a bit of trueness.

2. After a short distance of gentle riding.

If the wheel loses its trueness then the spokes were not properly stressed during building. Spokes may also have had unequal tensions, insufficient tension or far too much tension for the particular rim.

3. After a few rides.

If this is your first wheel you may have to make some *minor* adjustments (usually tightening one or two spokes at most), this is acceptable and should only need doing once. What is not acceptable is if you are constantly making adjustments in which case you will have to re-examine your building technique. If you cannot build a reliable 3 cross wheel with 32 or 36 spokes then it is pointless trying wheels with less spokes or any other lacing pattern. Learn the basics first.

4. Problems galore!

If you do experience a lot of problems when using your wheels then make sure they are suitable for the intended purpose, it would be unreasonable to expect a lightweight road rim with 28 spokes to withstand rough use by a strong rider or carrying heavy loads, or a lightweight mountain bike rim subjected to high drop-offs and poor landings.

Related topics

The previous instruction is all you need in order to build perfect wheels. I'll discuss here a couple of minor topics that may prove useful.

Spoke thread preparations

Many of the spoke manufacturers are advising the use of adhesive or other spoke preparations on the spoke threads to prevent the nipples coming loose and some manufacturers go further and make special self-locking nipples such as the *DT Proloc*, whereas many wheel builders (myself included) take the opposite view and use oil and never use Proloc nipples.

Okay, I'll own up. On my shelf is a bottle of *Loctite 222* threadlock adhesive which is a low strength standard engineering product for securing threaded fasteners. It has lubricating properties so achieving correct spoke tension is easy and it's also a non permanent adhesive which means you can still adjust the nipples if the wheel requires truing at a later date. Even if the bond is broken the product will continue to do its job keeping the nipple secure, not so much from adhesion but from the residue of the Loctite within the threaded joint. For more information go to www.loctite.com and do a Data Sheet search on 222. I use this product on mountain bike *customer* wheels because these wheels take a few knocks and a local flat spot in the rim could cause a loss of tension in the spoke and a chance for the nipple to unscrew, and then the neighbouring spokes would lose tension leading to a generally loose and unsound wheel. The threadlock keeps things in place and ensures the wheel stays good for as long as possible. Remember, I'm selling wheels to remote customers who have no wheelbuilding skills so I do everything possible to ensure their wheels last as long as possible.

Loctite 222 will start to cure after 30 minutes so to get the most benefit you need to be building the finished wheel in well under one hour. For completeness this is how I use Loctite 222 (for spoke manufacturers and others who produce their own thread preparations follow their instructions).

- Prior to lacing **do not** put oil on the spoke threads. Oil the rim eyelets as described.
- After lacing place a small amount of adhesive on each of the visible threads. Spin the wheel in the truing stand to force the adhesive over all the exposed thread and into the nipple.
- Build the wheel as described.

My own personal wheels are built with oil and you should be using oil for *your* wheels (including mountain bike). You will be monitoring your wheels and be fixing any problems resulting from riding incidents before they become serious. Chances are you will never have to touch them.

Mountain bikers reading this, perhaps using wheels built by less competent builders already know that fixing wheels appears to be part of the game, but a good strong wheel built using oil will sort out most things, especially if you are accustomed to the loose shop bought variety.

If you do encounter problems with your wheels built using oil don't immediately reach for adhesive or Proloc nipples as a magic cure. First make sure your wheel has even tension, sufficient tension and ensure you always release the spoke twist during building. If you dive straight in and go with adhesive without rectifying your building technique all you'll end up with is a poorly built wheel held together with adhesive that *may* perform a little better than previous.

Aligning the hub label with the rim valve hole

I didn't mention the procedure of aligning the hub label in the lacing section because I didn't want to unnecessarily confuse you on your first wheelbuild. It's not a critical operation but it's something I always do.

This is essentially a cosmetic exercise and has no effect on the wheel but is generally recognised as a sign that the wheelbuilder has shown attention to detail. Few people do this mainly because they do not know how or more likely they are not aware of this detail.

It does give some minor benefits. If the hub label points at the rim valve hole it makes locating the valve hole easier. The obvious although minor benefit is when you are installing an inner tube because it's easier to find the valve hole. Where I find it helps is when tightening the spokes because it's a quick method of finding the valve hole which is the starting and end point in a tightening sequence.

Look at the photograph of the hub in Figure 45 and imagine a rim superimposed with the valve hole at the top of the page i.e. pointing at the hub label, also refer to the *lacing step 1* on page 42 and consider the first spoke you are placing into the hub.

Taking the simple situation of a radial wheel, if the spoke leaves from hole 0 in Figure 45 and enters the rim hole directly to the left of the valve it's obvious the correct alignment will take place. If you were building a 3 cross wheel then the spoke would be placed through the hole marked 3 and this is your starting spoke in the lacing procedure in *lacing step 2* on page 43. The same procedure applies if you were building 1, 2 or 4 cross, just select hole 1, 2 or 4 and hole 0 for a radial wheel.

In summary look at the centre of the hub label, identify the spoke hole to the left (position 0) then count back the holes appropriate to the number of crosses being built and ensure this spoke is the first one you place in the rim.

Figure 46 shows the completed wheel (a tubeless rim) with the valve pointing at the hub label, and also note that the rim label is readable from the drive side – cosmetically perfect!

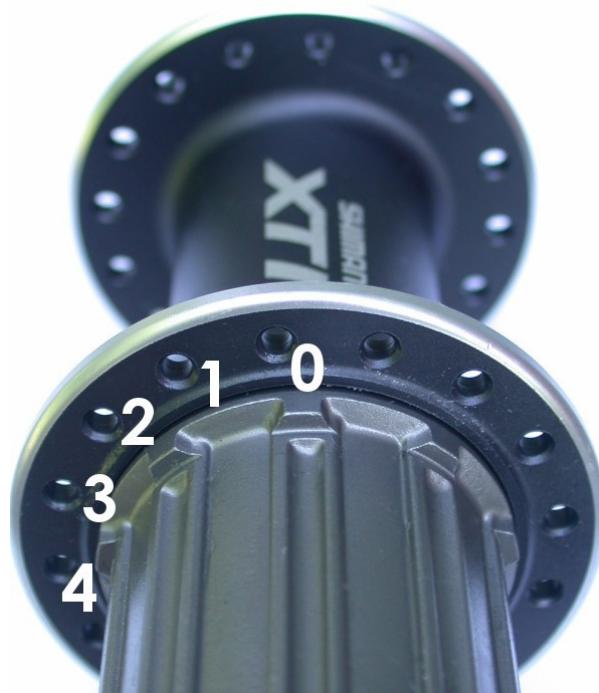


Figure 45 Aligning the hub label – the first spoke.



Figure 46 The aligned valve and hub label.

Building a Mavic UST rim

Building a Mavic UST tubeless rim requires some additional tools and procedures and it's not exactly the same as previously described for building a standard wheel. This rim does not have standard eyelets, the eyelets are only drilled through the lower rim surface with separately installed cups to support the spoke nipples. The photograph in Figure 47 shows a cross section of a Mavic UST rim with a nipple cup in place.

Mavic will supply the nipple cups and a building guide with the rim and their procedure mirrors mine.

Building a UST rim will take you approximately twice as long as a conventional rim but many people have successfully built a UST rim as their first build.



Figure 47

Tools

You need to purchase a special wrench for the installation of the nipple cups. Two common wrenches are available, one from Mavic and one from Park Tools (code SW-13). My preference is for the Mavic tool shown at the top in Figure 48 because it is faster to use although the Park wrench is just as good, just a little slower to use.

Note the tightening direction shown on the Mavic wrench (unlock=unscrew), the nipple cups have a **left hand** thread. Remember this if you ever have to dismantle a UST rim.



Figure 48

My example wheelbuild

In my example I'm building a Mavic XM819 UST rim with a Hope Pro 2 rear hub, 32 holes built 3 cross. Although Mavic say use 16mm nipples I use 14mm, don't use 12mm nipples because there's a danger of the nipple falling into the rim section, plus there's minimal engagement on the spoke wrench.

Work out the spoke lengths. If you use my calculator at www.wheelpro.co.uk/spokecalc/ and select these components it gives the lengths 258 and 259. Those lengths are okay for 12mm nipples but because I'm using DT 14mm nipples I need to adjust the lengths (for reasons why see page 95) so I subtract 1mm to get 257 and 258. These are the ideal lengths but I could have gone 258 on both sides.

Lacing

Do not apply oil to the spoke threads or nipple cups, **lace everything dry**. The reason is you don't want to get any oil on the nipple cup threads otherwise the adhesive applied later will not work too well.

The lacing procedure is virtually the same as shown in the building section on page 42. So, place 8 spokes through the hub and taking each spoke in turn place a nipple cup over the spoke and screw a nipple onto the spoke. Thread the nipple cup into the rim just one turn remembering that it is a left hand thread.

The spokes will not protrude through the rim as shown in *lacing step 2* on page 43 and you need to place the spokes in a tangential direction soon after you start lacing. So after you've placed 3 spokes rotate the hub in the correct direction ensuring the spoke adjacent to the valve hole slopes away from it, see Figure 49 with the valve hole at the top. Then continue to fully lace the wheel as previously described for lacing a conventional rim.



Figure 49 The first 8 spokes

Glue and tighten the nipple cups

Mavic recommends Loctite 243 and that's what I use and a small 10ml bottle doesn't cost much. With the wheel placed in the truing stand put a small drop of 243 on each the exposed threads of the **nipple cups**.

Then tighten the cups in place. Mavic say use a torque of 5.5Nm, I'm not sure what that feels like but using the Mavic wrench I give it a firm twist (bit ambiguous), watch out if using the Park wrench because there's more leverage on that one.



Figure 50

As a test I tried a lot of force by over tightening a nipple cup on an old rim and it failed with the nipple cup shearing. It took some effort and was not possible with the Mavic wrench and I had to use the longer leverage of the Park wrench. This nipple cup was the standard issue one that came with the rim, Mavic also make a lighter after-market aluminium version which will no doubt shear with less force than I used here.



Oil the nipples and spoke threads

After tightening the nipple cups you may find the spoke nipples have tightened themselves a little, in which case you might need to loosen some of them to ensure the spoke threads are visible.

Place a drop of oil into the nipple cup and onto the spoke threads. I'm using standard motor engine oil 5W-30 contained in a handy squeeze bottle from an old Hayes disc brake bleed kit.

Give the wheel a spin to distribute the oil.



Figure 51

Tighten the spokes to the same engagement point

Previously we used the nipple driver to take out the initial slack but this is not possible on the UST rims. Use a spoke wrench to tighten the nipples just enough to cover the exposed spoke threads.

I use a Park four sided wrench (SW-40) for this task because my favoured Spokey wrench hides the nipple and makes sighting difficult. As you can see I've modified my Park wrench. I reduced the depth of the jaws to make the nipples more visible (original thickness 5mm, mine 3.5mm). I also cut out the plastic grip and filed a small semicircular groove into the underlying metal because the original design fouled the spoke and made placing and removing a little too slow for my liking. If you tighten the nipples with the spoke in a more horizontal position the modified Park wrench spins real easy as the spoke rests on the cut-out.



Figure 52

Continue to build the same as a normal rim

I then pick up my Spokey and continue the tightening process. In the example I'm building here I gave each nipple 3.5 turns to take out the slack and get a little tension in the spokes. Next task is to get it running laterally and radially true. At this stage it will never be as true as a normal rim using the nipple driver because the nipple driver is very accurate at screwing down the nipples to the same engagement point so expect some error, mine was 4mm out of true laterally and about 1mm out in the radial direction.

Spoke length check

How do you know the selected spokes were correct? After you initially adjust the nipples to cover the spoke threads keep a count of how many subsequent turns you use in the build process. Then take a spare spoke (with the same length nipple) and screw the nipple to cover the threads then turn it the same amount you used in the build process and see how the spoke end finishes up in relation to the top surface of the nipple. With 14mm nipples it should be about 1mm beneath the top surface. In my build here the spokes had 6 turns and the spoke lengths were a good choice and confirmed that I could have gone 1mm longer as an alternate length.

Warnings

For all the wheels you build

If you have ANY doubts about how good your wheel is from a safety point of view DO NOT RIDE IT.

Instead get it checked by a competent cycle mechanic.

Your competence as a wheel builder should never be assumed greater than it actually is. At all times remember that for a given rider and riding conditions **do not build anything that is potentially dangerous.**

Without specialist test facilities there is little the builder can do to confirm any theories other than ride the wheel and see what happens. This is not a wise choice. I don't risk my health and that of others and neither should you.

Braking hard at the bottom of a long fast descent is not the time to find out any deficiencies in your wheel design or building technique.

Chapter 5

Repairing

It is surprising the amount of wheel damage that can occur before it becomes apparent to the rider and unless you inspect your wheels regularly many damaged wheels will go unnoticed. It is important to check your wheels to identify any potential problems and take corrective action before they develop into something more serious. Wheels do not need continual maintenance and a well built wheel will be good from the day it was built to the day it wears out through natural usage requiring little or no attention.

The front wheel should not suffer too many problems, it carries less weight and rim damage is usually reduced by the rider guiding the front end around potholes or other obstructions whilst the rear wheel usually hits whatever you are trying to avoid.

Checking the wheel

Checking the wheel is simple enough :

- Spin the wheel in the bike and check its lateral trueness using the brake blocks as a reference, for disc brake wheels temporarily attach something using tape to act as your reference. Trueness is a good indicator of the general state of the wheel, if it's badly out of true then something is wrong, a loose or broken spoke or a broken hub or rim.
- Wipe the surface of the rim and look for uneven markings and cracks both on the braking surface and other regions of the rim particularly around the rim eyelets.

