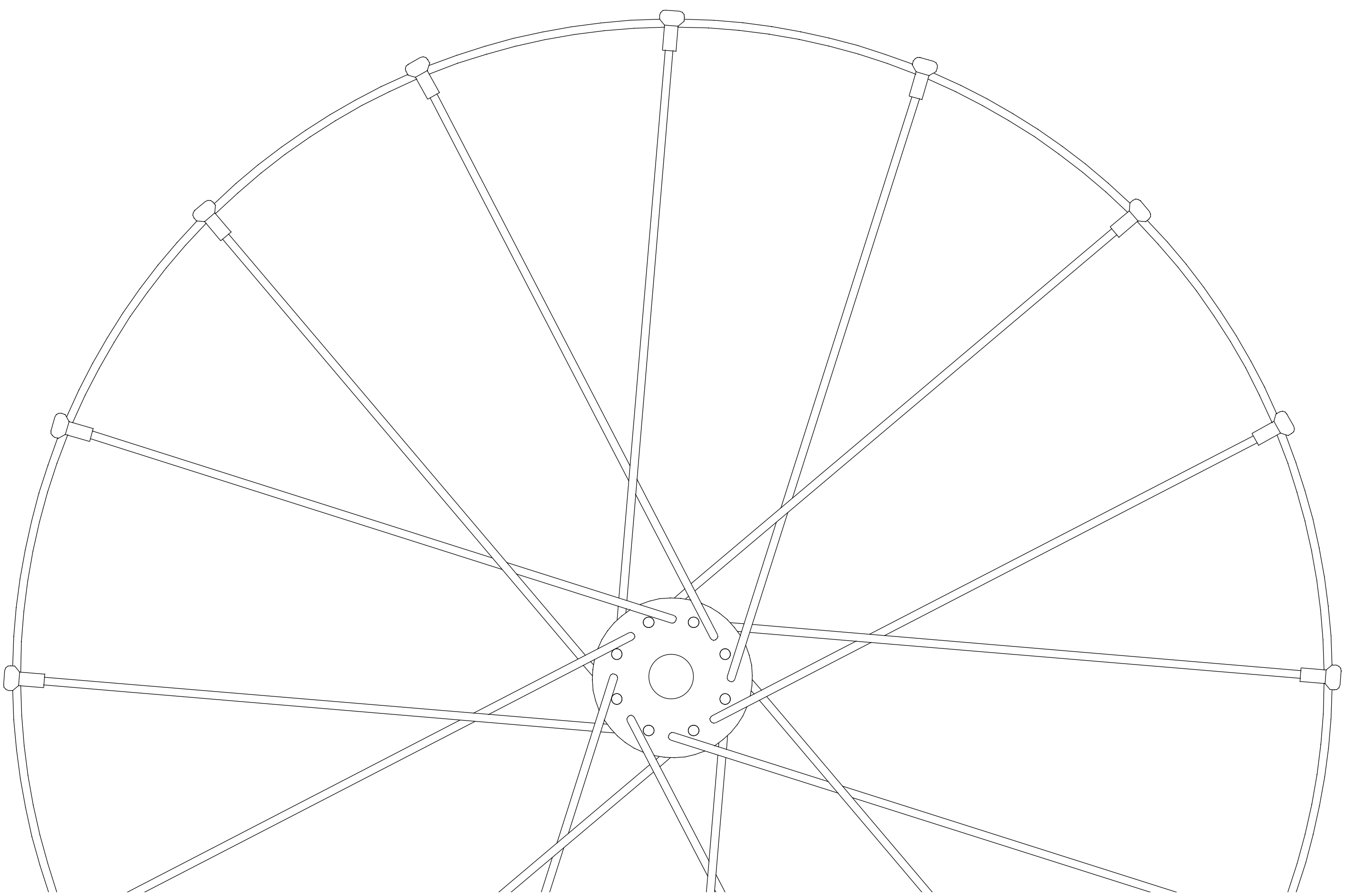
PROFESSIONAL GUIDE TO

WHEEL BUILDING

A Complete Reference for Cyclists



Roger Musson

7th Edition

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Contents

Writing this book and keeping it updated requires a lot of work. The book is not expensive, yet some people will still try and obtain a free copy by whatever means. If you are using a free copy of this book and you are benefitting from my work then please go to www.wheelpro.co.uk and make a purchase. Thanks, Roger.

Chapter 1

Introduction

Building a wheel is a standard procedure of assembling and tightening the spokes in the correct sequence and if you understand a few basic principles you'll soon be building wheels that will certainly be as good as, and more likely better than anything you can purchase.

If you ever see me build a wheel it looks simple and effortless but I'm following the exact procedure described in this book, it's just that the individual elements merge together into a flowing operation from start to finish. I know what to do in a given situation and I have manual dexterity and go about building a wheel with little fuss and it won't take long for you to achieve this standard. There's no art or artistic interpretation because your wheels will turn out the same as mine.

What I have done in this book 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 after reading this book you'll know as much about wheels 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.

The information provided in this book is based on my wheelbuilding experiences gained over many years which started out building wheels for my own use followed by owning a business that specialised in custom wheelbuilding. As well as customer wheels I've built wheels for professional race teams, I've run wheelbuilding courses and provided wheelbuilding demonstrations at numerous cycle shows. I also go to cycle race events to provide technical support (fixing wheels) for the riders, so I've fixed plenty of broken and out of true wheels and I think I've seen most things that can happen to a wheel. I've accumulated a lot of information and I'd like to share it with you.

I have a theoretical and practical engineering background and I like to form my own opinion on what is good and what is bad. I evaluate all aspects of the building process and find the techniques that enable me to build wheels efficiently and to ensure those wheels perform reliably when used, and these techniques are fully tested because I build plenty of wheels and have lots of feedback on how they perform from team riders and customers.

In the world of wheelbuilding there's no Einstein or some other lofty figure who we all look up to trying to tease information out of them, or to admire their skill and knowledge which seems a long way in front of what we are currently doing, these individuals in the wheelbuilding business do not exist. We are not in a field of science that has yet to make discoveries, that's where you'll find the mathematicians and scientists. You may think that superior wheelbuilding knowledge and superior wheels exist because if you shout loud enough or use the most exotic wheelbuilding tools it can be very persuasive, but when it comes to building wheels you can only go so far. Once you understand the concepts and can put them into practice by building reliable wheels then there's nowhere else to go and you join the rest of us who are building perfect wheels (there are also poor wheelbuilders who never make the grade and I've seen lots of these people who make basic errors resulting in poor wheels). I want to convince you that you can be as good as any of the top wheelbuilders and if

I do come across someone who is doing something special then I'll let you know, but please note, I'm not that someone.

You will come across wheelbuilding discussions on the Internet that may appear to give conflicting advice but until you have sufficient knowledge you have no way of knowing how good the other information is. Once you have built a wheel by following the procedures in this book you will be in a better position to assess what other people say and form your own opinion on how accurate and useful it is (or inaccurate and useless). Just don't take things at face value – not everything on the Internet is true! But generally there is nothing fundamentally different in what all the good wheel builders do apart from a few minor things here and there which may seem different but in reality are of little consequence.

A wheel is a pre tensioned elastic structure and the theory relating to how it reacts to applied forces is not trivial. Far too many people look at a wheel and make assumptions based on what they *think* is happening, but much of what is *actually* happening is counter intuitive and so mistakes in understanding are often made. You don't need to understand any of this theory to build a reliable wheel, but where relevant I'll go into a little more detail to backup some of the statements I make. Jobst Brandt in his book *The Bicycle Wheel* takes a closer look at the theory of the wheel and by using correct analysis he describes why components fail and dispels many long held myths surrounding the subject of wheels. One thing to bear in mind is that today's components are far superior to those analysed by Jobst, in particular modern hubs and rims are better designed and they are stronger and spoke material is now more fatigue resistant which means component failure is not the problem it once was. Jobst Brandt has also made valuable contributions to Internet discussions where his analysis on all topics (not just bicycle wheels) is based on sound engineering principles and I've quoted Jobst a couple of times in this book.

This book describes how to build wheels using hubs and rims with equally spaced holes and stainless steel spokes (round or bladed), what I call standard, or conventional wheels. The same method of building is used for all types of wheels whether they are for road, all aspects of mountain biking, BMX and many other wheels because *all cycle wheels are built the same*, once you've built one wheel you can build all the others and that includes low spoke count road race wheels with carbon fibre rims. Factory made wheelsets often use non standard components, but the principles of building them remain the same although replacing spokes or rebuilding them may be complicated by obscure assembly techniques and the difficulty of obtaining replacement rims and spokes.

I hope that you are soon riding on a pair of your own hand built wheels.

Thanks for purchasing,

Roger Musson

Chapter 2

Quick start guide

This quick start guide will give you the essentials for building a wheel with links to sections of the book that require reading, the rest of the book is a reference for further information.

Don't be alarmed by the amount of information I've given you, wheelbuilding is not difficult and I could have written a much briefer guide, but I'm sure you wouldn't want that, you are getting my full and complete knowledge with nothing left out. Read the sections that are relevant to your particular wheels and read through the rest of the book, not necessarily to understand everything in detail, but to acquaint yourself with the topics covered.

I build all wheels exactly the same way whether they are for road race, mountain bike or any other cycling discipline, I don't build wheels differently for different applications, all that changes are the hubs and rims, which means you only need to learn one building technique.

Dismantling an existing wheel and rebuilding it for practice is not required because you don't need to practice before doing the real thing. Rather than dismantle your existing wheel you'd be better off studying it and fixing any errors and by doing this you will gain some additional wheelbuilding skills, take a look at *truing an existing wheel* on page 104.

The best place to start is by building a new wheel.

1. Select your wheel components

To give you some advice on selecting components read the chapter on Wheel design on page 35.

If you are using some components taken from an existing wheel then read these guidelines below.

A previously used hub

Read the section on *previously used hubs* on page 10 because your aim is to match how it was originally laced and match the previous indentations made by the spoke elbows. So you *may* need to modify the lacing instruction (it's all described in the lacing section). You'll learn a lot from this exercise.

A previously used rim

For your first build it will be better if you use a brand new rim that is flat and round because it will be easier to learn the wheelbuilding principles. For example if you are building with a previously used rim and trying to fix a radial error you won't be sure if the error was caused by incorrect tightening of the spokes or due to an existing flat spot in the rim when the wheel hit a rock when it was last used. If you are struggling to obtain lateral trueness with equalised spoke tensions then you don't know whether it's a mistake in your building technique or that the old rim is warped. So make sure your used rim is in very good condition and ideally flat and round.

Previously used spokes

Reusing old spokes is perfectly acceptable, but there are a few do's and don'ts which are described on page 102. In particular, you need to know their complete history because using poor quality spokes, or spokes that have some damage (often not visible) is not a good idea, nor is using brand new spokes taken from a new and unused wheel (as explained on page 102).

For your first wheelbuild I recommend using new spokes from a recognised manufacturer because they will be in 100% perfect condition and you will calculate and purchase the correct length. For future wheels you will be able to reuse these spokes with confidence because you know the exact history of them.

2. Work out your spoke lengths

My aim is to teach you wheelbuilding and being able to calculate spoke lengths is an important part of the wheelbuilding process. If you take the easy route and use spoke length data found on the Internet or from other sources then be prepared for an expensive mistake because quite often this information is wrong. This means you must read the chapter on calculating spoke lengths on page 51, and don't forget to record your data (page 56).

You need to obtain your hubs and rims and work out the spoke lengths, and **then** order your spokes. You cannot order everything in one go because trying to save on postage or time is false economy.

When your hubs and rims arrive, measure them and pop the dimensions into the same spoke length calculator that I use (as advised in the spoke length chapter). The number of crosses in the lacing pattern has no effect on the performance of the wheel, so if you are building a road or mountain bike wheel with 36, 32 or 28 spokes use a 3-cross lacing pattern, for 24 spoke wheels use a 2-cross pattern. If you are building a small diameter wheel or something with a large diameter hub, for example and internal gear hub, then you may need to reduce the number of crosses to prevent an adverse spoke entry angle as advised on page 39.

Buy your spokes

You will not get better performing wheels by spending more on spokes, so a standard double butted spoke is an excellent choice, something like the *DT Competition* or an equivalent from other manufacturers. Do not use self locking nipples because they offer no advantage and actually make building the wheel more difficult due to increasing the spoke twist.

When the spokes arrive you need to make sure you were supplied with the correct length. Look at Figure 18 on page 21 and take a ruler and measure yours, if they are wrong then you won't be able to build the wheel.

3. Obtain some wheelbuilding tools

- A spoke wrench, I use a Red *Spokey* (page 43).

- A truing stand. Building your wheel in the bike frame is okay but a truing stand is much better. If you haven't got a truing stand then consider making one exactly like the one I use, full details for making the stand are shown on page 111.
- A dishing tool. Make the one described on page 45 because it's very good.
- A nipple driver. This is an extremely useful tool. See page 47.
- A pair of substantial leather gloves. See page 49.

4. Lace your wheel

Lace your wheel starting on page 65. The instructions are the same for all cross laced and radial wheels and the only time this procedure *may* need altering is if you have a used hub and need to match the spoke indents in the old hub (it's all described in the lacing instructions).

Once laced it's a good idea to strip the wheel down and lace it up again. You need to be able to lace it without looking at the book. If you are using two lengths of spokes then remember to keep them separated.

5. Complete your wheel

Finish your wheel starting on page 81.

6. Review what you've done

Read the completion steps again (starting on page 81) so that you become familiar with the process.

7. Your next wheel

Don't assume you can build it without looking at the book because it's easy to miss out something important. So for the next few wheels continue to read the lacing and tensioning chapters, then after you've done a few more wheels you can start using the checklist on page 109.

A note for new wheelbuilders

If these are your first wheels then it's important you follow the lacing and completion instructions **exactly as written**. Do not miss out any steps and do not incorporate any techniques from other sources because I want to give you a solid foundation in wheelbuilding using the techniques that I use. Once you are building reliable wheels then you can look at what other wheelbuilders are doing and use your knowledge to assess how useful the other information is.

Chapter 3

Components and features

This chapter takes a close look at the features of a wheel and its components.