Loose spokes

A wheel losing some of its lateral trueness is usually caused by a spoke coming loose. Perhaps you've hit the rim on some rough ground and put a small flat spot in the rim, even a minor knock can reduce the rim diameter a tiny fraction to cause a spoke to lose tension. It is better to tighten a loose spoke as soon as possible because adjacent spokes will start to lose their tension leading to a rapid deterioration of the wheel (see Lateral truing later in this section). Check that the spoke is not coming loose through a rim failure where the rim is cracked and pulling apart in the region of the eyelet (see Figure 56, page 76).

Damaged spokes

These are spokes that are still in one piece but have obvious damage such as kinks or surface indentations. A few indentations along the length of the spoke from stones hitting the wheel won't cause any problem, remember that Sapim stamp SAP into their spokes close to the elbow without weakening the spoke in any way (see Figure 10 on page 17). The one you should avoid at all costs is the chain drop.



Figure 53 The chain drop

Dropping the chain between the largest rear sprocket and the hub whilst changing gear, or bouncing it off on rough ground will cause the chain to gouge the spokes close to the spoke elbow. This will cause a degree of out of trueness and the weakened spokes will eventually break through accelerated fatigue failure. If you regularly damage your spokes in this way then consider fitting a plastic spoke protector and make sure your derailleur is correctly adjusted. It's a pity spoke protectors have an un-cool image because they are a piece of ugly cheap plastic often found on entry level bikes. Now if someone made a nice high tech version then everyone would rush out and fit one and we could forget about chains harming our wheels.

If you have dropped your chain replace any severely damaged spokes or inspect them regularly to see if they break, others with only slight damage along the length can be left alone. In Figure 53 the chain hit the shoulder of the lightweight double butted spokes of the 2mm 1.5mm type. Two spokes snapped immediately and the others were severely gouged, needless to say his race was over.

Spoke breakages

A spoke can break for no apparent reason with a clean break across the spoke elbow. This is due to a fatigue failure in the spoke material caused by the fluctuating load on the spokes as the wheel rotates. A fine crack will appear and start to propagate across the spoke over a period of time ultimately leading to a fracture. Spokes do not break due to the power exerted by the rider, it is because the spokes are already in a severely weakened state due to fatigue cracks and an extra push on the pedals will be sufficient to snap the un-cracked remainder of the spoke. It tends to occur at the spoke elbow because this area has the greater concentration of stress. This type of break should not happen in the first place and can be virtually eliminated by using the correct building technique described in the *Building* section (aligning the spokes and stress relieving).



Figure 54 Fatigue crack

If a spoke has failed through fatigue then carefully examine the other spoke elbows on the same wheel and you may see hairline cracks appearing on apparently sound - their days are numbered too. In Figure 54 the wheel had a broken spoke which was obviously a fatigue failure and on closer inspection all the remaining spokes had hairline cracks. If only one spoke has broken and no obvious signs of other fatigued spokes then replace it but mark it with tape and monitor the wheel's progress. If other spokes start to break then it may be worthwhile rebuilding the wheel with a complete set of new spokes. With all the care you lavish on your building you cannot legislate for a manufacturing defect in the spoke material that subsequently causes it to fail, although this is very rare these days.

The **wrong** advice people give to cure spoke breakages is to use bigger spokes, either going to plain gauge because they *look* stronger, or using larger diameter spokes that usually go by the name of tandem spokes with a diameter of 2.3mm at the hub end rather than the standard 2mm. The correct advice, assuming you've built a wheel using the techniques outlined in this book, is that very occasionally a spoke will snap and just accept that it was unlucky and it had nothing to do with rider weight or rider strength or riding on rough ground. Rebuilding with bigger spokes achieves nothing.

Rim wear and damage

Rims eventually wear out and they have a limited life and like tyres they are consumables. You are going to be spending more on tyres than rims so it's not a major issue throwing out an old rim. Remember that the same spokes will be used with a replacement rim of the same diameter (ERD, see measuring rims, page 101) so keep a couple of spare rims in your garage. It's nice to know that you can wreck a rim on a Saturday ride then pop a new one in ready for Sunday.

Some aspects of cycle sport such as off road riding are hard on rims so it may be advisable to use a cheaper rim i.e. good quality but no expensive features such as surface treatments and fancy colours and replace it when the expected damage occurs. Since you will be doing the replacement work yourself the only cost is that of a new rim every now and then.

Rim damage is the most common thing to look out for on a wheel so it pays to check them regularly.

Look out on older rims using rim brakes for concave sides, cracks and non uniform surface markings on the braking surface which suggests the metal has almost worn through. In Figure 55 the sidewall of this rim was so thin it led to a failure whilst riding the bike that caused a section going around one third of the rim to rip off instantaneously. When this happens it is very dramatic and often accompanied by a loud bang and would be very dangerous if you were riding fast at the time, plus it means your days riding is over. So check your rim for wear and if in doubt replace it.



Figure 55 Worn out rim!

Cracking of rims around the spoke eyelet where the spoke is pulling itself out of the rim is not a result of excessive spoke tension, it is usually the result of a poorly designed rim that contributes to fatigue cracking. A rim that has cracks will need replacing immediately. The crack in Figure 56 was interesting because this was a mountain bike rim that I'd never had any problems with and there were several cracked eyelets on this one. It turned out that the customer used his mountain bike for commuting to work and used narrow section high pressure tyres and after 3000 miles the cracks started happening. The rim manufacture said the rim was not designed for this type of use and that under normal mountain bike conditions using wide low pressure tyres it would be fine (which it was). The rim was replaced by a stronger one, i.e. one that was heavier with more metal on it – the original seen here was a very lightweight XC rim.



Figure 56 Fatigue crack in rim

Check for any flat spots resulting from impacts and if any have caused the spokes to lose some tension then tighten them up.

Although the flat spot will remain in the rim it is unlikely it will be noticed whilst riding so there is usually no need for anything more elaborate. If the impact has been severe and you are using rim brakes then check that the local flat spot does not cause the brakes to chaff the tyre causing an early tyre sidewall failure, and if it is a severe flat spot you may have insufficient threads on the spokes to do the necessary adjustment.

Beating out indentations or trying to bend a crash damaged rim back into shape is troublesome and can often make things worse, at most it will only be a temporary repair until the rim can be replaced. In general just keep an eye on the rim and if it appears too far gone and it starts to affect the ride quality or has safety implications then it is better to replace it. It is perfectly acceptable to use the same spokes if using a similar rim.

Hub damage

Not a lot to say about hubs they just seem to go on working. Don't forget to look after your bearings and renew any worn out *sealed* cartridge bearings, remember that these are *sealed* to keep the grease in and not water out so if you ride in wet conditions or jet wash your wheels (don't) then water will get in and contaminate the grease and rust will set in. To prolong the life of cartridge bearings you can periodically prise out the plastic seal and insert some fresh grease then push the seal back. For cup and cone bearings get yourself some cone spanners and periodically back off the cones and push some grease in. When tightening the cones don't do them too tight because when placed back in the bike the action of the quick release compresses the axle and tightens them a little more.

Dismantling an old wheel

There are three reasons for dismantling a wheel and each has a particular technique for dismantling it as described below. Always remember to remove the rear cassette and any disc brake rotors first otherwise you will have difficulty removing them later.

1. Replacing the spokes

The spokes may be damaged through a poor initial wheel build i.e. you are continually replacing broken spokes, or you have damaged them yourself such as dropping the chain off the largest rear sprocket and gouging them. In both cases it is usually better to rebuild the wheel with new spokes using the existing hub and rim.

Before dismantling examine the spokes in the wheel and see if they were the correct length, ideally they should finish flush with the top surface of the nipple as a maximum. Any spoke length errors can be compensated for when purchasing the new spokes so do not perpetuate any errors by using the same length replacements. My advice would be to dismantle the wheel and measure the hub and rim and work out your own spoke lengths for the rebuild. Trying to accurately measure the length of used spokes is not that easy.

Start dismantling the wheel by using the wrench to back off the spoke tension a little at a time going around the wheel backing off a turn on each nipple, then a couple of turns, going around the wheel several times until all the tension is released. You then have the option of using wire cutters (see Figure 57, page 78) to quickly take out the spokes or continuing with the wrench and nipple driver to completely dismantle the wheel.

If you do decide to cut out the spokes then **ALWAYS** back off all the spoke tension with the wrench and **ALWAYS** keep the rim tape on whilst cutting because you **NEVER** want a spoke to fly out of the rim and hit someone (or yourself).

Clean the hub and rim ready for rebuilding. When rebuilding I always ensure the spokes are placed through the hub so that the spoke elbows match the previous indentations in the hub flange. Putting the spokes in a different orientation will look cosmetically poor, see the discussion on spoke orientation on page 88.

Replacing just a single spoke is easy but don't worry too much about bending the spoke along its length as you push it through and work it around the opposing spokes. It may look banana shaped but you can bend it back again with no harm whatsoever to the spoke.

If you replace a single spoke then oil the rim eyelet and spoke thread, lace the new spoke in the wheel and attach a nipple. It's better if you mark this spoke because it's usually only this spoke that requires tightening and marking it makes it easier to locate. Take up the slack then *Align the spoke* (page 53), then tighten and true and finally stress the spoke (page 59) squeezing the two pairs of parallel spokes that contain your newly placed spoke.

2. Replacing the rim

The hub and spokes are perfectly okay but the rim is in a poor state and needs replacing. We are assuming here that the replacement rim is the same or is another brand or model that has the same effective rim diameter (ERD) in which case the existing spokes will be the correct length and can be reused (see the discussion on reusing spokes below). If you are rebuilding using a *different* rim to the original then measure the diameter of the new rim to see if the existing spoke lengths are suitable (see measuring rims on page 101). This assumes you know the diameter of the old rim,

either from a reliable data source or if it was previously built by yourself you measured it prior to building it. I always recommend measuring hubs and rims prior to building and keeping reference notes for future use.

There is no need to completely dismantle the wheel and there are benefits from not doing so. Oil the inside of the eyelets on the new rim. Back off the spoke tension in the wheel using the wrench by going around several times loosening each spoke. Then tape the new rim to the side of the old rim so that the valve hole positions are identical. Now transfer each spoke across to the new rim i.e. take out the nipple and replace it in the same hole in the new rim, dab a bit of oil on the spoke thread then re-attach in the new rim a couple of turns. Doing it this way has the advantage that you do not change the orientation of the spoke elbows in the hub flange. The spoke elbows will have taken a particular bend and it is important to replace them in a similar fashion in the new wheel and transferring them across does this automatically, i.e. they are never removed from the hub. Just consider the hassle if you completely dismantled the spokes from the hub. You would need to segregate all the spokes and for a rear wheel that would be four bundles : inside (drive); inside (non drive); outside (drive) and outside (non drive), a standard front wheel will have two sets: inside and outside (and a disc front wheel four sets), then you'd need to ensure they went back in the same side they came out of.

There is a case for cutting out the spokes and it's purely a commercial or time related decision because cutting out the spokes is a lot faster than the transfer method described above. An example would be doing race service where a rider requires a new rim quickly. Given the chance I always reuse spokes as previously described – even for professional riders.

If you do decide to cut out the spokes then **ALWAYS** back off all the spoke tension with the wrench and **ALWAYS** keep the rim tape on whilst cutting because you **NEVER** want a spoke to fly out of the rim and hit someone (or yourself).

For information, the cutters I use are the C.K. model 4371A because standard pliers or other more delicate wire cutters will struggle with tough stainless steel. These go through a spoke with little effort. In the photo they look like massive bolt cutters but in real life they are a small single handed tool.



Figure 57 *The last resort!*

3. Replacing the hub

Whatever the reason for replacing the hub, the existing spokes and rim will be used for rebuilding with the replacement hub. The existing spoke lengths will be suitable providing the new hub has a similar geometry. A chunk of material ripping out of the hub flange may be covered by the manufacturer's warranty so check first before purchasing the replacement.

Again back off the tension as described and continue to remove the spokes from the **rim only** leaving the spokes still in the hub. The reason is that they are nicely segregated and when you come to lacing the new wheel just pull a spoke out of the appropriate side (it helps if you gently shake out the weavings first), the spoke elbows will have taken a particular bend and it is important to replace them in a similar fashion in the new hub. Again, the old brass nipples should be re-usable but old aluminium nipples will ideally need replacing.

Reusing spokes

When replacing the rim or hub described above it is normal to reuse the original spokes. A set of spokes will last a very long time and will easily outlast many rims so there is absolutely no reason to throw the old spokes away because using new ones will offer no advantage. The old nipples are fine too providing they are brass. I am not keen on reusing aluminium nipples.

I only reuse the spokes if the original wheelbuild was my own because I would know the spokes were good quality and they were not previously damaged through bad building. Any other previously used spokes with an unknown history would be thrown away because I'm building wheels for other people (customers) and need to guarantee everything I do, however if the spokes in your old wheel previously built by someone else (or some machine) have proved reliable then you may as well reuse them.

If reusing the same spokes then **before** you dismantle the wheel examine the spokes in the wheel and see if they were the correct length, ideally they should finish flush with the top surface of the nipple as a maximum. If the previous builder has made a large error, say protruding through the nipple a couple of mm then you might be better using new spokes of the correct length.

When rebuilding a *dished wheel* and reusing someone else's spokes you are advised to check the dishing early in the build sequence and make any compensations for less than ideal spoke lengths. For example the previous builder could have used the same length spokes on either side and the resulting dishing error would be larger than normal so it's best adjusted while the spokes are not too tight.