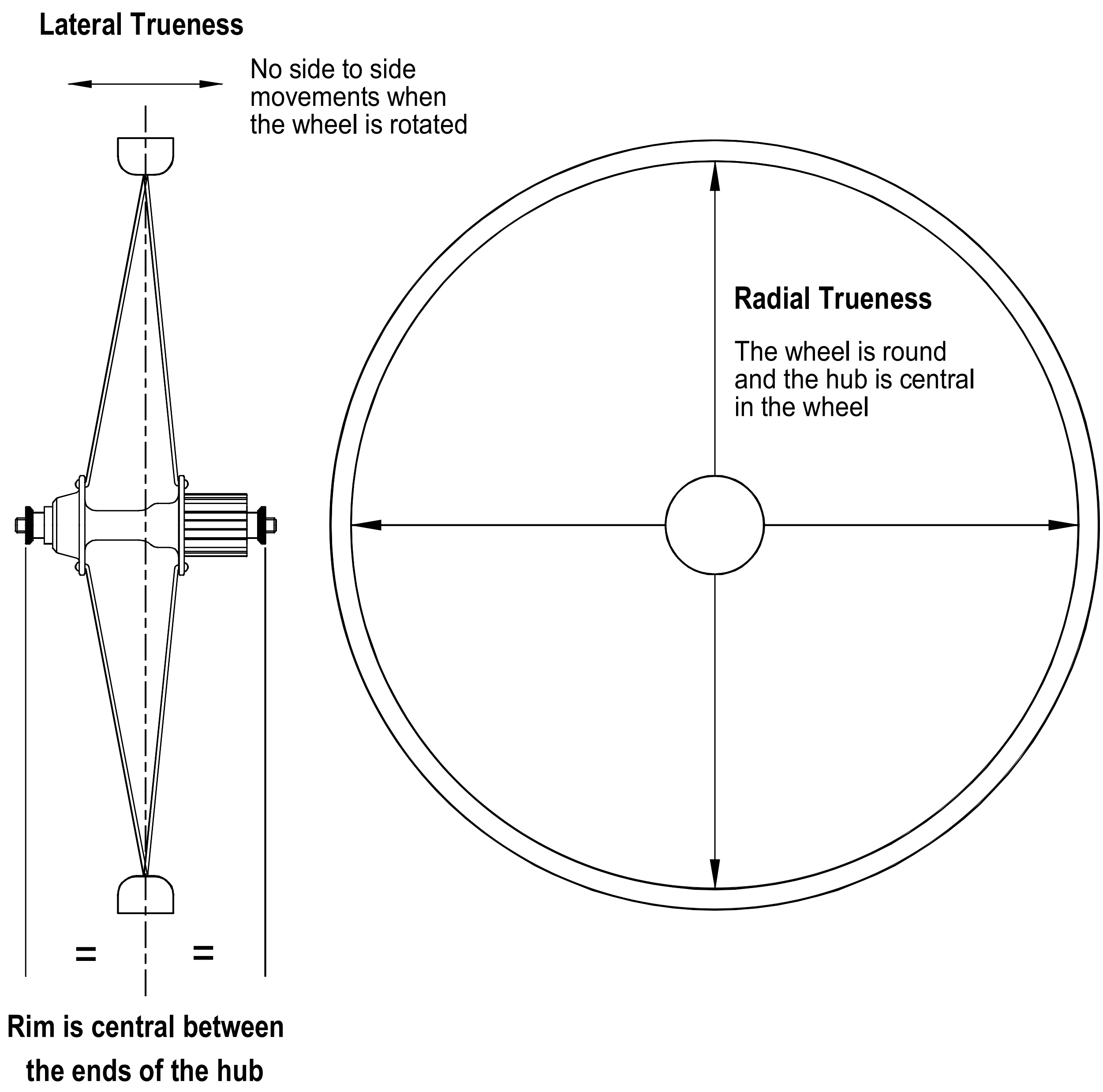


Figure 1 A true wheel

Hubs

Hubs have a left and right side and it is usual to use the terms *left* and *right* to identify the particular side of the hub. Manufacturers will often quote the flange offset dimensions as centre to left and centre to right. Left and right is from the rider's perspective which means the right side of the bike is where the chain is. An alternate naming convention for rear hubs is to say *drive side* for the side of the hub that takes the cassette sprockets and *non drive side* for the opposite side.

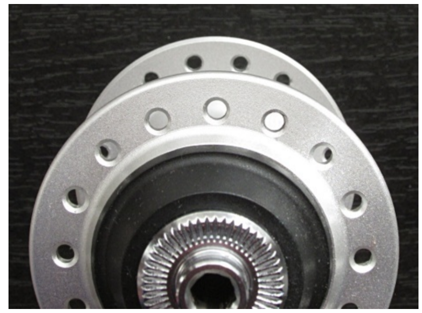


Figure 2 Hub spoke holes

The spoke holes on the hub flanges are offset so that 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 identify the offset holes.

Hub countersunk holes

The spoke holes in the hub will usually be countersunk to accommodate the elbow of the spoke. Countersinking is not an important consideration on aluminium hub flanges since the spokes will bed themselves into the softer material regardless of any countersinking.

Hub flange thickness

The thickness of the hub flange should adequately support the spoke. Very thin flanges can lead to increased spoke breakages due to the elbow flexing and one solution to help prevent this is to use a small washer as packing between the head of the spoke and the hub flange. This was common on old generation hubs often with thin steel flanges but all of today's aluminium hubs have adequate flange thickness which makes the use of washers unnecessary and consequently I have never used washers in any of my wheels.

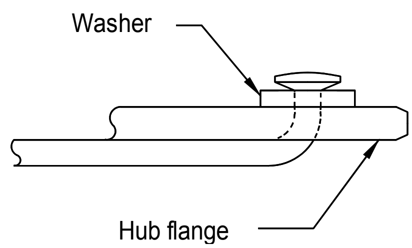


Figure 3 Spoke head washers

Spoke hole diameter

Ideally the spoke should be a snug fit in the hub so that the spoke elbow is fully supported. If a normal 2mm diameter spoke seems a tight fit in the hub there is the temptation is to use a spoke head punch to fully seat it. I have never used a spoke punch and even on tight fitting spokes the spoke tension in conjunction with stress relieving is enough to fully seat the spoke in the hub flange. Nowadays hubs have to be compatible with wheel assembly lines and wheelbuilding machines so hubs tend to have more spoke hole clearance resulting in a looser fit because tight fitting spokes would slow down this method of building.

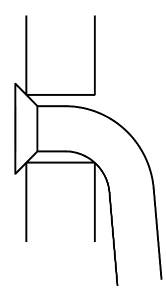


Figure 4 Spoke hole too large

If you are using oversized spokes then your hub must be designed to take them, oversized spokes are described on page 22.

If the diameter of the spoke hole is too large then the conical head of the spoke will move into the hole leaving the spoke unsupported and floating in mid air and the poor fit will influence the fatigue life of the spoke.

Non standard spoke holes

A factory made wheelset using a non standard lacing pattern is likely to use a hub and rim with a unique hole pattern. Hubs taken from these wheels are usually impossible to lace it into conventional rims and even if there were a way of lacing them it's likely to be a compromise, and working out spoke lengths will be very difficult. Any hub that doesn't look like the one shown in Figure 2 on page 8 will cause you problems.

Reader John Shearron kindly sent a photograph showing how the holes in this hub were perfectly aligned. A spoke has been placed through the hub to show how the holes are not offset. This hub is specific to a factory made wheelset using a paired spoke lacing pattern and it is not possible to lace it into a rim with equally spaced holes.

Figure 5 Perfectly aligned hub holes

Another example of a non standard hub are rear hubs used with the triplet lacing pattern (sometimes called 2:1 lacing) which have twice the number of holes on the right side. These hubs are built into rims with equally spaced holes but you need to be careful when selecting a rim. A conventional rim expects a hub with the same number of spokes either side and if the rim holes are staggered, for example a 24 hole rim, it will have 12 staggered left and 12 right. A 24 hole triplet lacing pattern requires a rim with 8 holes staggered left and 16 right or a rim with zero stagger. If you lace a triplet hub into a conventionally staggered rim you will introduce severe bends into some of the spokes as they enter the rim which will increase the likelihood of a fatigue failure at the spoke threads. Triplet lacing is going out of fashion because it offers no real benefit and if a left side spoke breaks whilst out riding the wheel will go severely out of true making it virtually unridable, plus there is a limited supply of suitable rims.

Straight pull hubs

A straight pull hub is one that is designed to take straight pull spokes. The design of the hub will dictate the lacing pattern to use, for example if it's a 3 cross design then it's impossible to lace it 2 cross. Straight pull hubs offer no advantage over normal hubs, they do not increase wheel strength and stiffness and they do not eliminate spoke breakages (read about straight pull spokes on page 23). When calculating spoke lengths you must use a spoke length calculator that is straight pull compatible, this is covered in the spoke length section on page 63.

Previously used hubs

When I rebuild a previously used hub I always lace it with the same spoke orientation as the original build which ensures the spoke elbows match the previous indentations in the hub.

This is essentially a cosmetic exercise because I don't want the old marks to be visible although there is some theory that says matching the original indents is better from a metallurgical point of view and helps protect the hub from fatigue failure (where cracks propagate outwards from a spoke hole eventually resulting in a piece of the hub flange breaking off).

Figure 6
A previously used hub

If you are taking a hub from an old wheel then before you remove the spokes take a close look at the spoke elbows on the hub flange and determine which lacing option it uses, you might want to take a photograph of it. If you obtained a used hub on its own then a little extra thought is required and you need to carefully study the wear marks to determine how it was previously laced. It's going to be one of the options on page 30 and instructions for lacing these are given in the chapter on lacing the wheel. 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. The hub in Figure 6 is shown on page 30 built into a wheel using an Option C lacing pattern.

Rims

Rim sizing

Rim sizing is confusing because the size often includes a numeric value in millimetres or inches that does not correspond to any physical dimension on the rim. Some of the popular sizes are 700C, 650B, 20", 26", 27.5" and 29'er and the size refers to the outside diameter of a typical tyre when installed on the rim which is very vague and provides no useful information. Incidentally, the "C" in 700C refers to a tyre of type C and not a metric unit of measure; the wheel is 700mm in diameter when a type C tyre is fitted (and I doubt anyone knows what a type C tyre is or a type B for that matter).

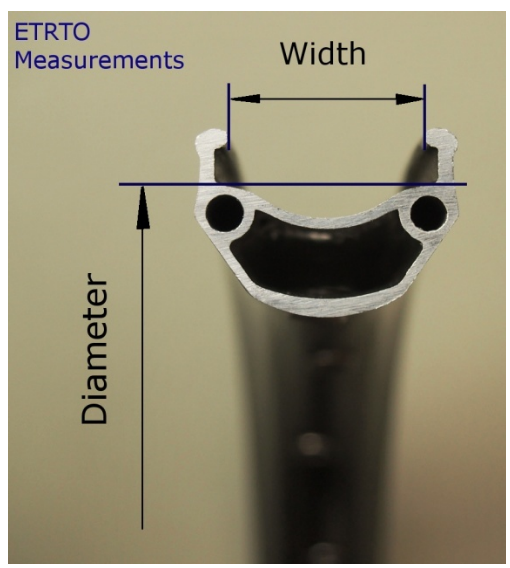


Figure 7 ETRTO rim dimensions

The actual diameter of the rim is defined by the *European Tyre and Rim Technical Organisation* (ETRTO). The dimension is in millimetres and is measured at the point where the tyre locates (also known as the bead seat diameter) as shown in Figure 7.

The ETRTO also define the inner width of the rim and both diameter and width will appear on rim labels (see Figure 8). Do not put the ETRTO diameter into spoke length calculators!

Figure 8
Rim label dimensions

The ETRTO publish a comprehensive document which standardises the dimensions of tyres and rims for all ground vehicles. A subset of the cycle wheel definitions now form the basis of ISO 5775 published by the International Standards Organisation. ISO 5775-1 covers tyres, and ISO 5775-2 covers rims.

Here are some common rims and their actual diameter.

Name	ETRTO*	Application
27”	630	The old standard for road bikes. These rims are mainly used for restoration projects.
700C	622	The modern standard for road wheels.
29’er	622	Large mountain bike wheels. These are the same diameter as a 700c road rim. Put the two side by side and they will be identical in diameter.
650B	584	Medium sized mountain bike wheels. Based on the ETRTO diameters you can see that these rims are 25mm larger in diameter than a 26” rim.
27.5	584	An alternative name for 650B.
26”	559	The old standard for mountain bike wheels.
20”	406	Standard BMX wheels.

* Bead seat diameter in millimetres.

Rim ERD

For calculating spoke lengths you require the *Effective Rim Diameter (ERD)* which is the diameter of the rim at the spoke ends in the finished wheel as shown in Figure 9. The term *ERD* is universally known amongst wheelbuilders and rim manufacturers and its sole purpose is for calculating spoke lengths.

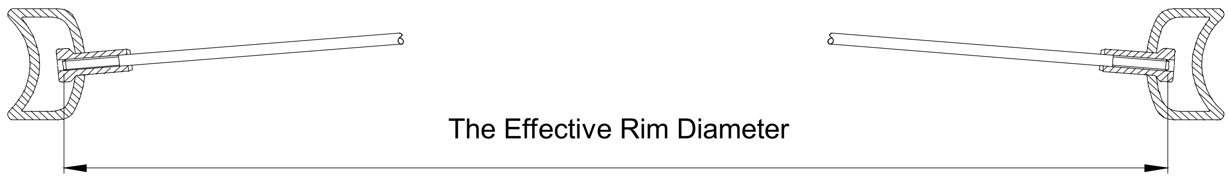


Figure 9   Rim ERD

The ERD often appears on rim labels and usually listed on the manufacturers websites, but the values shown are often wrong and you should not use them. The ERD is not a strictly defined measurement and can be interpreted differently by rim manufacturers. When calculating spoke lengths you must measure the ERD yourself using the correct procedure which is described in the spoke length chapter on page 51. In the example in Figure 8 the ERD actually measures 542mm and if the spokes lengths were calculated using the figure specified on the rim they would be 1mm too long.

Rim spoke hole stagger

The spoke holes in a rim usually have a left/right stagger and it is important to identify this since left orientated rim holes have their spokes connected to the left hub flange and right rim holes to the right hub flange. Look on the inside of the rim at the spoke holes either side of the valve hole (shown in black in Figure 10) and see how there are two possibilities. It doesn't matter which way up the rim is because the orientation will not change. For illustration purposes the left/right stagger shown here is greatly exaggerated and on an actual rim it is not so obvious and often difficult to see and some rims will have the holes positioned centrally with no left/right stagger. It's unwise to check the stagger by looking into the rim channel from the outside because rims with angled or directionally drilled spoke holes can give a false indication of the stagger (these rims are described on page 13).

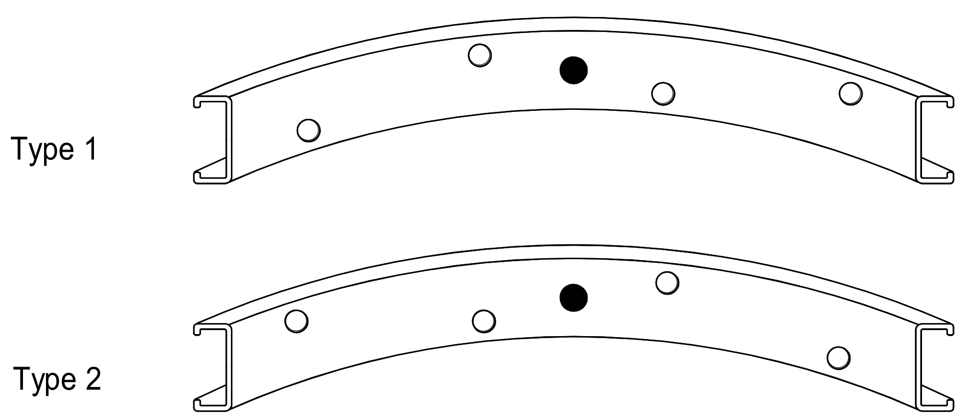


Figure 10   Spoke hole stagger

I'm calling the two rim staggers type 1 and type 2 in order to remove all ambiguity when describing how to lace them. The type 1 pattern is by far the most common but you should always check before lacing the wheel. If you have a type 2 rim and incorrectly lace it as a type 1 rim then the spokes will be forced out of their natural alignment and the bending stress at the spoke threads will eventually result in fatigue fractures causing your spokes to start snapping at the spoke thread.

You may come across various names for the two types of stagger, for example the normal type 1 stagger is sometimes called European, French or F2, and the alternate type 2 stagger known as F1.

If you are in Europe then watch out for *city bikes* or low cost wheels where the type 2 stagger is occassionally used.

I recommend you examine every rim you use and check to see what type of stagger it has stagger.

The spoke hole stagger is usually quite small and will not affect spoke length, however if there is a visually large stagger, for example on fatbike rims, then this needs to be taken into account when calculating spoke lengths and is described on page 57 (right hand diagram).

Angled spoke holes

On some rims the spoke holes are drilled at an angle to allow a natural spoke line between the rim and hub, this is also known as directional drilling and is common on carbon fibre rims and others where the rim profile has a V section.

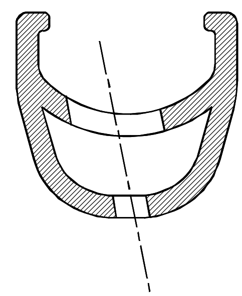


Figure 11
Angled spoke hole

On these rims it is not advisable to look into the rim channel from the outside because the stagger may appear on the opposite side to which it actually is. In Figure 11 the rim hole is positioned left but the spoke goes to the right side of the hub. If you laced it to the left side of the hub there would be a massive spoke misalignment which will eventually lead to a fatigue fracture at the spoke threads.

Figure 11 shows a rim with a spoke hole drilled in an axial direction. The rim holes can also be angled in a radial direction to allow a natural spoke line for cross laced wheels which is useful when using large diameter hubs (see adverse spoke entry angle on page 39).

Figure 12 shows an example of a carbon rim with angled spoke holes. The central hole is the valve hole and note how the spoke to the left hole goes to the opposite side of the hub. Looking on the outside of the rim it appears to be a type 2 stagger but it's actually a rim with a type 1 stagger.

Figure 12 Carbon rim with angled spoke holes (type 1 stagger)

How to check the rim stagger

If you want to see how the spoke holes affect the spoke line then pass a spoke through the rim and attach a nipple and you will soon see the natural line as you gently pull the spoke sideways left and right because it will move further to one side than the other. If the rim is centrally drilled then it will pull the same amount on both sides.

Eyelet design

A rim with no eyelets has plain drilled holes and the single eyelet design adds a simple steel collar around the spoke hole to provide a more robust bearing surface for the spoke nipple. The double eyelet design can be used on 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 feature because the spoke tension is distributed across two surfaces 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.

Choosing which eyelet design is not a consideration for the builder, the rim manufacturer has made the choice for the particular rim and there is no difference when it comes to building either type.