Lateral truing

If the wheel is excessively out of true due to a *riding incident* that results in some excessive warping then no amount of spoke tweaking is going to cure a bent rim. Going through a corner with a major front end sideways slide (i.e. you made a mistake in cornering) puts a massive sideways load on the wheel and even the best made wheel can fail. You can try and flatten it a little by pressing down on the circumference of the rim then get some more trueness by adjusting the spokes but your spoke tensions will be way out with some excessively tight ones and some very loose ones. At best you want to get something that you can ride carefully home and put a new rim on.

So the procedure described here is for sorting out a wheel that has lost some of its lateral trueness i.e. it has a side to side wobble that turned up from **normal riding**.

This exercise can be carried out on the bike using the brake pads as a reference or by taping a reference pointer onto the fork/frame, or more conveniently placed in a truing stand, there's no need to remove the tyre. Applying a drop of light oil where the nipple protrudes from the rim will help, I don't always do this but it sometimes helps on old wheels.

Spokes **do not** tighten themselves when the wheel is used so it's not usual to loosen spokes to correct an out of true wheel.

The out of true is usually caused by one or two spokes losing some tension and quite often it's only one spoke.

Spin the wheel and note the point of maximum deviation.

Identify the offending spoke which will be on the same side of the wheel in the region where there is maximum deviation *away* from the reference point. Spokes with a lower tension will make a dull sound in comparison to adjacent spokes (on the same side) when plucked close to the nipple.

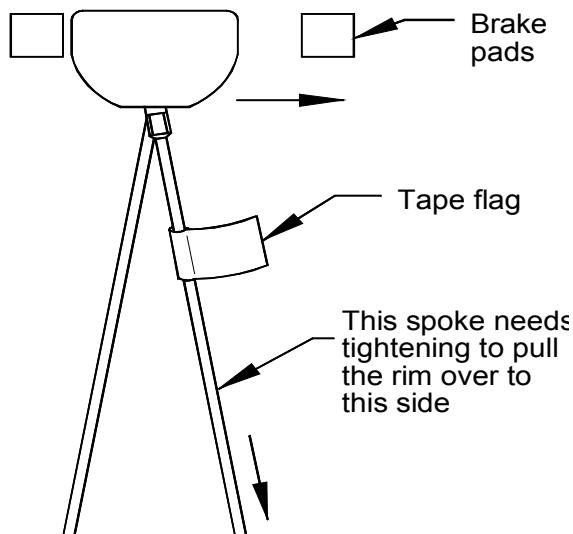


Figure 58 Adjusting lateral trueness

The spoke will require tightening to pull the rim back towards the central (true) position. Before using the wrench make sure you know which direction to turn it. It becomes second nature after a time but it can trap the unwary who sometimes turn it in the opposite direction which makes the trueness even worse.

The use of tape flags was described within the discussion on *Spoke twist* on page 58 and it should be read again since flags are equally important here to check if the spoke is twisting rather than tightening. The flag serves an additional purpose here, it marks the spoke to adjust and if over tightened causing out of true in the opposite direction, you can easily locate it and back off a little tension. Identify the likely spoke and apply a flag by firmly wrapping a piece of tape over the spoke to prevent it flying off.

Note, whilst tightening, the spoke friction may suddenly release with a crack with the flag snapping back to its original position and the spoke will be tightened an amount based on how far the wrench was turned. You may find this condition on well-used wheels where the nipple has become firmly attached to the spoke threads.

It is better to make several small adjustments rather than one big turn of the wrench because it is very easy to over tighten the spoke and cause the wheel to go out of true in the opposite direction. The mistake then would be to start tightening an opposite side spoke which although curing the trueness will also have caused the radial trueness to go out resulting in a localised flat spot. The correct solution is to back off the spoke that you inadvertently over tightened which is easily identified because it has a piece of tape applied to it.

Turn the wheel slowly backwards and forwards over the region you are working on and note the improvement in trueness. If the wheel is still out of true and the spoke is still not as tight as its neighbours then give it another fraction of a turn and possibly look for other slack spokes in the immediate vicinity.

Notes on truing

1. If the flag rotates more than half a turn without the spoke tightening then the nipple is probably stuck firmly on the spoke threads. Further turning can result in the spoke snapping. If you suspect the nipple is stuck then untwist the spoke and leave it. Try an alternative strategy such as tightening two adjacent spokes or even loosening an opposite side spoke. If all the spokes are impossible to adjust then the previous builder could have used permanent adhesive on the threads or aluminium nipples without oil resulting in them seizing. If this is the case you have a major problem and if the out of true cannot be tolerated then it will need rebuilding with new spokes.

I've seen high end factory made wheelsets where the nipples were secured with strong adhesive. If you encounter one of these and the nipples are not turning then gently warm the nipple using a cigarette lighter which breaks the adhesive bond sufficient to enable the nipple to be turned. Once adjusted the nipple will stay in place because the adhesive wasn't really necessary in the first place.

2. In the region of out of trueness and with no low tension spokes look for a *tight* spoke on the side of the wheel where there is deviation *towards* your truing reference point. The previous builder may have left you with a spoke that was too tight. Apply a flag and loosen the spoke, observe the flag since the spoke can just as easily twist as before and will require untwisting.
3. If all spokes appear to be similar in tension then by all means loosen one side and tighten the opposite, but first look for individual spokes that are slack, then look for those that are too tight.

4. If the wheel is in a bad state then you may end up adjusting the majority of the spokes in which case you will have to check the wheel dish (see *Wheel dishing* on page 56). It is also worthwhile stressing the wheel (see *Stressing the wheel* on page 59).
5. If you are attempting to true a wheel built by someone else then you may have to rectify some of their building errors. My first step is to try and equalise the spoke tensions before starting to fine-tune the trueness.
6. Do not dive straight in and adjust spokes at random without giving careful consideration because you will no doubt make things a lot worse.
7. On a rear wheel the drive side spokes are much tighter and it is usually the case that a spoke on the *opposite* side will lose tension first. Note, only compare spoke tensions on the same side of a rear wheel.
8. Warning. If you remove the tyre and rim tape do not look into the rim channel while you tighten a spoke. A spoke that breaks can fly out of the rim and hit you in the eye.
9. If you are continually retrueing your wheel or replacing broken spokes then the initial wheel build is at fault. In this case it is better to dismantle the wheel and rebuild using the correct technique.

Chapter 6

Wheel Designs

The design of rims, hubs and spokes has evolved slowly over many years and they are now so well sorted that all components from the major manufacturers are capable of being built into top class wheels. This means you should never discount even the most humble of hubs and rims from lower down their product ranges because I hope you will have realised by now that it's the quality of the building determines the success of the resulting wheel.

Each year the component manufacturers will introduce new hubs and rims. They are obliged to do this to keep business ticking over and keep up with the others who are also introducing new products and the marketing material they issue makes it very tempting to believe there is good reason to *upgrade*. There may be other areas of the bike that benefit from advancement in design but there's not much scope for reinventing the wheel. The spoke manufacturers are also battling to produce new spokes and as a result there are dozens of variations on a simple piece of stainless steel. As a wheelbuilder you are now in a better position to wade through the marketing material and select components based on function rather than cosmetic features or features that offer zero benefit to the performance of the wheel, and of course you will always be paying a premium for these additional *features*. By all means try new components and in time you will find those that work best for you, but I'd say start with ordinary hubs, rims and spokes first.

It is not possible to design for comfort other than choosing a wider rim that takes a wider and therefore softer tyre. The number of spokes, the type of spokes (plain gauge or butted) or the lacing pattern have no effect on ride comfort. A 3 cross wheel and a radial wheel with the same tyre and same pressure will be indistinguishable. A touring cycle may have a 4 cross wheel but that's down to convention, to suggest that the longer (and more tangential) 4 cross spoke gives a more springy ride is wrong. A road race wheel may seem harsh but that's a result of a narrow section tyre pumped up to over 100lbs pressure. This may be hard to accept that the tyre is the major influence on harshness of the ride so try a test yourself with a couple of wheels with different spoke patterns and spoke counts but make sure both have the same tyre and pressure. Ride one wheel then come back and repeat the ride with the other wheel.

Building your wheels with ultra light components will not make you go faster. When you add up the few grams saved it may sound an impressive figure (70g or whatever) but when compared to 80,000 grams of rider plus the weight of the bike it sort of puts things in perspective (I weigh 80kg). If you want to go faster then train harder and mountain bike riders should also brush up on their bike handling skills. Actually a set of standard wheels (i.e. normal components) will allow you to ride faster because they will take more abuse without letting you down. You often see people with ultralight expensive wheels apply the brakes when they encounter a rough section of track, meaning their lightweight wheels have slowed them down! Those with standard wheels ride harder (faster) down a rough track without having to worry about putting a few scratches in the rims and if a new rim is eventually required then normal rims are cheap, plus no labor charge to rebuild it.

If you want to make a stronger wheel then use a stronger rim but *strength* is a difficult one to define. A well built wheel is seen as *strong* because it doesn't go out of true and continues to perform as required. All rims can withstand the rider weight and that's down to spoke tension and

having enough spokes in the contact patch at the bottom of the wheel. If you are using 32 spokes then that's plenty for all riding conditions although touring wheels will benefit from 36 spokes, 28 spokes are okay for lightweight use but I've only ever built a few of these for road riders. I certainly haven't built any wheels with 24 spokes or less, those wheels are best left to the factory built wheelsets and if you ever see one then note the high spoke tension they use to make up for the low spoke count. If you want a rim to withstand a few knocks then a heavier rim is stronger since it will have thicker material whereas the sidewalls on a lightweight rim may easily bend. If you want long term durability to ride thousands of miles carrying heavy loads then use more spokes because the load is distributed over more spokes and helps provide a more fatigue resistant wheel. If you want a laterally stiffer wheel then choose a wider rim. So in general use the rim manufacturers guidelines, select something suitable for your intended tire width, ask around to see what others use (get actual user feedback, not someone taking a guess) and form your own opinion on which specification is best. Just build it well!

Often people who have trouble with their wheels will look for an alternate lacing pattern or different spoke arrangement or something else hoping to find a magic cure when they should be examining their building technique first.

There are many sources of additional reading, some good, some plain wrong! Here are a couple of interesting ones that are accurate:

Wheel Stiffness

What makes a stiff wheel, is it the number of spokes, the tension in the spokes, the type of spokes? Damon Rinard does the tests...

www.sheldonbrown.com/rinard/wheel/index.htm

Bike Physics

My set of wheels is better than your set of wheels. I know why and I can prove it.

John Swanson explains at...

www.bikephysics.com

You don't need to understand John's theory but you should read his conclusions towards the bottom of the "Paper".

Here's something to try. Take a low cost Mavic rim, get a Shimano hub from lower down their range, get some *good quality* double butted spokes, build it up and see how it compares to something costing many times more. Yes, cup and cone bearings, much maligned by those people who go for something *better* with cartridge bearings. The cup and cone bearing and axle design found in Shimano hubs is *very good*. Shimano are responsible for some of the greatest innovations in cycle technology yet still use cup and cone bearings because they say it's the best design for cycle hubs. So build your economy wheel and tell me if you notice any difference!

All that remains are lacing patterns and as a wheelbuilder you now have the option of lacing your wheel in a variety of patterns and not the stock 3 cross wheel you were normally provided with, so let's look at the options available to you.

Standard crossed wheels

In the building section we built a standard 3 cross wheel which is one option from a family of crossed wheels. The other cross patterns available to you are 4 and 2 cross, and also zero cross (known as radial).

Changing the cross pattern has no performance benefits but it does give you options on spoke length which may allow you to use up some spokes that you already have in stock. Reducing the number of crosses uses slightly shorter spokes but any weight saving is negligible. With fewer crosses you will also get more acute weaving close to the hub.

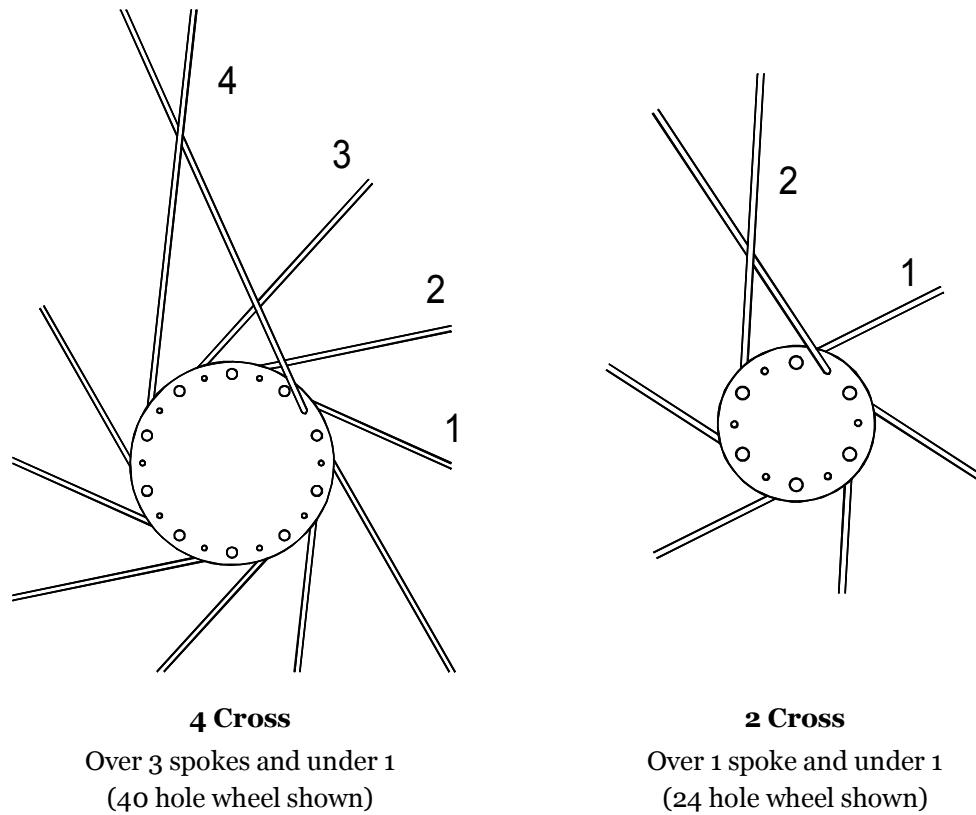


Figure 59 Other standard cross patterns

When counting the crosses remember that the first cross is very close to the hub and is often missed if you don't know what you are looking for.