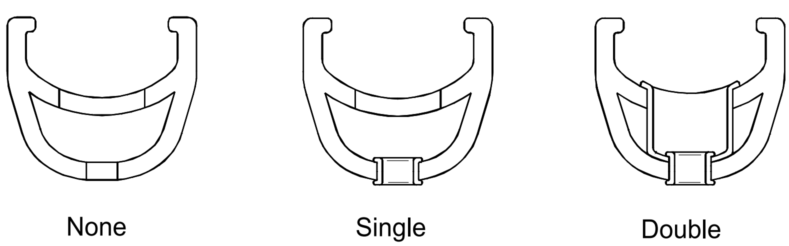


Figure 13 Rim eyelet design

Nipple washers

Putting a washer underneath the nipple on a non eyeleted rim sounds like a good idea. The washer provides a bearing surface to protect the aluminium as the nipple is tightened and it spreads the spoke tension over a greater area. If a rim cracks *without* using nipple washers then it was a poorly designed rim with insufficient spoke bed thickness.

I have never used nipple washers on any of the wheels I've built and they have all been trouble free, both in building and in use. If washers were necessary then the manufacturer would mention this with the rim specifications found on their website. If you have any doubts about using washers on lightweight rims with no eyelets you can always ask the rim manufacturer.

If you decide to use washers then make sure they are supplied by a spoke manufacturer, for example Sapim, which ensures they are properly designed for the task in terms of shape and thickness. When calculating spoke lengths take the washers into account because they will increase the rim ERD which in turn increases the spoke length, so measure the rim ERD then add on the thickness of two spoke washers.

Pinned rim joints

A rim starts as a piece of aluminium extrusion which is formed into a circular shape and joined together using either a pinned or a welded joint. The pin jointed rim has a couple of pins inserted into one end of the rim and the other end pushed flush against it, there is no adhesive on the faces of the rim and the pins. In the example in Figure 14 the pins are a tight friction fit. The sleeve jointed rim works on a similar principle but instead of pins a small sleeve or plug is used. Pinned and sleeve jointed rims are often thought as being weaker than a welded rim 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. One feature of the pin or sleeve jointed rim is that during manufacture the rim faces are not always pushed perfectly flat against each other and the tiny gap often concerns new wheelbuilders who believe they have a defective rim. The rim is not defective and the gap will quickly close during building once the spokes start to tighten. 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, however it makes no difference which means you lace pin jointed rims the same as any other rim. The discussion on compressive force on page 16 will explain all this.

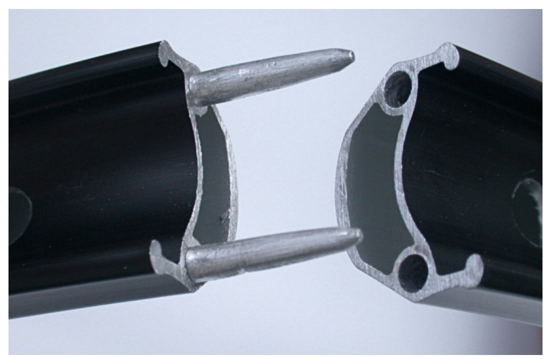


Figure 14
Pin jointed rim

Welded rim joints

The other type of joint is the welded joint. First a small sleeve is inserted to align the two faces and hold them together and then the joint is welded. 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 will result in a weak rim meaning all methods of joining rims are reliable and safe.

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 so balances the wheel.

Rim compressive force

The rim in a fully tensioned wheel is subjected to a high compressive force and to illustrate this I built a wheel from a rim sawn into pieces. The pieces were initially held together with tape forming a circular rim and I laced it up and gave it a small amount of tension then removed the tape. The joint faces of the cut sections were not perfectly aligned so I just pushed one assuming it would slide easily. It didn't, and I had to back off a fair bit of spoke tension before I could slide the joints and align the edges. Even a small amount of tension puts a significant amount of compressive force in the rim pushing the joints together so you'll realise that under full tension the forces are massive. I completed the build and the fully tensioned wheel was a solid structure and with the wheel flat on the ground it could easily withstand my full weight on the edges of the rim.

Figure 15 Rim pieces

Like all structures there is a limit to how much force can be tolerated before something has to give, and if you keep increasing the compressive force in the rim by tightening the spokes the rim will eventually start to buckle. Imagine the rim straightened out as a long slender strut with a compressive force applied to the ends trying to buckle it. 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 aluminium road rim. I'll talk more on this in the building section when determining spoke tension.

Rim centering and wheel dish

Wheels are built with the rim central between the ends of the hub (the hub faces that rest against the frame or fork). This ensures the rim aligns correctly with other components of the bike such as the frame, forks and rim brakes. There is an exception where the rim is not central and this is for rear wheels used in an offset frame (see page 19).

It's still common to use *central between the locknuts* to describe a centred wheel and is derived from hubs using cup and cone bearings with locknuts either side of the hub to secure the cones after adjusting the bearing end load. Locknuts are still found on hubs from Shimano that use cup and cone bearings but most hubs now use cartridge bearings with push on end spacers or caps rather than locknuts. You will sometimes come across the term *over locknut dimension* often abbreviated to OLD which refers to the width of the hub, for example 135mm OLD.

If the wheel is not built central it will be noticeable with rim brakes because swapping different wheels in your bike will require adjusting the position of the brakes pads. A non central rim will not affect the position of a disc brake rotor because the rotor is located on the hub and is not influenced by the position of the rim. If the rim appears to be too far over to one side and getting close to the frame or fork then don't assume it's a centering error because it will need to be a very poorly built wheel to cause this situation, more likely it will be the hub that is misaligned in the fork or frame dropout with the wheel being tilted over to one side. If you have a rear wheel that has the rim positioned too far over to the right you may have an offset frame with a non offset (normal) wheel placed in it (see offset frames on page 19).

Wheel dish is a visual feature of a wheel. If the centre to left and centre to right flange distances of the hub are different then the spokes either side will connect to the rim at different angles and the resulting wheel will resemble a dish. Rear wheels in particular look like a dish as the right side flange is moved inwards to make room for the cassette sprockets (see the wheel in Figure 1 on page 7). Front wheels using rim brakes are a *dishless* or symmetric (centre to left and right dimensions being the same), rear single speed wheels are often dishless, and if a rear hub has sufficient width then a multi speed cassette hub can be designed dishless (see Figure 16 on page 18). Front wheels that take a disc brake are dished because the left side flange is moved inwards to provide room for the disc rotor. You'll often hear the phrase "checking the dish" whereas in reality you are checking that the rim is centred between the ends of the hub using a dishing or centering tool (see page 45).

Wider rear hubs result in less dish which makes a stronger wheel because the spokes on the right side are less steep and the improved bracing angle means the wheel is better at withstanding side loads from the right, plus the spoke tension difference between left and right is improved meaning the left spokes can take more of the vertical load without going slack. But it's all relative to the wheel's intended use which means the 130mm rear width of modern road hubs is plenty strong enough, but heavily laden touring bikes which require more strength will use 135mm rear hubs, and for mountain bikes the rear hubs start at 135mm and for downhill race bikes a 150mm rear hub is available which results in an almost dishless and very strong rear wheel.

142mm, 157mm, 177mm and 197mm rear hubs are 135mm, 150mm, 170mm and 190mm hubs with the axle extended 3.5mm either side to provide a better means of locating the hub in a compatible frame. The axle extension does not alter the wheel dish, for example if the same hub is available in 135mm and 142mm then both will have the same flange spacing and hence the same dish.

Figure 16 shows how a wider hub improves the dish. The example is drawn to scale using the dimensions of the Aivee MT3 disc hub, the red line is the centre line between the hub faces. The first is a 135mm hub and the flange spacing (32.5 and 21.5) will build a dished wheel. The second hub is the 150mm version and the flange spacing now results in a dishless wheel.

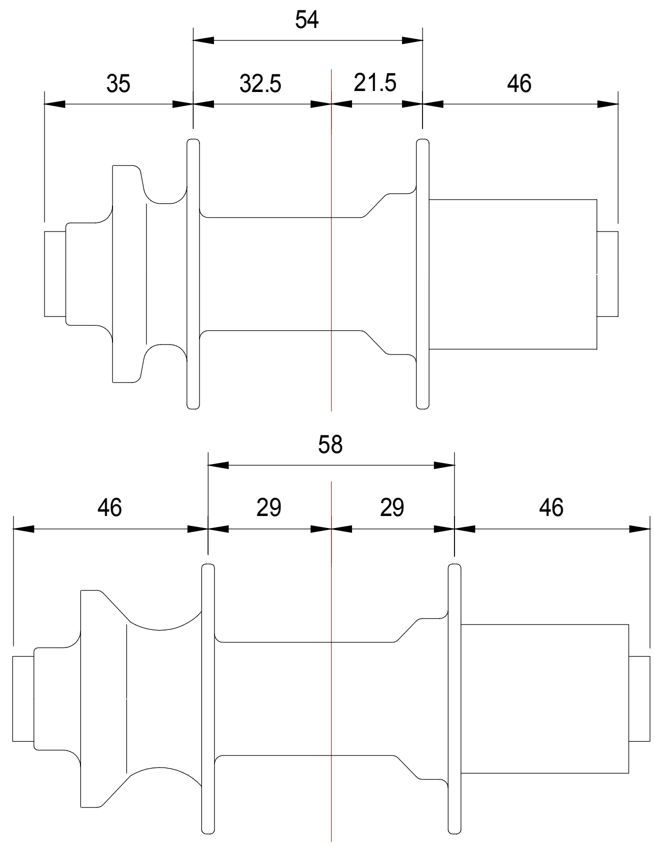


Figure 16 135mm and 150mm hub flange spacing

Tension differences in a dished wheel

The spokes on one side of a dished wheel will have a lower tension when compared to the other side, the lower tension spokes being the rear left and the front right on disc brake hubs. The lower tensioned side will still be tight enough to ensure a reliable wheel but many new wheelbuilders are concerned about the tension difference and that one side seems far too low. When you build a wheel you always measure or assess the tension of the tight side spokes, you never measure the other side. The tension in the other side (the slack side) is determined by the hub flange offsets and the spoke lengths. This formula is only provided for information purposes, you do not need to make any calculations or take this into account when building a wheel.

$$\text{Tension}_{\text{Low}} = \text{Tension}_{\text{High}} \times \left(\frac{\text{Offset}_{\text{Small}}}{\text{Offset}_{\text{Large}}}\right) \times \left(\frac{\text{SpokeLength}_{\text{Large-offset-side}}}{\text{SpokeLength}_{\text{Small-offset-side}}}\right)$$

Where:

Tension = Spoke tension

Offset = Centre to flange hub dimensions

This is the theoretically correct formula, however the spoke lengths either side only differ by a couple of mm and will have a negligible effect on the result so it is usual to ignore the spoke lengths. For example, a rear hub with flange offsets of 33mm left and 19mm right, the tension in the left side will be TensionRight * 19/33, and if your right side tension was 125kg the spoke tension in the left will be 72kg.

You cannot do anything during building that will affect the amount of dish in the finished wheel and neither can you try to balance out the left and right spoke tensions. You build wheel with the rim central and accept the resulting dish and the difference in spoke tensions. The hub geometry dictates the amount of dish and the hub manufacturer will ensure the resulting wheel is suitable for its intended use. Problems can occur if you modify a hub and inadvertently change the left and right flange offsets, for example changing the axle spacers on an old 126mm 7 speed rear hub (taking spacers off the left side and moving them to the right) to make room for a modern wider 10 speed cassette body will result in a wheel with extreme dish and near vertical spokes on the right side which will have a detrimental effect on the wheel's reliability and safety.

Offset rims

A technique to reduce wheel dish is to use a rim where the spoke holes positioned away from the rim centreline by around 4mm. These rims are called offset or asymmetric rims (sometimes abbreviated to ASYM). Offset rims are not common because there is nothing wrong with standard rims although offset rims do give a small benefit since they improve the dish and the imbalance between the left and right spoke tensions.

Figure 17 Offset rim

To build a wheel using an offset rim you need to calculate the spoke lengths differently and this is explained in the spoke length chapter on page 57. When lacing an offset rim you need to orientate the rim correctly:

- For rear wheels the offset is positioned away from the right side as shown in Figure 17.
- For disc brake front wheels the offset is away from the left (disc) side and the rim in Figure 17 would be flipped around.

Offset frames

A standard cycle frame is symmetrical and requires a wheel with the rim central between the ends of the hub. An offset frame is not symmetrical with the rear triangle positioned off centre to the right. For an offset frame the rim is not central between the ends of the hub but positioned more towards the left side so that when the wheel is placed in the frame the rim lies central in the cycle. The frame manufacturer will specify the amount of offset the frame has.

Conventional offset frame

These frames have an offset of around 6mm which requires the rim positioned towards the left side of the hub by 6mm. This has two advantages, the is rim more central between the hub flanges which reduces the wheel dish and makes a stronger rear wheel, and on mountain bikes where the trend is for wider rims it provides additional clearance between the chain and tire.

Conventional offset frames are not common; current examples are the Cannondale frames which feature Ai Asymmetric Integration. If you fit a standard centrally built wheel into an offset frame the rim will be far too close to the right side of the frame and the Cannondale user manual says: *Standard wheels assembled on this frame will result in insufficient tire clearance leading to rubbing and serious frame damage. This kind of damage is not covered by the Cannondale Limited Warranty*.

Fatbike offset frames

Fatbikes use extremely wide rims and you need to ensure the chain doesn't hit the tyre. The solution is to move the rear cassette and chainline outwards to the right and away from the tyre and there are two methods of accomplishing this. You can use a very wide frame spacing that takes a wide hub (fatbike hubs from 170mm to 190mm are available). Or use a standard 135mm hub in conjunction with a frame that has a large offset (fatbike frames with offsets of 17.5mm to 28mm are available). With these large offsets you cannot use a rim with the spoke holes positioned down the centre and must use a specific fatbike rim with the spoke holes positioned to the right. This is illustrated in Figure 52 on page 58 in the spoke length chapter which shows a 135mm fatbike wheel placed in an offset frame, the lower hub in the diagram is not offset and as can be seen the chain will hit the rim and tyre.

Building a wheel for an offset frame

The hub for an offset frame is not special and any rear hub can be used. To build a wheel for an offset frame there are two changes to the standard building procedure:

1. You need to calculate the spoke lengths differently and this is explained in the spoke length chapter on page 57.
2. During building you need to modify the technique for checking the wheel dish. For example, if you are building a fatbike wheel for a 17.5mm offset frame you need to make a spacer double this width (35mm in this example) and when checking the dish place it on the left side hub face. For correct dish the dishing tool should touch the end of the spacer and when the dishing tool is transferred to the other side it should touch the right side hub face. The fatbike manufacturer Surly Bikes makes a 35mm wheelbuilding tool that clamps onto the hub as a permanent fixture whilst building the wheel but you don't need this, just build the wheel with the truing stand set for a 135mm hub width and use any 35mm spacer when checking the dish, or use the Surly wheelbuilding tool as the spacer without clamping it to the hub (the tool is incompatible with some hub designs and if you do clamp it on the hub the width goes to 170mm and you may not be able to hold this in your truing stand).

Spokes

Spokes need to be good quality which means choosing a recognised and trusted brand. In the 1980's I did encounter poor quality spokes and it was even possible to snap them during building. With today's better materials spoke reliability is no longer an issue and I have to assume that all modern spokes are good quality. You do hear of spokes breaking when the wheel is used but the main contributing factor here is poor building technique.

For your first wheels I recommend you use spokes from a well established brand and build some reliable wheels, in the future you can explore the less well known alternatives but for now you need confidence in your spokes. I have built extensively with *Sapim* and *DT* spokes and have little experience with other brands. I have not used titanium spokes or spokes made from any material other than stainless steel so cannot comment on their suitability.

Spokes are manufactured in metric units of measure however you often see spoke diameters specified in *standard wire gauge* (swg), for example 14 gauge instead of 2mm. The swg measurement is an approximation of the spoke diameter and spoke manufacturers do not use it, the exception are a few manufacturers who use the occasional swg reference in their spoke descriptions but their specifications are in millimetres. Length is always in millimetres.