To lace the wheel using 4 or 2 cross all you need do is make one change at Step 7 of the lacing procedure on page 47 and use either the drawing for 4 or 2 cross shown above. You will of course require the appropriate spoke lengths because changing the crosses changes the spoke length.

When it comes to the number of crosses there is a recommended maximum for each drilling as shown in Figure 60. I've not included 40 spoke wheels because I've not built any so cannot give a definitive recommendation and if I had to build one then I'd choose 3 cross, and for 24 spokes I'd use 2 cross..

Spokes	Preferred cross	Optional cross
36	3	4
32	3	2 (but try and use 3)
28	3 or 2 are equally preferred	

Figure 60 Hub drillings and preferred cross patterns

Lacing using the crosses shown in Figure 60 will ensure there is no over lapping of the spoke heads on the hub flange which puts an unnecessary bend and stress on the spoke at the elbow and it also makes replacing a broken spoke more difficult. The example in Figure 61 shows a 32 hole wheel and the relative positions of the spokes for 3 cross and the non preferred 4 cross.

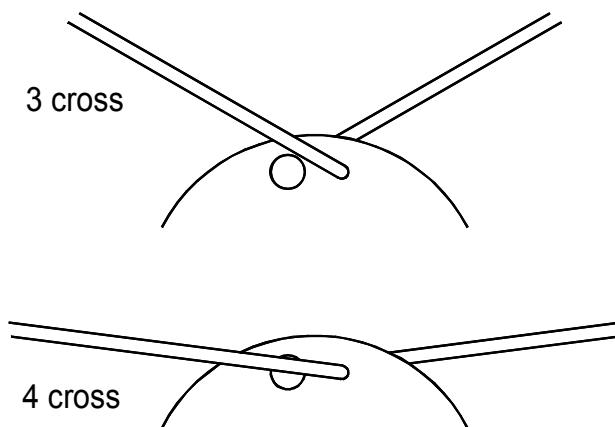


Figure 61 A 32 hole wheel laced 3 cross and 4 cross

On **small diameter wheels with large diameter hubs** you need to be careful with the angle of the spoke where it enters the rim. As the number of crosses increases the spoke entry angle becomes more acute and the nipple may not swivel enough to match the natural spoke line.

The wheel in Figure 62 is a 390mm diameter 36 spoke BMX rim laced to a hub with a flange diameter of 90mm (a large non standard drum brake hub for a special application). It's laced here 2 cross and even with this arrangement you can see the mismatch in angles between the nipple and spoke. If it were laced 3 cross the mismatch would be too great and the additional strain on the spoke at the threaded end could result in an eventual fatigue failure, i.e. the spoke snapping at the thread.



Figure 62

Tying and soldering

Tying and soldering spokes where fine copper wire is wrapped around the spoke crossing points and then soldered in place is something I never do because I can see no benefits to this technique. Some people may claim stronger wheels but I very much doubt it. Take a look at your new wheel and imagine wrapping a bit of flimsy copper wire around the crossing point of a pair of spokes, then adding a blob of solder – do you think it will make *any* difference to the strength or rigidity of that wheel? For track racing where the technique used to be popular many years ago one advantage was to keep a broken spoke in the wheel and allow the rider to complete the race, but nowadays modern quality spokes do not break as easily so there's no need to worry about tying and soldering. I've never even seen a tied and soldered wheel.

Radial wheels

Radial lacing can be used on the front wheel, it can also be used on the rear wheel non drive side but **never** the rear drive side which needs the tangential design from a cross pattern to transmit the drive torque without the hub twisting in the wheel. For disc brake users you should never use radial on the disc side (front and rear) because that side needs to withstand the braking torque.

The radial pattern puts a lot of stress on the hub flange which can lead to fatigue fractures when used over a period of time. For this reason many hub manufacturers do not recommend lacing their hubs radially and doing so could invalidate any warranty if the hub subsequently fails. Shimano use forged hub shells and allow radial lacing on several of their hubs, but if you are contemplating radial lacing on any hub then always check with the manufacturer first. If you look at a cross laced wheel then the stress on the hub flange from one spoke is counter balanced by an adjacent spoke pulling in the opposite direction and the more tangential the spokes (the more crosses) the less resultant stress there is on the hub.

The radial pattern has no spokes crossing and is straightforward to lace. It is usual to lace one complete side of the wheel at a time since there is no possibility of spoke tangles. The only decision on placing the spokes is whether to have the spoke heads on the inside or outside, or alternate them. There is no preferred technique but aesthetically the wheel may look better if all the spokes are placed with the heads on the outside. There is no performance benefit from using radial wheels but they do look different.

Cross combinations on the same wheel

You can use different cross patterns either side of the wheel. So you could for example build a rear 32 spoke wheel with 3 cross drive and radial on the other side – often referred to as half radial (if you plan to use radial then read the preceding discussion). It's going to be interesting to build but no one other than another wheelbuilder is likely to notice. There are no performance benefits in doing this.

If you choose to use a different cross pattern on the opposite side of the wheel then Lacing Step 4 on page 44 (placing the first spoke on the opposite flange) requires a small change. Figure 63 shows where to place the first spoke on the opposite side when using Type 1 rims (page 9) and this spoke will then dictate the placement of all the others on that side. Complete the lacing by following the remainder of the lacing procedure as previously written.

In the diagram *Normal* represents the standard placement when using the same number of crosses either side. For example if the near side is built 3 cross and you require 2 cross on the opposite side then place the spoke through the hole marked -1 (i.e. $3-1=2$ cross). For radial you would place it through the hole marked -3 ($3-3=0$ crosses, i.e. radial). The spoke is placed in the rim as previously described always to the left of the sighting spoke.

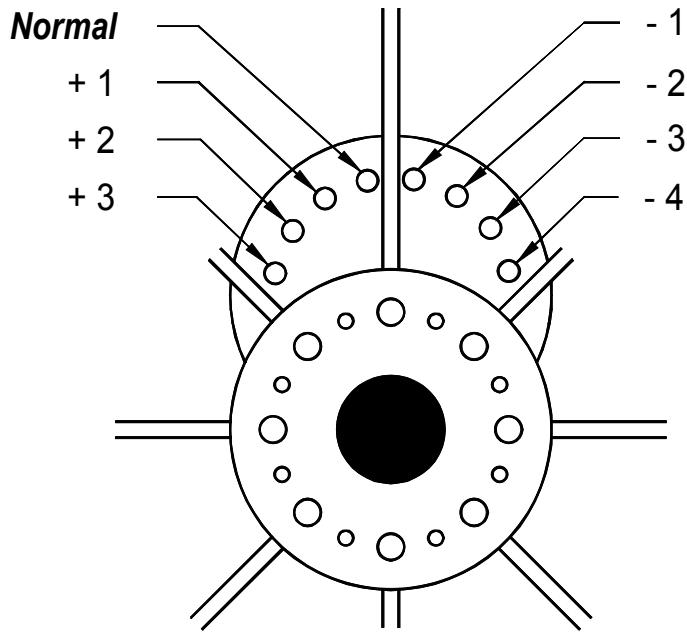


Figure 63 Different cross pattern on the opposite side - the first spoke

Inside or outside pulling spokes

The pulling spokes on a crossed wheel can be arranged in one of four permutations as shown in Figure 64 (imagine looking down on a rear wheel at the pulling spokes leaving the hub flange). If you build your wheel using the instructions in this book it will look like diagram A. All options will work equally well and consequently you will see all options in use and the preference of the builder is more than likely based on the lacing method they were originally taught. When I started building wheels I looked at wheels used in the *Tour de France* and most then were type A so I built mine the same and have done so ever since although I'll occasionally use one of the other options if the situation requires it (see *Previously used hubs* later). Looking at the 2008 Shimano catalogue their WH-R500 road wheelset built with conventional hubs uses a type A lacing on the rear with radial lacing on the front.

It's not important which option you choose and they all perform the same and if you understand the basics of lacing then switching between the options is easy. Of the four, the symmetrical patterns of A and B are the most common and easiest to lace. To lace option B using the procedure shown in Lacing the Wheel on page 41, start with the hub the other way round i.e. in Lacing Step 1 place the spokes through the non drive (left) side to start with.

The only other option I've seen is pattern C and if you read the documents that come with Shimano disc brake hubs they advise lacing this way. They give no reason and I've yet to find any valid theories to justify this pattern. You might hear some people saying the spokes that resist the brake force lie on the outside of the hub and are supported by the hub flange but this makes no difference, they apply the same logic to rear wheels where the spokes transmitting the drive force should lie on the outside, again no difference. I've built many hundreds of disc brake wheels and have always used lacing pattern A which is the pattern you'll end up with if you follow my building instructions.

If you want to lace a wheel using option C this is how you do it. When you reach Lacing Step 4 (page 44) place the first spoke on the opposite side into the hub from the *inside* and not from the outside as described. Place the spoke in the rim as described then continue the same way with the remaining 7 spokes placing them through the inside of the hub. Rotate the hub as described but stay on the opposite side and completely lace that side. This helps reduce any tangling issues but you may need to gently flex each spoke to guide it around the drive side spokes.

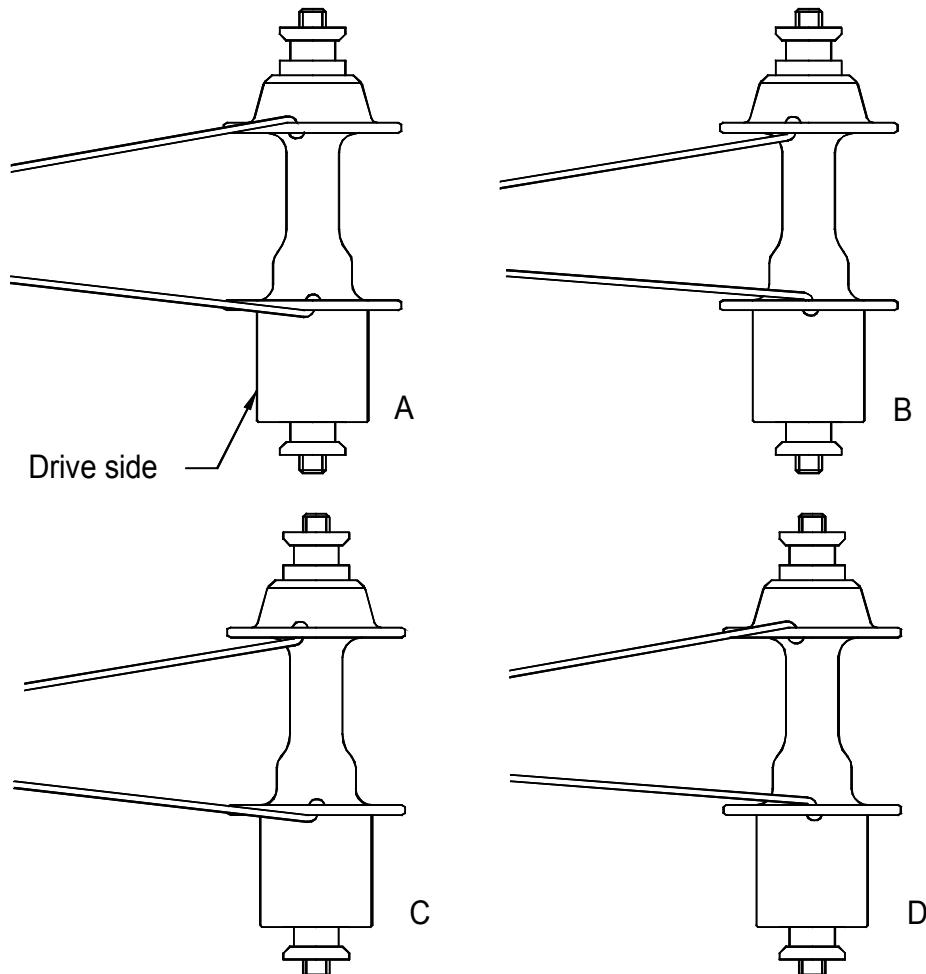


Figure 64 Inside and outside spoke orientations

The photographs on the next page shows options A, B and C.