There are lots of spoke manufacturers but they all produce essentially the same spoke range albeit with different names, for example the *DT Competition* is dimensionally the same as the *Sapim Race*, the *DT Revolution* is the same as the *Sapim Laser*, and there will be similar spokes from other spoke manufacturers. Each manufacturer will have a different method of making spokes, for example the transition from 2mm to 1.8mm on the *DT Competition* spoke is very gradual and can easily be mistaken for a plain gauge spoke whilst the butting on a Sapim spoke it is visually obvious. These are the common types of round spokes:

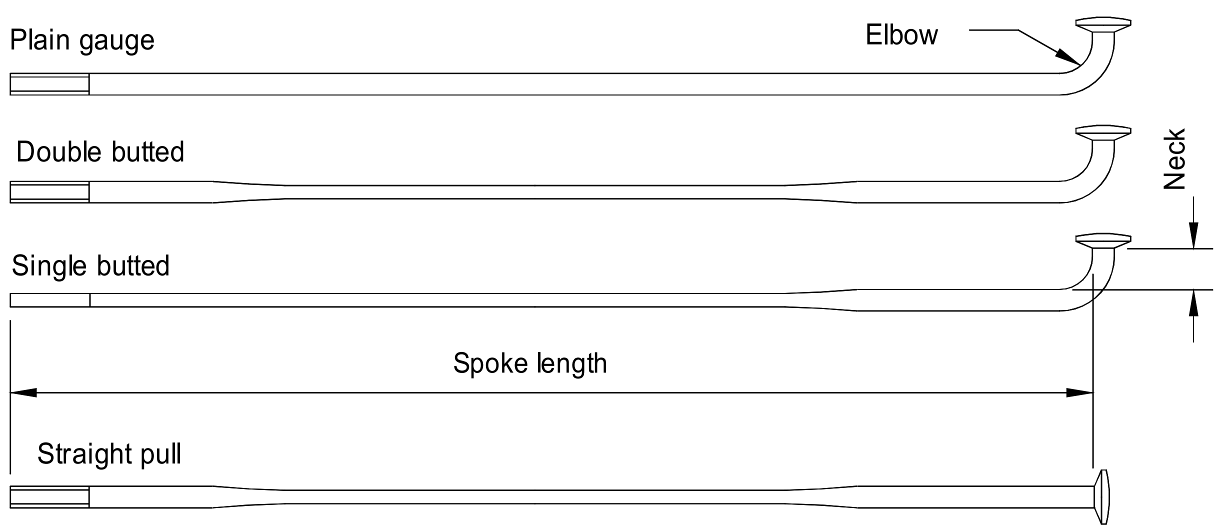


Figure 18 Common spokes

Plain gauge spokes

Plain gauge spokes (also called straight gauge spokes) have a constant diameter which is typically 2mm (1.8mm plain gauge spokes exist but I have never seen them). It may 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, in fact plain gauge spokes are theoretically more prone to fatigue failures at the spoke elbow (for the reason see *Double butted spokes* next). By all means build with plain gauge but just remember that you aren't doing it for strength reasons. Modern spoke material will help alleviate the problem of fatigue failures and I've built wheels with plain gauge spokes that have survived thousands of miles. The short spoke lengths required for small diameter wheels are usually only available in plain gauge and they are perfectly okay. If you are using lightweight aluminium rims then don't use plain gauge spokes because the spokes are not elastic enough to absorb the greater rim deflections causing the nipples to unscrew, and the lack of elasticity will cause the lightweight rim to crack at the spoke holes. However, if you have the choice and you want the best in long term durable wheels then choose double butted spokes.

Double butted spokes

Double butted spokes (also called swaged spokes) have a central portion of a reduced diameter and the reason is not primarily for weight saving. The mid section of the butted spoke is more elastic compared to its ends and this section will cushion the fluctuating spoke tensions as the wheel rotates. With a plain gauge spoke the fluctuating load is taken directly on the spoke ends and hence the greater chance of a fatigue failure particularly at the elbow which is already a heavily stress region. Fatigue is where concentrated cyclic loads cause the metal to slowly form a crack which ultimately results in a fracture, an example of this is the cracked spoke on page 100.

The standard double butted spoke is 2mm-1.8mm-2mm (thread-centre-elbow) and these dimensions make an excellent fatigue resistant spoke which is a fraction lighter than the plain gauge spoke. A true lightweight double butted spoke has the dimensions 2mm-1.5mm-2mm (*DT Revolution and Sapim Laser*). The lighter version builds a wheel that is just as strong as those built with standard double butted spokes and you aim to build the wheel with the same tension. These slender spokes twist easily during tensioning and are therefore more difficult to build with (identifying spoke twist and compensating for it is described in the building chapter). The weight saving from using the lightweight spoke is small and you will have to judge for yourself whether any weight savings are noticeable when riding the bike.

Triple butted spokes

A triple butted spoke has three diameters along its length and the most common triple butted spoke you'll come across is the *DT Supercomp* with dimensions 1.8mm-1.7mm-2mm (thread-centre-elbow). The Supercomp costs more but offers no advantage other than marginal weight saving when compared to a standard double butted spoke and because it uses a 1.8mm thread you need to be careful (see the discussion on 1.8mm spoke threads on page 25).

Oversized spokes

An oversize spoke is any spoke that has a diameter greater than 2mm, for example a single butted design such as the *Sapim Strong* where the diameter is constant for the majority of its length at

2mm but with an increase to 2.3mm towards the spoke elbow, or a triple butted design such as the *DT Alpine* with dimensions 2mm-1.8mm-2.3mm (thread-centre-elbow). This type of spoke came from the logic - *if it breaks then make it bigger* which may have had some merit many years ago when spoke material was a lot poorer and spoke failure at the elbow was more common. Oversized spoke elbows are not a cure for spoke breakages, good building technique solves spoke breakages, nor do they give the wheel added strength or weight carrying ability. With the high quality steel available today the standard double butted spoke is more than strong enough for all wheels and consequently I have never used oversized spokes. If you try to use an oversize spoke in a hub that was not designed for them then you will have difficulty rotating the spoke elbow through the hub so you are advised to check with the hub manufacturer before using these spokes.

Bladed spokes

The original flat bladed spokes had a width of around 3mm and although they still exist (*DT New Aero* at 3.3mm wide and *Sapim CX* at 2.8mm) they are not a spoke you would choose because they will not pass through the holes in a normal hub. When this was the only bladed spoke available the work-around was to file small slots in the hub holes to allow the bladed spoke to pass through which was never a good solution because it weakened the hub and invalidated the hub warranty. I have never used these large bladed spokes.

The large bladed spoke has now been superseded by lightweight bladed spokes such as the *CX-Ray* from Sapim and the *Aerospeed* and *Aerolight* from DT. The width of these spokes is typically around 2.3mm and they will pass through the spoke holes in all hubs. These spokes twist easily when building and require a special tool to hold them whilst tensioning (described in the tool section) and without such a tool they would be impossible to tension sufficiently. The lightweight bladed spokes are expensive and you need to be realistic in your expectations and the benefits you are likely to gain from using them. I would not use lightweight bladed spokes in mountain bike wheels because they will not improve the aero effect, they won't make the wheel poorer, they just add a considerable amount to the cost. Marketing claims from Sapim refer to additional strength for the lightweight bladed spokes but they only endure more cycles on their fatigue testing machine which does not correspond to wheel strength, and the increased fatigue life that is quoted has no bearing in the real world. On road race wheels the increased aero performance is small and the good riders whose wheels I build with these spokes tell me they notice an improvement, but I cannot tell any difference myself.

Straight pull spokes

There is nothing special about a straight pull spoke, in fact it's easier to make because they take it off the spoke making machine one stage early before it receives the thump that bends it over to form an elbowed spoke (sometimes referred to as a J-bend spoke). Shown here are Sapim straight pull spokes, Sapim identify their spokes with the letters SAP stamped into the spoke.

Figure 19
Straight pull spokes

Wheels built with straight pull spokes are not stiffer and they are not stronger than those built using normal elbowed spokes, nor are straight pull spokes more resistant to breakage.

People often believe the elbow on a conventional spoke is a source of weakness because when a spoke breaks it usually occurs at the spoke elbow and occasionally at the spoke threads and by removing the elbow using a straight pull design it will therefore remove a source of failure. This reasoning is wrong, in fact the straight pull spoke is a poorer design as explained by Jobst Brandt although today's higher quality spoke material will overcome some of the deficiencies. One of the reasons you see more elbowed spokes breaking is the simple fact that there are far more wheels built with elbowed spokes including many low cost wheels and others where poor building is the cause of the elbowed spoke breaking.