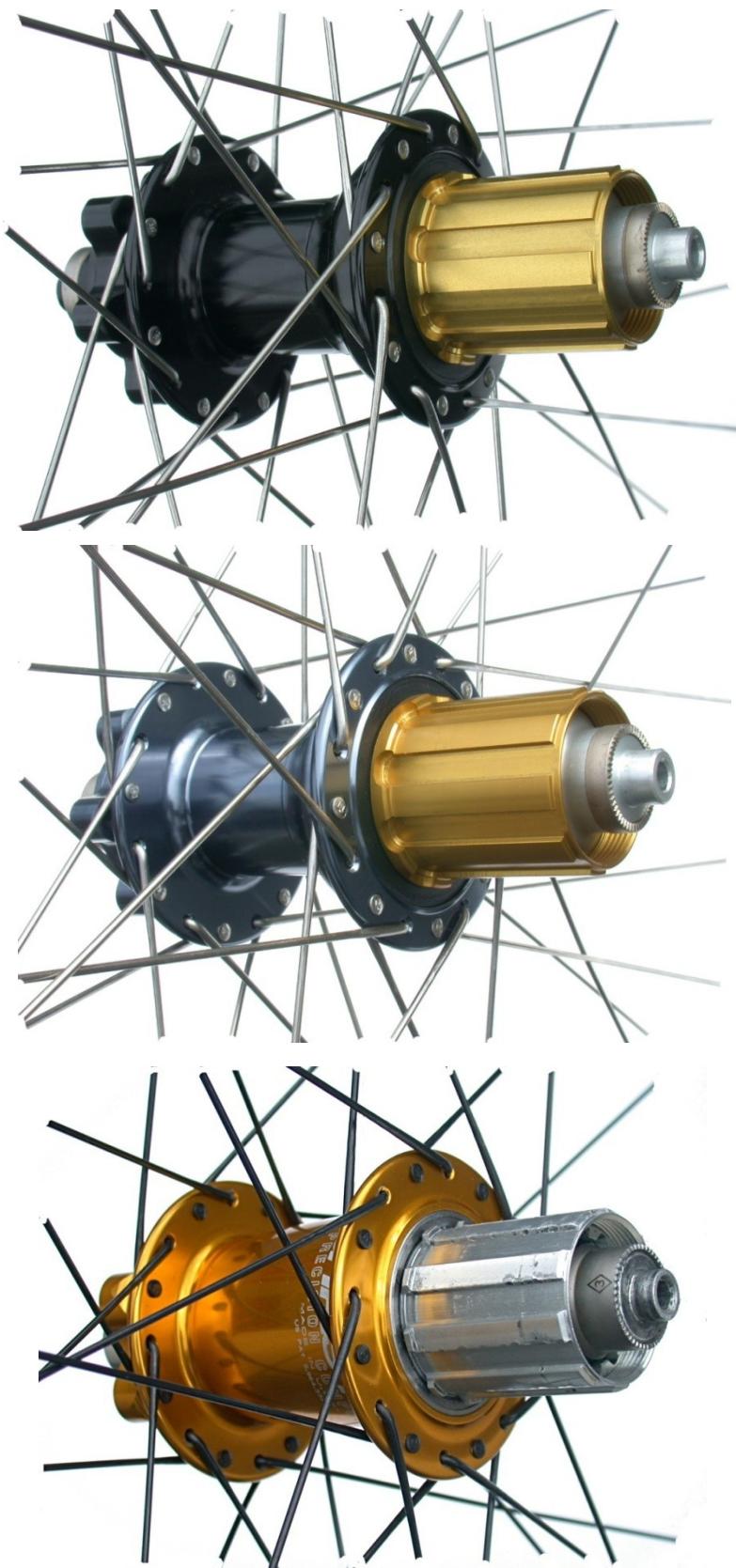


Figure 65 Lacing options. From top to bottom, A, B and C

Inside or outside : a historical viewpoint

Consider wheels that transmit torque, either drive torque from pedalling or braking torque from *disc brakes* (not rim brakes) and how the spokes react to the applied forces at the spoke crossing points. As torque is applied the spokes that transmit the forces will try to straighten and in doing so pull (or push) the other spoke at the crossing point either inwards or outwards (depending on the lacing orientation used). If they push outwards there is a chance of the spokes at the crossing point touching a closely positioned rear derailleur (when using the largest sprocket) or hitting the front disc brake calliper. In the early days of disc brakes the brake callipers were large and fork clearance small and the spokes could hit the calliper under heavy braking. Lacing using option A was better because the spoke pulled inwards under braking and away from the calliper (the 2008 Chris King ISO disc hub manual still advises a type A lacing for the front disc hub). With modern cycling components there is plenty of clearance and no chance of spokes touching them so it doesn't matter which option you choose.

Previously used hubs

When I rebuild a previously used hub I always maintain the same spoke orientation from the original build and ensure the spoke elbows match the previous indentations in the hub. This is purely a cosmetic exercise since I don't want the old marks to be visible. If you are rebuilding a wheel take a close look at it before dismantling and also examine the indentations prior to lacing and determine which lacing option to adopt. If you are struggling to match the previous wheel then it's not a problem if you lace it another way and put new indents into the hub opposite to the original ones. There is some theory that says matching the original indents is better from a metallurgical point of view and helps protect the hub, but in reality it makes no difference.

The hub in Figure 66 is a customer supplied hub and it was previously built using option C lacing so that's what I used and is shown finished in Figure 65. The option B laced hub in Figure 65 is a customer wheel I built to illustrate the lacing option. Option A is my default build because that's the way I started many years ago. So you see, I'm building and selling wheels using each option and I have no concerns with any of them.



Figure 66 Old indentations

Other lacing patterns

As you become more interested in wheels you will be tempted to look at other lacing patterns but you should realise there is a good reason why you rarely see anything other than the standard cross pattern. There are other options for lacing a wheel, anything other than the standard cross pattern is likely to be cosmetic or an academic exercise only to show that *this could be possible* but with no theory to backup any claims of a *better wheel*. Trawling around the Internet you will no doubt find strange lacing patterns and often they only exist within a computerised drawing program or at best built up and rode a short distance. The thing is you never see any of these on real wheels and if there were a magic lacing pattern then we'd all know about it by now. Anyone remember the snowflake or twist lacing pattern that was popular for a year or so in the 90's yet soon lost favour? So don't mess with these alternate patterns or you will be asking for trouble, see my warnings in the building section on page 72.

Missing out hub and rim holes

Not recommended. The hub and rim was designed to use the specified number of spokes to maintain its structural integrity and strength - so use them. Never build wheels using less than the full complement of spokes in the hub and rim. If you want to use less spokes then get the appropriate components that were designed for that purpose.

Number and type of spokes

In the majority of cases you will find 32 and 36 hole components built 3 cross and you will have to come up with a very good reason for doing something different. 95% of my customer wheels for road race, mountain bike and those of the professional downhill racing teams use 32 spokes. The exceptions are a few 36 hole wheels for road touring and BMX, and a few 28 hole wheels for road race. I've never built any 24, 40 or 48 hole wheels (because I've never been asked).

The only spokes I use are standard double butted (2mm/1.8mm) for the majority of the wheels and a few lightweight double butted (2mm/1.5mm) for light cross country mountain bike wheels, I've been using some 1.8mm/1.6mm double butted spokes on road sport/race wheels (but for no real reason). I never use plain (straight) gauge and try not to use bladed spokes wherever possible unless a road customer really wants them (mountain bikers never get these). I never use different types of spoke either side on rear wheels, for example heavier spokes on the drive side, some people do but it offers no benefit.

Design considerations - the Last Word

If I do have any advice then it is not to get side tracked with the many arguments for and against particular components or lacing patterns. Don't lose sight of the original task which is to build a wheel that allows you to go out riding. What is more important is that you actually build something that *you* are satisfied with. Use whatever components you want and in any colour you want and you'll eventually discover your personal preferences. Just make sure reliability is top of the list.

For the record, and after building customer wheels using all sorts of permutations of components and after riding many options myself, my own personal choice is now a silver rim, a silver mid range hub and 32 double butted spokes (2mm/1.8mm), brass nipples, laced 3 cross.

Chapter 7

Spoke Lengths

Building wheels with the correct length spokes makes things easier. Building with the wrong length spokes can often mean the wheel will not build and you'll only realise this half way through the build sequence or later if you don't recognise the symptoms early.

Even many good wheelbuilders struggle when it comes to selecting spoke lengths but it's not difficult at all. It is definitely worth spending some time to understand the techniques available, that way you'll be independent and be able to work out spoke lengths for any hub and rim combination.

I never trust any spoke length related information (actual spoke lengths or component dimensions) given to me by others unless I'm 100% certain it's from a reliable source. When I require a spoke length *I always calculate my own.*

The spoke length calculator

1. Measure your components.

See *Measuring rims* on page 101 and *Measuring hubs* on page 103.

2. Then use the online spoke length calculator at www.wheelpro.co.uk/spokecalc

I designed and wrote this calculator a long time ago and it's all I ever use, over the years I've fine tuned it and if there were something wrong with it I would have changed it by now. I build all sizes of wheels and I use a large range of components and the calculator provides all my spoke lengths. Yet too many people go there and just see a couple of small tables of hubs and rims and depart looking for a bigger database that miraculously might contain their wheel components.

Forget component names. All you are interested in are a few key dimensions and how to measure your hubs and rims. Learn the basics and you will always be able to calculate your spoke lengths regardless of what you build.

If you do some analysis using the spoke calculator and try changing the component dimensions you will see that changes to the hub have a small effect on the resulting spoke lengths for a cross laced wheel. The rim diameter has the biggest influence and a 10mm increase in diameter would make the spokes 5mm longer.

Rounding the spoke lengths

The spoke length calculator aims to calculate a spoke length such that the spoke in the finished wheel is just below the top surface of the nipple which is the ideal length when using standard 12mm nipples. If you cannot obtain the exact length you still have the opportunity of going plus or minus 1mm to find something suitable.

When using my calculator and using my logic for rounding the spoke lengths it's important to use a nipple driver with a 3mm point.

So what happens when the calculator gives out a fractional length? I treat the calculated lengths as maximums so would initially look to round down. For example say I calculate a spoke length at 265.6mm my first choice would be 265mm. If I was obliged to use even length spokes then I'd choose 266mm because rounding down to 264 is too much, it's 1.6mm below the ideal length and out of the +/- 1mm range. In general, if the fraction is up to 0.6 longer then I round down, over 0.6 I round up.

Another example, say you calculate 263mm but can only obtain even length spokes, you can easily go + or - 1mm giving you the option of 262 or 264. If you round down 1mm or more you will be getting tight spokes early in the build process and you'll notice this when taking up the slack with the nipple driver so you should make sure the nipple driver point is at least 3mm long and it may benefit from being a little longer if your spokes are on the sort side.

There is quite a bit of leeway in selecting spokes, I always try to get close to the ideal because it makes building the wheel a little easier.

Record your data

The techniques described above required you to measure your components (hubs and rims) as well as the spoke lengths you initially selected - **you need to write these down**. When you build the wheel examine how the spokes finished up and write down the exact spoke lengths for the specified wheel. Your initial selection may not have been perfect so you may need to revise the length based on your observation of the finished wheel. In the future these notes will become your most valuable wheelbuilding information and believe me, you will kick yourself if you didn't record your data.

When I write my information down I always examine the finished wheel then write down two sizes. The first is the preferred size and the other an alternate size that would still build the wheel. This gives me the option of saying in the future when I build the same wheel "*well I haven't got the preferred size in stock, but I know the alternative will work just as well*" and if I knew the alternative was say 1mm longer I would know this when building the wheel and give the nipples a few extra turns when taking up the initial slack.

I've made recording your data easy for you. Use the spoke calculator at www.wheelpro.co.uk/spokecalc, calculate your spoke table and print the page, record your data and keep the sheet somewhere safe. You have no excuse!

Spoke lengths for a different rim

You have a hub that you've **previously built** but your next wheel requires a different rim.

Once you have built a wheel then selecting spokes for any other rim using the **same hub** with the same number of spokes and cross pattern is easy. All you do is compare the old and new rim diameters.

For example, I have already built a wheel using rim xyz and the spokes I used (which I wrote down when I built it) were 262mm. The next wheel I am going to build uses the *same hub* but this time using a totally different rim which I have never used before - so what spokes should I use? The previous rim measured 540mm in diameter (which I wrote down when I built it and I'm referencing my notes), the new rim measures 544mm in diameter so the spokes for this rim are

2mm longer and I will use spokes at 264mm (providing I'm using the same cross pattern and same spoke count).

All I did was measure my new rim then use half the difference in rim diameters to modify my existing spoke lengths. Obviously if my new rim was smaller in diameter I would be subtracting rather than adding.

You only need one reference pair of wheels per hub and the technique is accurate for all rims even where there is a large discrepancy in rim diameters. I use this method all the time, it provides very accurate spoke lengths and no computers are required.

If you have the same hub but with a different spoke count or require a different cross pattern then use the online spoke length calculator. However, once you build the wheel and determined the exact spoke lengths they then become your standard for this hub (and spoke configuration) and for other rims just compare rim diameters to the one just built.

How nipple length affects spoke length

When the spoke manufacturers make nipples longer than the standard issue length of 12mm the spoke length *sometimes* needs modifying. I say sometimes because it's based on how the manufacturer designs the threaded portion of the nipple.

For **DT nipples** modify the spoke length:

14mm nipples subtract 1mm

16mm nipples subtract 2mm

DT-Swiss nipples

DT-Swiss increase the thread length on their longer nipples and for illustration purposes I've produced some cross sections of 16, 14 and 12mm DT nipples shown in Figure 67. The ruler is in 1mm increments, the blue lines mark the top of each spoke and the line on the 12mm nipple is the spoke length determined by the spoke calculator. The red lines indicate the start of the thread in the nipple and the black lines mark the end of the threads on the spoke. All the spokes are screwed into the nipples so that 1mm of thread is below the red line meaning there is 1mm more to go before the unthreaded spoke hits the nipple threads. Once it hits the nipple threads it will easily tighten with the wrench but the spoke will be deforming the nipple threads and whilst generally okay I always try to avoid this by selecting the correct length spoke.

All spokes in the photograph are *perfect spoke lengths* because each one still has 1mm of tightening left in them but as you can see the spokes for the 14mm and 16mm nipples are 1mm and 2mm shorter than the length for the 12mm nipple.

The DT-Swiss spoke length calculator automatically subtracts 4mm if you specify a 16mm nipple and subtracts 2mm if you specify a 14mm nipple, both of which I find excessive compensations.

Other makes of nipple

If you are using nipples other than DT then do a simple test to determine if any spoke length compensations are necessary when using longer nipples. Take a 12mm nipple and screw it on to a spoke as far as it will go, don't force it, and note the position of the end of the spoke. Do the same

with the longer nipple and note where the end of the spoke is. The difference between these two points is the amount the spoke length needs shortening. For example with Sapim nipples no spoke length compensation is necessary.

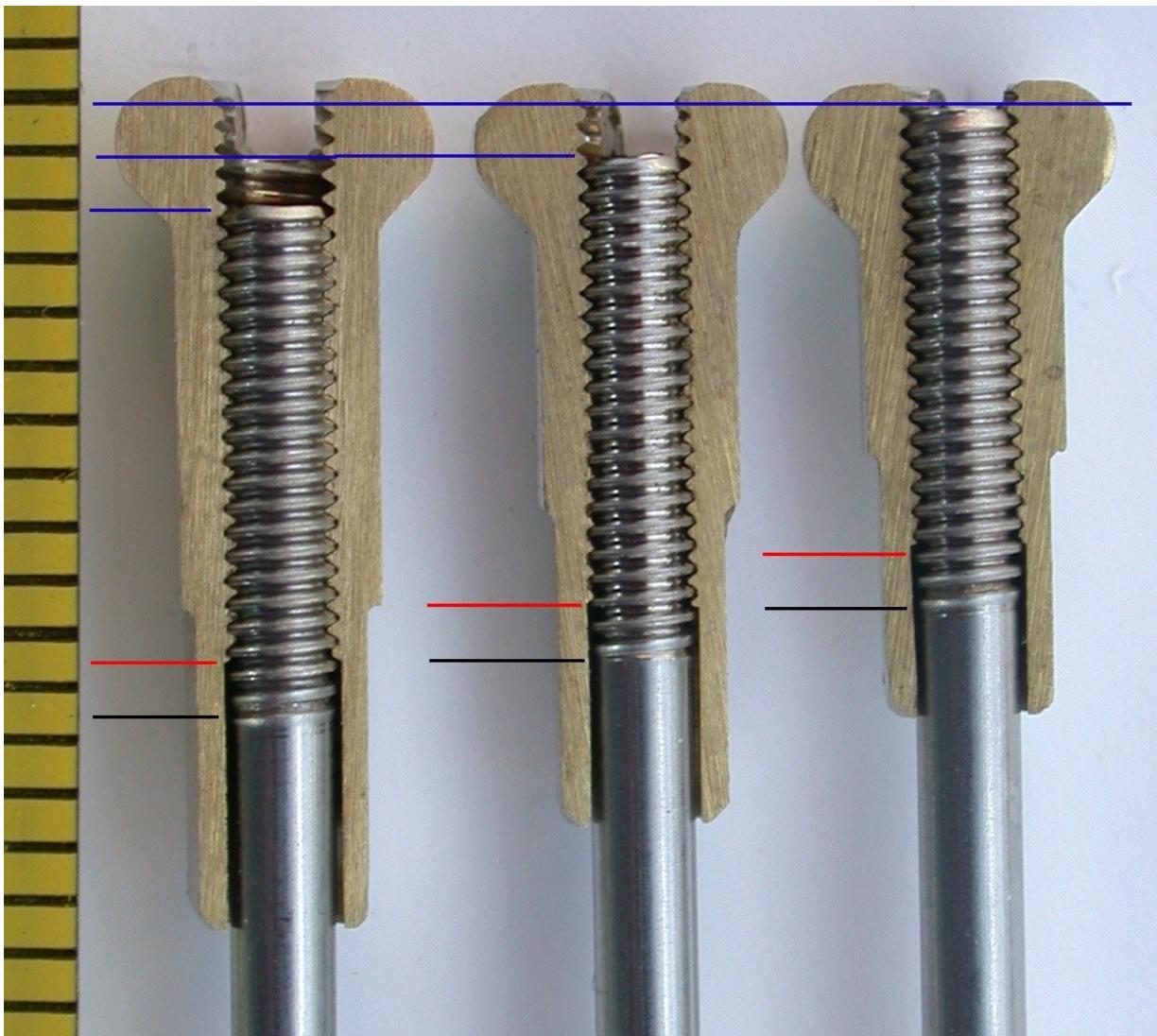


Figure 67 DT Nipples, 16mm, 14mm and 12mm

Note : 14 and 16mm nipples

Longer nipples are only required on deeper section rims where the standard 12mm nipple does not protrude through the rim enough to locate the spoke wrench. I have never built a conventional rim that required something longer than the standard 12mm nipple. If you do encounter a rim that requires a longer nipple and the nipple design calls for shorter spokes then take this into account when using the nipple driver to take out the initial slack since the 3mm point on the nipple driver may benefit from being 1 or 2mm longer. I do use 14mm nipples but they are for use on Mavic UST rims (page 68) where it's not possible to use a nipple driver.

The spoke length formula

If you want to create your own calculator then you'll need the spoke length formula.

For completeness, the proof of the formula is given later.

$$\text{Spoke Length} = \sqrt{R^2 + H^2 + F^2 - 2RH \cos\left(\frac{720}{h} \cdot X\right)} - \frac{\phi}{2}$$

where :

R = Rim radius to spoke ends (based on ERD, page 101)

H = Hub flange radius to spoke holes

F = Flange offset (dimensions C and D, page 103)

X = Cross pattern

h = Holes in rim

ϕ = Diameter of spoke hole in hub

Figure 68 The spoke length formula

Notes when using the formula

1. Take accurate measurements from your hub and rim (refer to page 101).
2. Many spreadsheets use angles in radians for their cosine function. The value used in the formula is in degrees so make the necessary conversion if required by multiplying by $2\pi/360$ to obtain the value in radians.
3. Check a trial calculation using the worked example on the next page. It's easy to make errors that yield acceptable looking spoke lengths but you will only find they are wrong when you start building the wheel.
4. For radial wheels the number of crosses in the calculation is zero giving identical spoke lengths regardless of the number of holes.
5. For dished wheels e.g. rears and disc fronts you will need to do separate calculations for each side of the wheel.

Trial calculation

For example purposes a 540mm diameter rim is used and a Shimano small flange front hub with 32 holes built 3 cross.

R	270
H	19
F	36
ϕ	2.3

Substitute these values into the spoke length formula in Figure 68.

$$\text{Spoke length} = \sqrt{270^2 + 19^2 + 36^2 - 2 \times 270 \times 19 \times \cos\left(\frac{720}{32} \times 3\right)} - \frac{2.3}{2}$$

Spoke length = **264.61mm**

The online calculator

The online spoke calculator at www.wheelpro.co.uk/spokecalc is programmed it to knock 0.3mm off the theoretical lengths which is a good compromise and makes the results more accurate in the real world.

If you are checking the above calculation with the spoke calculator then A and B = 38, C and D = 36 and the rim diameter = 540. The spoke length it gives is 264.3 because it knocks 0.3mm off.

See page 93 for the discussion on how to round up (or down) the fractional sizes produced via the calculation and page 95 if you are using something other than 12mm nipples.

The spoke length formula proof

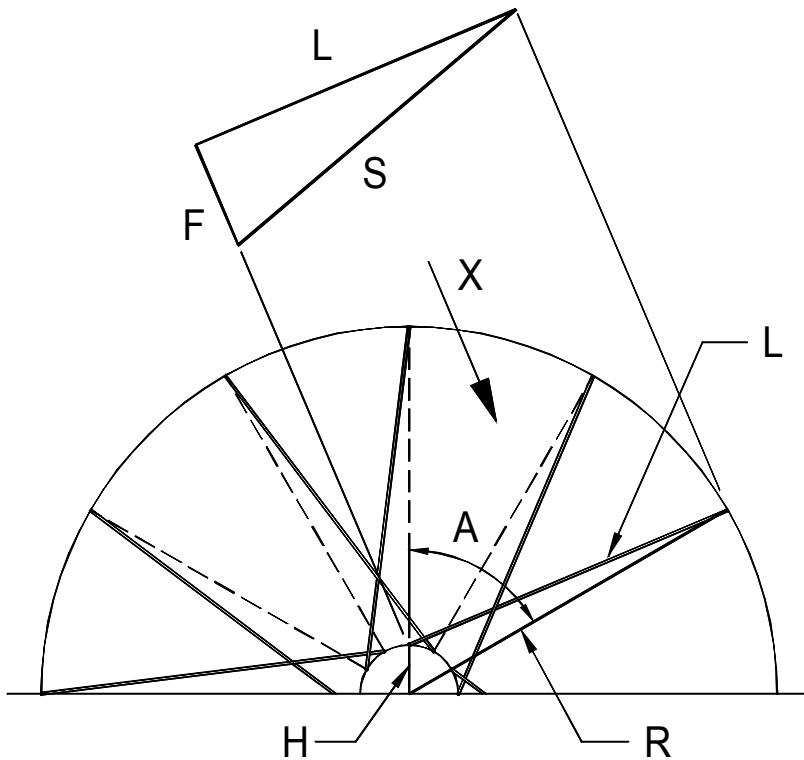


Figure 69 The geometry of a 24 hole 2 cross wheel

Look at the spokes in one side of a wheel (Figure 69) and consider the triangle with sides H, L, R with included angle A where :

L = Intermediate length

R = Rim radius (to spoke ends)

H = Hub radius (to spoke holes)

Using the Cosine rule

$$L^2 = R^2 + H^2 - 2RH \cos A \quad (1)$$

Now take into account the 3 dimensional construction, with the spoke joining the hub at the hub flange making the triangle F, L, S i.e. looking in direction X on Figure 69.

$$S^2 = L^2 + F^2 \quad (2)$$

where:

S = Spoke length

F = Flange offset (dimensions C and D on page 103)

Substituting L^2 from (1) into (2) gives

$$S^2 = R^2 + H^2 + F^2 - 2RH \cos A$$

and

$$S = \sqrt{R^2 + H^2 + F^2 - 2RH \cos A}$$

This gives the spoke length to the centre of the hub hole. Spoke lengths are measured to the bend of the spoke which rests on the edge of the hub drilling so half the spoke hole diameter in the hub must be subtracted.

$$S = \sqrt{R^2 + H^2 + F^2 - 2RH \cos A} - \frac{\phi}{2} \quad (3)$$

where ϕ = the diameter of the hub drilling.

The angle "A" depends on the cross pattern and the number of holes on the hub flange. Study Figure 69 (and Figure 76 on page 107) and note how the angle changes with cross pattern. Each cross takes up one sector (Figure 69 is a 2 cross wheel).

If h = total holes in the rim

Then the number of sectors on the hub flange = $\frac{h}{2}$

$$\therefore \text{Angle in one sector (degrees)} = \frac{360}{\frac{h}{2}} = \frac{720}{h}$$

For any cross pattern X

$$A = \frac{720}{h} \cdot X \quad (4)$$

Substituting (4) into (3) gives the general spoke length formula.

$$\text{Spoke Length} = \sqrt{R^2 + H^2 + F^2 - 2RH \cos\left(\frac{720}{h} \cdot X\right)} - \frac{\phi}{2}$$

where : R = Rim radius to spoke ends

h = Holes in rim

H = Hub radius to holes

X = Cross pattern

F = Flange offset

ϕ = Dia. of spoke hole in hub

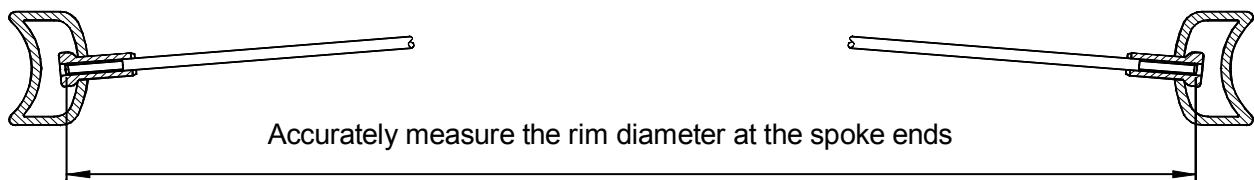
Chapter 8

Measuring Components

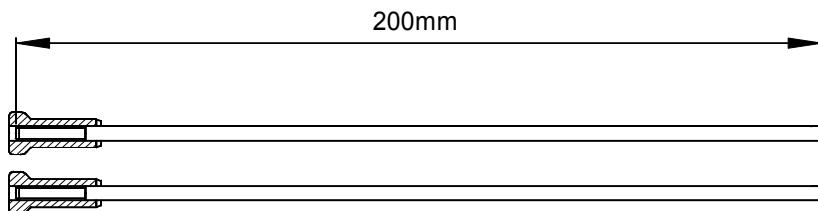
This is only required for calculating spoke lengths.

Measuring rims

The only rim dimension that matters for spoke length purposes is the Effective Rim Diameter (ERD), all other profiles and rim dimensions are irrelevant. You must measure the diameter *before* lacing the wheel. Rim diameter has the biggest effect on spoke calculations so measure it accurately.



Take two spokes and cut them down accurately to 200mm. Screw down the nipples so that the spoke ends are flush with the bottom of the slot and glue in position. I always kept a set of these in my toolbox.



Now place these spokes in opposite sides of the rim and measure the gap between the ends. Add 400mm to get the rim diameter. Average several diameters.

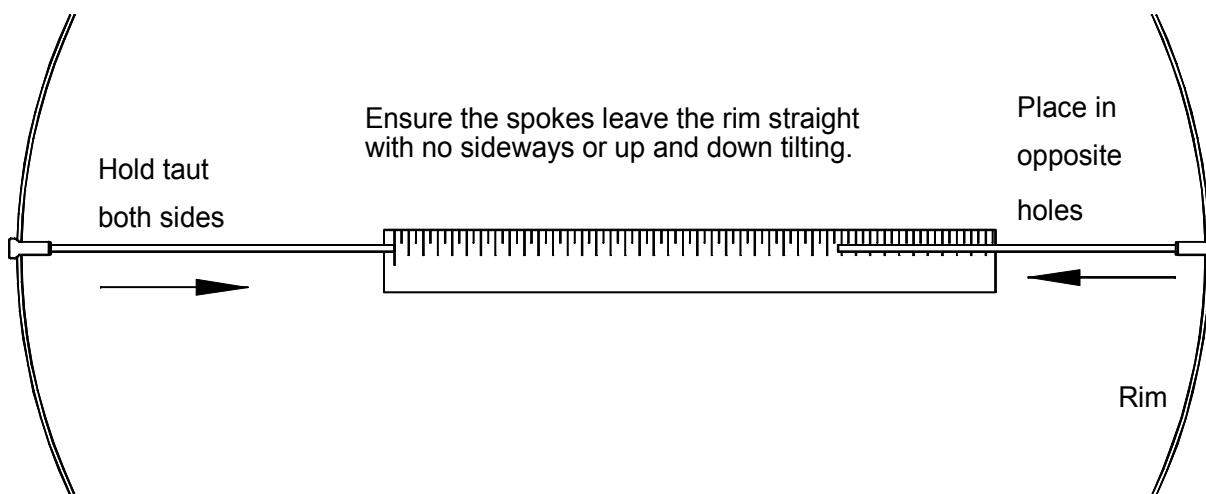


Figure 70 Measuring the rim diameter

I **do not** advise using any ERD measurements supplied by the rim manufacturers, I never trust their data and neither should you. The reason is that the ERD is not a fixed point on the rim and the ERD is not a strictly defined term. Some rim manufacturers guess correctly and some don't and an error in the ERD will result in you calculating the wrong length spokes. So use the measuring technique above.

Write your measured rim diameter down, the reason why is given in the spoke length section *Comparing rim diameters* on page 94 and the diameter can also be entered directly into the online spoke calculator at www.wheelpro.co.uk/spokecalc

Figure 71 Rim data

Measuring hubs

There are only a few key dimensions on the hub that are required for spoke length purposes.

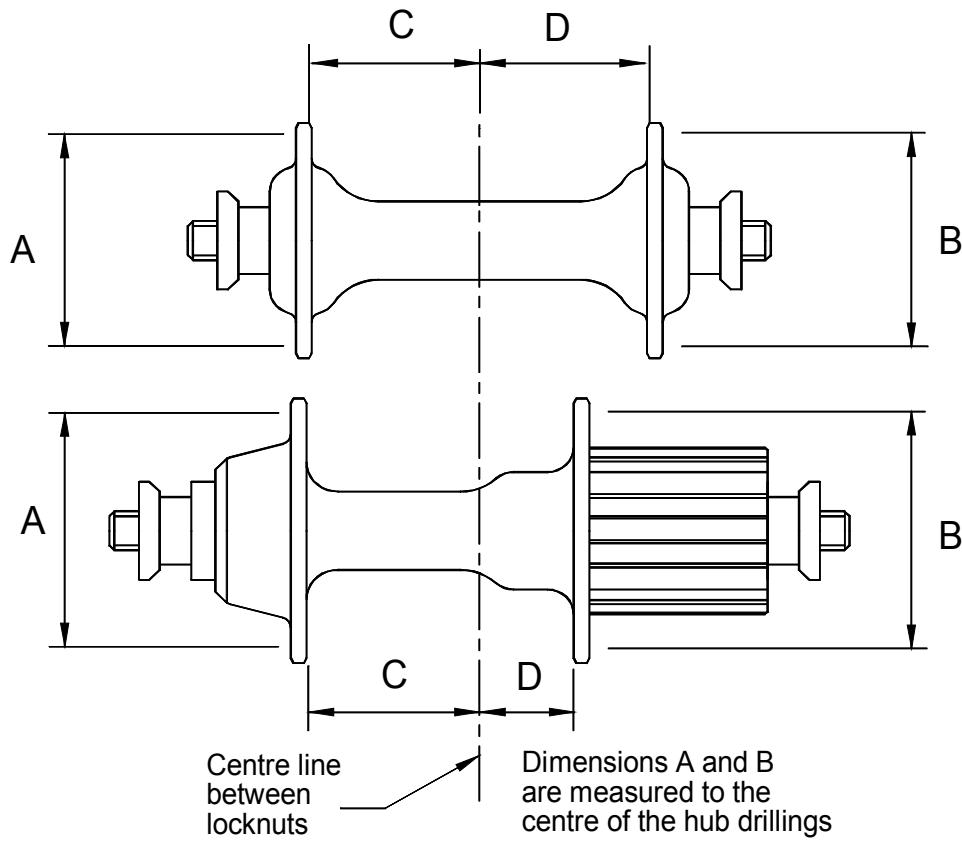
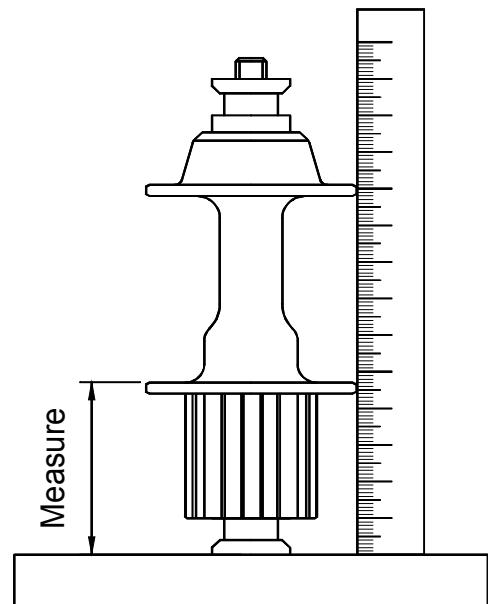
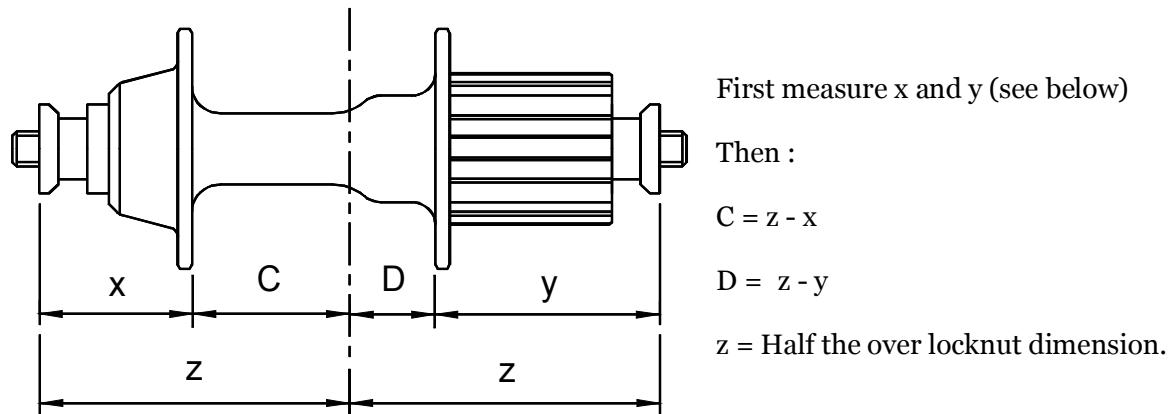


Figure 72 Key dimensions for a pair of hubs

The dimensions A, B, C and D relate to the data entry boxes at the online spoke calculator at www.wheelpro.co.uk/spokecalc

If you don't yet have your hubs you can safely take the figures supplied by the hub manufacturer which are usually available on their website. Unlike rims the hub measurements are to fixed points on the hub with no ambiguity. They will refer to dimension C as *centre to left flange* and dimension D as *centre to right flange*.

Measuring your own hubs is straight forward. With standard symmetrical front hubs obtain dimensions C and D by measuring across the hub flanges and dividing by two (C and D being identical). For the rear and front disc hubs which are non symmetrical use the following technique to measure dimensions C and D.



Measuring x and y

To gain greater accuracy when measuring x and y , drill a piece of wood and let the hub stand upright on its locknut. Take the measurement then turn over and repeat.

If the hub flange diameters are a different size then using a ruler is impractical (try it and see why). Instead use a piece of card and mark the position then measure separately.



Figure 73 Measuring the rear hub

Always record your measurements for future reference. The table on the next page is provided for this purpose.

Hub data sheet

Measure the dimensions A, B, x, y.

Use your ruler to measure the distance between the flanges - dimension F in the table below.

Now calculate C and D where:

$$\mathbf{C} = \mathbf{z} - \mathbf{x}$$

$$\mathbf{D} = \mathbf{z} - \mathbf{y}$$

z = half the over locknut dimension.

Check your calculation since C + D should be the same as F.

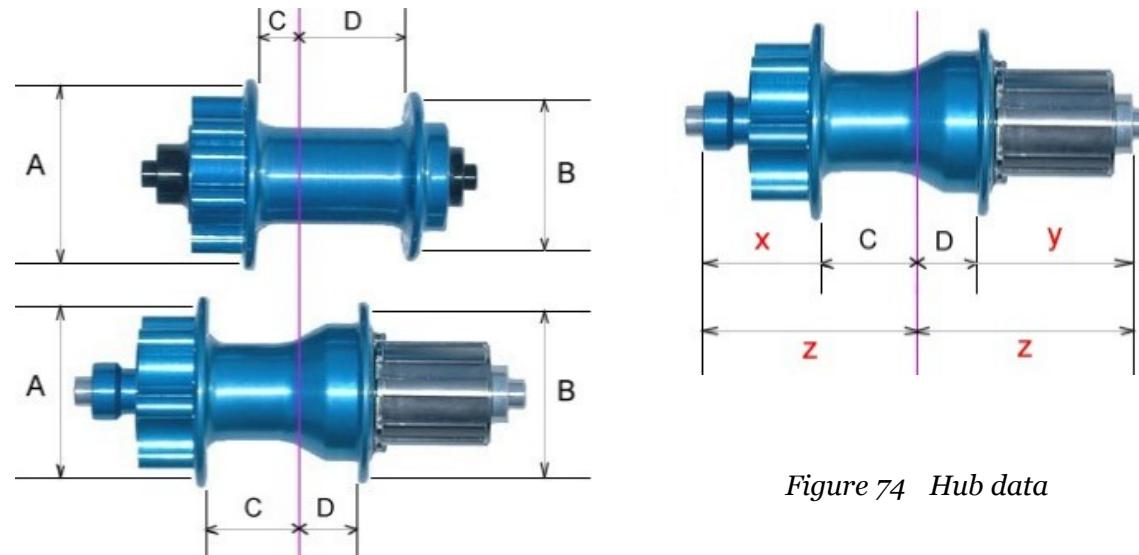


Figure 74 Hub data

Chapter 9

The Geometry of a Wheel

The discussion on geometry presented here is for builders who would like to sketch their own wheels or draw them to scale using a computer drawing program. Understanding the geometry enabled me to determine the precise way of aligning the valve hole with the hub label (page 66), it allowed me to determine the method of lacing different cross patterns on either side of the hub (page 87), it was required for the analysis of the spoke length formula (page 97) and it showed me how to draw the wheels used for illustration purposes throughout this book.

If you are reading this section on-screen at normal resolution the diagrams may not appear too precise in which case zoom in to get a clearer view.

The construction of a wheel may appear complex but with the aid of simplified diagrams a regular geometric pattern is easily identified. For reference purposes when studying the following diagrams get hold of a completed wheel (not a radial one) with the skewer removed and a fine piece of string.

Look at one side of your wheel and completely disregard the spokes on the other side since each side can be considered in isolation. The key to understanding the geometry is to notice how holes in the hub flange are aligned radially with the holes in the rim. This can be seen on your reference wheel by stretching a piece of string across the wheel diameter passing it over the hub centre and over a hole in the hub, observe how it intersects a rim hole on the *same* side.

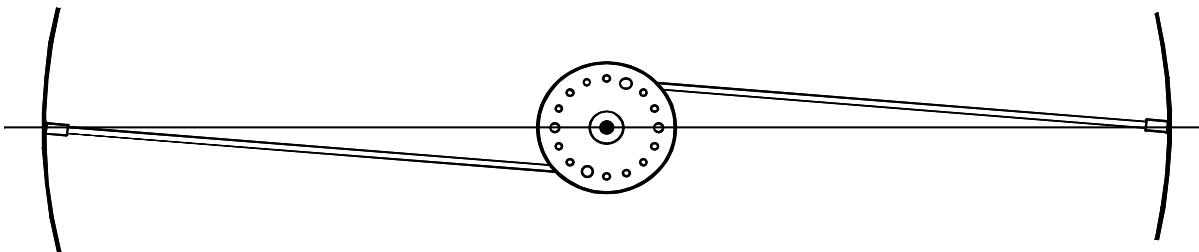


Figure 75 The alignment of hub and rim holes, 3 cross wheel

The diagram in Figure 76 shows the placement of a single spoke for the various cross patterns. The radial guidelines align with the hub and rim spoke holes. I now use the same hub hole and extend to different positions on the rim, for clarity the spokes are shown in red when viewing the pdf on-screen. Only one side of the wheel is shown. As can be seen, a more precise definition of the term *cross* is the number of sectors crossed when the spoke is connected between the hub and rim. A 36 hole wheel is drawn but the procedure is just the same for the other standard drillings.

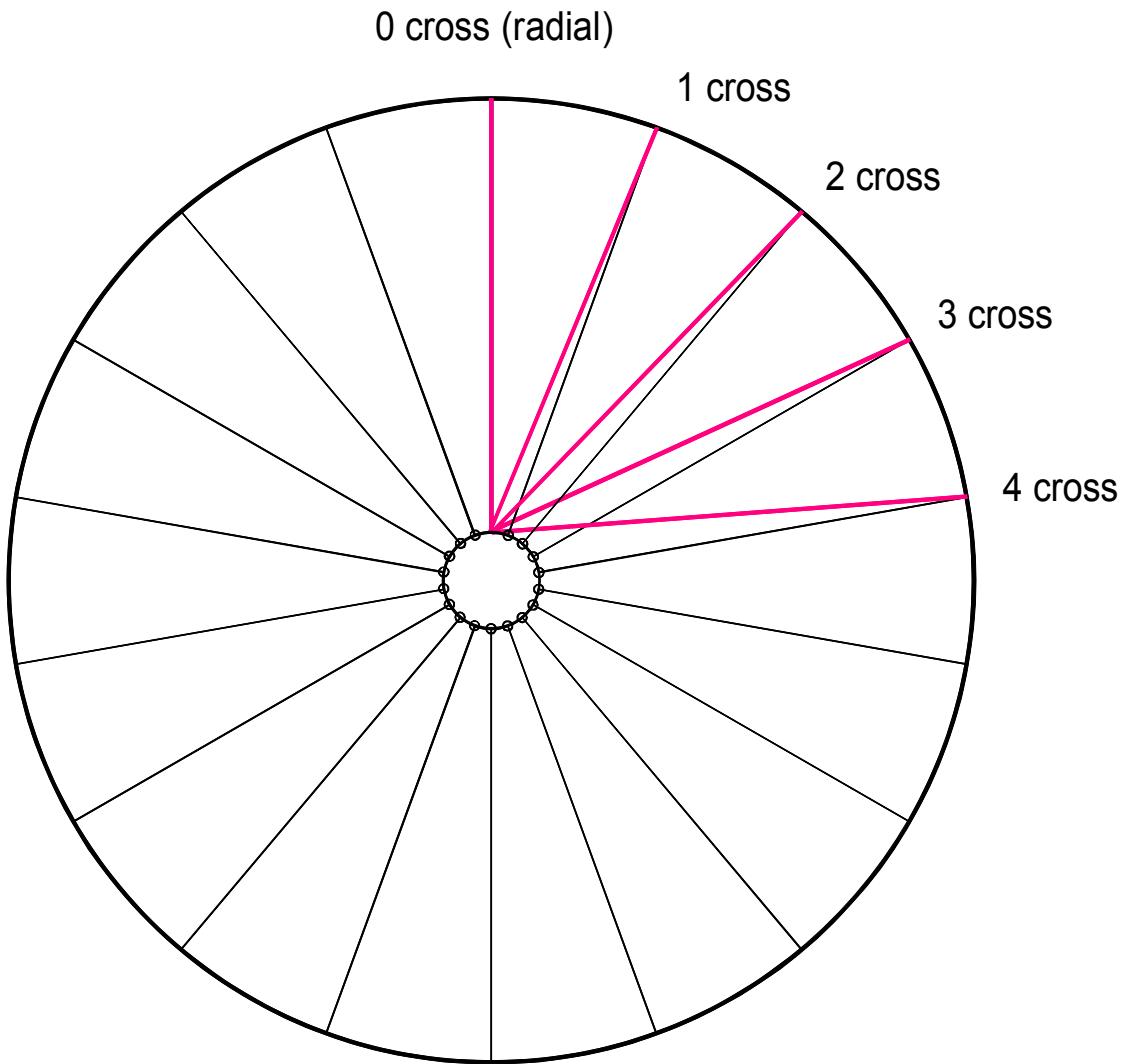
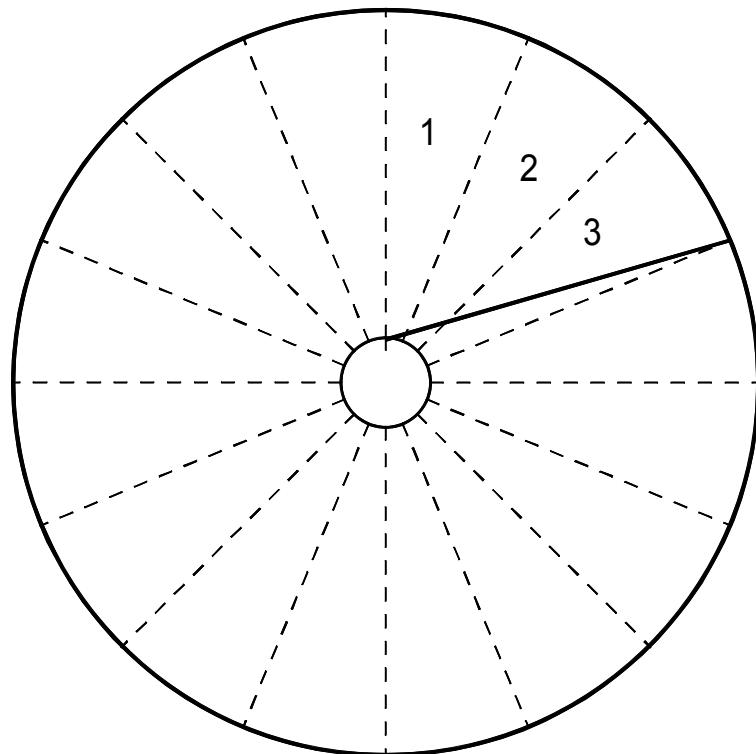


Figure 76 The placement of spokes in a crossed wheel

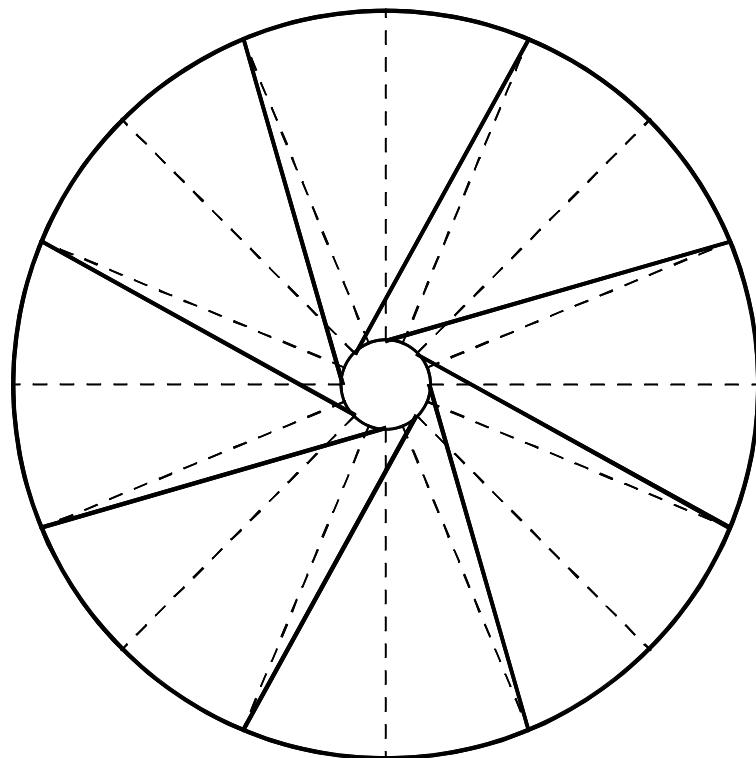
How to draw a wheel

The following diagrams show you how to draw a 32 spoked, 3 cross wheel. It is only necessary to draw one side because the opposite side is identical but rotated half of one hub hole pitch. The same technique is used for all other drillings and cross patterns (for cross patterns other than 3 cross modify the first step).

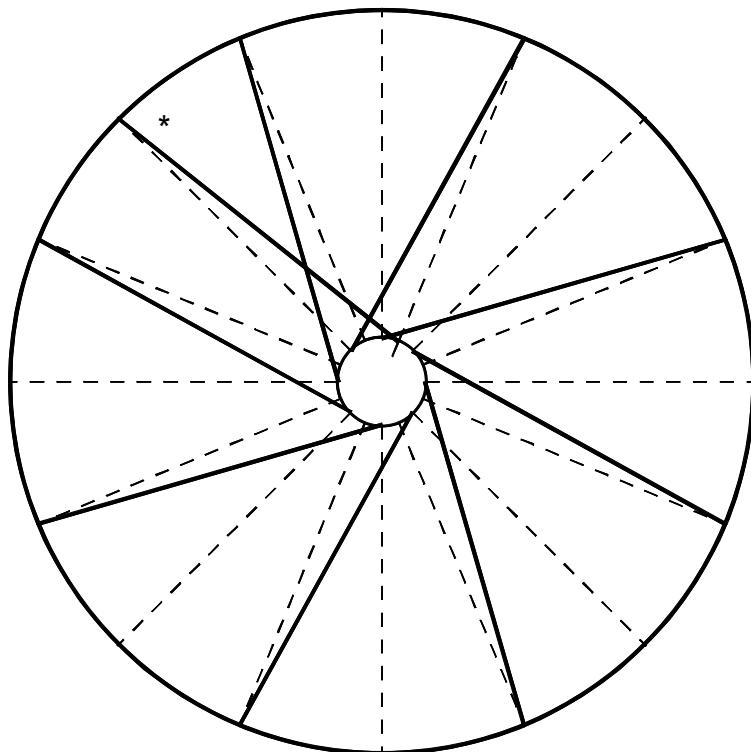
**Step 1**

The first spoke is shown in position.

Since it is a 3 cross wheel the spoke crosses 3 sectors before entering the rim.

**Step 2**

This spoke is now replicated 8 times.

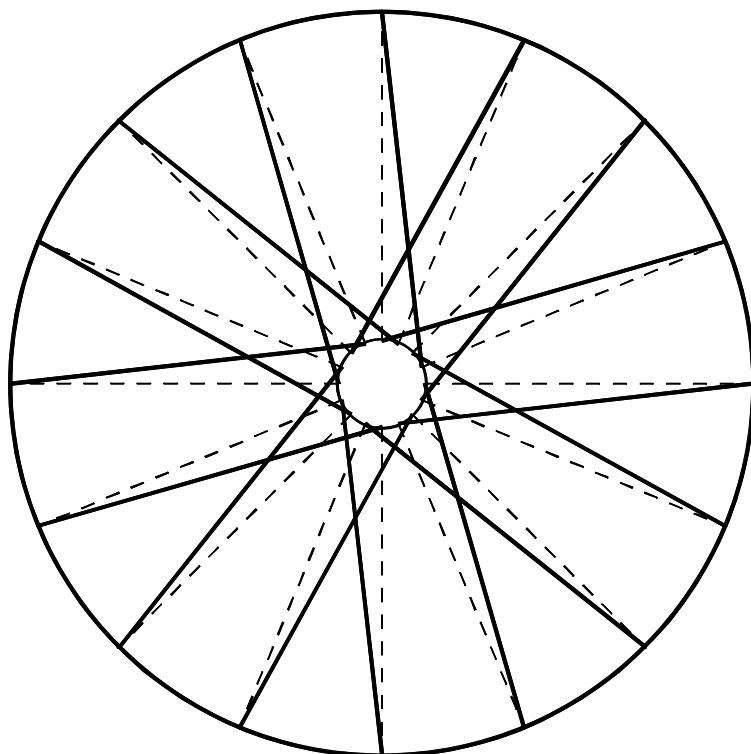


Step 3

The first spoke in the opposite direction is now in place (marked *).

It too crosses 3 sectors before entering the rim.

It actually crosses 3 other spokes which is the normal way of describing *cross pattern*. The first spoke it crosses is very close to the hub and is often missed when counting crosses on a built up wheel.



Step 4

The wheel with one side drawn.

Take a look at the wheel in Figure 41 on page 49 which has both sides laced and was drawn using the technique shown here.

What appears to be a complex arrangement is in fact quite a simple repeating pattern.

Wheel Building Checklist

Preparation and Lacing (*page 40*)

Measure your components and record the data including the spoke lengths being used. Oil the rim eyelets and spoke threads. Lace the wheel making sure you get the first spoke correct to ensure the valve hole ends up in the correct place. Complete the wheel in 8 steps:

1. Take up the slack (*page 51*)

Tighten the nipples using the nipple driver to take out the initial slack. If they are still loose then tighten a couple of turns with the wrench. The spokes must not be tight.

2. Align the spokes (*page 53*)

Press down any bows in the spokes at the hub flange.

3. Take up all of the slack (*page 53*)

Use the spoke wrench. Take care to always turn the wrench in the correct direction. The spokes will make a tone when plucked close to the nipple. Don't make them too tight.

4. Improve the lateral trueness (*page 54*)

Make the wheel laterally true, the closer the better.

5. Adjust the radial trueness (*page 55*)

Make the wheel radially true.

6. Equalise the spoke tensions (*page 55*)

The spokes should have the same tone when plucked. Only compare tensions on the same side on dished wheels. Make another check during final tensioning.

7. Check the wheel dish (*page 56*)

Take out most of the dish error and check regularly from now on and ensure it becomes perfect during final tensioning.

8. Complete the final tensioning (*page 60*)

Watch out for spoke twist (*page 58*)

Remember to stress the wheel (*page 59*)