Jobst Brandt's views on straight pull spokes:

Grain alignment in drawn wire is longitudinal and cold forming a head onto the end of a wire disturbs this uniform structure. That is the main reason why this is the weakest place on a spoke. The elbowed spoke does not pull directly on the head, and therefore, transfers most of its load to the flange by a stronger part of the spoke.
https://groups.google.com/d/msg/rec.bicycles.tech/EVeMsN-TDEU/OMlTAPJ4fQcJ

The whole spoke is cold formed, and axially ramming a head onto a wire that has longitudinal grain structure definitely makes a scramble of the structure, both developing discontinuities in the grain and a sharp transition in cross section at the juncture of the conical head and cylindrical wire. Even if the grain orientation were not a problem, just hanging the entire tension on the head would present a substantial durability problem at the transition from wire to the head, the main problem in wire spokes.

https://groups.google.com/d/msg/rec.bicycles.tech/Cvq957sVuWU/pL2R0PWgbasJ

Spoke threads

Figure 20
Spoke threads do not bottom out

Spoke threads are cold forged into the spoke using a process called rolling. The resulting thread diameter is greater than the spoke diameter as the threads bulge out, for example on DT and Sapim 2mm spokes the thread diameter is 2.2mm. The difference in diameters means that spokes that are too long will not bottom out (come to an abrupt stop preventing further tightening) because the thread of the spoke is high enough above the spoke diameter that all you hear is a cork screw sound as the thread in the nipple becomes flattened which enables a wheel to be built with spokes that are a fraction too long. Tightening a spoke through the nipple using a spoke wrench is easily done and a couple of mm above the top surface of the nipple will not cause any problems although you wouldn't want the situation shown in Figure 20 because you are starting to run out of thread engagement and the protruding spoke can cut through rim tapes on shallow rims and puncture the inner tube.

Rolling the spoke thread also makes it stronger due to the improved grain flow and it is less prone to fatigue failure. Rolling a thread is not a metal removal process. Obtaining the appropriate spoke lengths by *cutting* the thread into a trimmed down spoke using a threading die is not an ideal solution because it disrupts the grain flow and the smaller thread diameter will not be an ideal fit in the nipple, both of which will affect the long term durability of the spoke. Some very expensive tools are available for rolling spoke threads but it's far easier to buy your spokes at the correct length.

1.8mm spoke threads

The vast majority of spokes use a 2mm spoke thread but 1.8mm threads do exist. For example the *DT Competition* double butted spoke is almost exclusively supplied as a 2mm-1.8mm-2mm spoke and uses a 2mm thread, but it is also made with dimensions of 1.8mm-1.6mm-1.8mm using a 1.8mm thread. The 1.8mm spoke thread you will come across is on the *DT Supercomp* because this spoke is widely available and doesn't have a 2mm thread option.

If you are using spokes with a 1.8mm thread then make sure you are using 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 which can easily go unnoticed. If you mistakenly use 2mm nipples with 1.8mm spokes the wheel will have poor reliability and you may even strip the threads whilst building the wheel. If you want to check that you have 1.8mm nipples they will not screw onto a 2mm threaded spoke.

Spokes these days are very reliable and in a well built wheel spoke breakages are not common but I had 4 broken spokes in two wheels that I'd built. All of the spokes snapped at the spoke thread which is very unusual and in both cases the threads were 1.8mm. Both wheels were 32 spoke rears; one was a mountain bike wheel with *DT Supercomp* spokes, the other a road wheel with *DT Competition* spokes (1.8mm version). On each occasion I replaced the broken spoke and a few months later another one goes. In the end I rebuilt both wheels with *DT Competition* (2mm spoke threads) and both wheels have since performed faultlessly.

The most probable reason for the spokes breaking is that the diameter of the spoke at the bottom of the 1.8mm thread is just too little to withstand the dynamic loads which eventually results in a fatigue failure, and this failure will happen sooner when heavy loads are involved. This explains the failures I saw in the rear wheels, rear wheels carry more rider weight and both riders were heavy guys! So bear this in mind if you consider using spokes with 1.8mm threads.

Black spokes

Black spokes are exactly the same as their silver counterparts except they have a black finish applied to them. They perform exactly the same. The reason I'm mentioning this is because you may come across Internet discussions where people claim black spokes are brittle and prone to breaking but I have never encountered this or heard anything scientific being discussed, just the perpetuated myths with no basis to them.

Spoke nipples

Brass nipples are usually supplied with the spokes and they 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. Brass nipples are tough enough to be reused several times.

An alternative to brass nipples are those made from aluminium, sometimes called *Alu* nipples or *alloy* nipples. You tighten the aluminium nipple to the same tension you would use for the brass nipple and it is advisable to use a wrench that grips on four sides to avoid damaging the softer material, I use the *Spokey* wrench shown on page 43. By using aluminium nipples you will save a few grams in weight and the wheels themselves will be just as reliable as those built with brass although I treat aluminium nipples as single use only and would not reuse them.

When I last purchased a box of 72 *DT Competition* spokes in *black* they were supplied with silver aluminium nipples, but you are not obliged to use them and obtaining brass nipples is a low cost option. If you are not sure whether you have brass or aluminium nipples then weigh them, for 12mm nipples, 32 brass nipples weigh 30g and 32 aluminium nipples weigh 10g.

When providing 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 making it impossible to locate the spoke wrench and I've often seen aluminium nipples that were frozen to the spokes making any adjustment impossible. These problems resulted from poor building technique, in particular using a poor spoke wrench and/or the lack of oiling the spoke threads and rim-nipple interface during building, and using far too short a spoke length.

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. I have never used 16mm nipples and only use 14mm nipples on Mavic UST rims, all the rest of my wheels use 12mm nipples.

Self locking nipples

Once the wheel is built the only way a nipple can unscrew is if the spoke becomes slack. Even a small amount of tension is sufficient to prevent a nipple unscrewing. Putting oil on the spoke threads has no effect on the nipples unscrewing.

If you build your wheels correctly then ordinary nipples will not unscrew and consequently I have never used self locking nipples. Self locking nipples will produce more spoke twist when building the wheel. Examples of two spoke manufacturers who make self locking nipples are:

- The *DT Proloc* nipple contains adhesive within the nipple that is activated once it is screwed onto the spoke and is described here: www.google.com/patents/EP1169182B1
- The *SAPIM Secure Lock* nipple has a deformed thread that creates extra friction and is described here: www.google.com/patents/EP1844951A1

  Sapim have redesigned their self locking nipple, it still uses a deformed thread and is described here: patentscope.wipo.int/search/en/detail.jsf?docId=WO2013131564

Internal nipples

Internal nipples, sometimes called hidden or inverted nipples are located *within* the rim and do not protrude through it like conventional (external) nipples. The shape of some internal nipples is similar in appearance to conventional nipples but they are a specific design and you cannot simply use a normal nipple turned upside down. For your particular rim you cannot choose whether to use internal or external nipples because it's the rim design that determines the type of nipple to use.

The manufacturers who use internal nipples in their wheels say the advantage is that the nipple is in compression and so can withstand high spoke tension without the nipple head failing compared to a conventional nipple that is in tension. I've never experienced conventional nipples failing even on high tensioned wheels, and you see plenty of high-end factory built wheels using conventional external nipples. People also quote internal nipples improving the aerodynamics of the wheel, but it's difficult to quantify the benefits (if any).

The main issue with this type of nipple is tightening them because you cannot use a standard spoke wrench and you need a special socket wrench available from cycle tool suppliers such as Park Tools. You also need to remove the tyre in order to true a wheel which is very inconvenient, especially if you are running tubeless or road tubulars.

My building instructions in this book assume the use of normal nipples but the principles remain the same for internal nipples, and that includes spoke length calculations which is covered in the section on *non standard nipples* on page 53. If you need to build a complete wheel from scratch using internal nipples then you'll need to adapt the building procedure yourself because I have not built a wheel with internal nipples. You cannot use a conventional nipple driver so the problem to solve is how to initially tighten the nipples to the same engagement point (the nipple driver on page 47 is used for normal nipples and makes obtaining a radially true wheel a lot easier). One thing's for sure, a wheel using internal nipples will take a lot longer to build.

Interlacing of cross laced wheels

Interlacing spokes has nothing to do with strengthening the wheel but is done to give added resistance to spoke loosening. Under shock loads such as the wheel encounters at speed over rough ground, spokes momentarily become slack at times. The interlacing allows an adjacent tight spoke to pull on the slack spoke to keep it from becoming entirely loose and thus preventing the nipple from unscrewing. The benefit of interlacing is small and as a consequence radial (unlaced) wheels perform fine. Interlacing also pulls the spokes inwards by approximately 1.5mm at the spoke crossing which gives more clearance between a close running rear derailleur or a front disc brake caliper.

Inside and outside spokes

Spokes can lie on the inside or the outside of the hub flange. When lacing a wheel it is desirable to lace all the inside spokes first and then the outside ones. This eliminates the spoke tangles when placing the outside spokes and will be better appreciated when you start lacing wheels.

A feature of the outside spokes is the excessive bows they take when they are connected to the rim. These

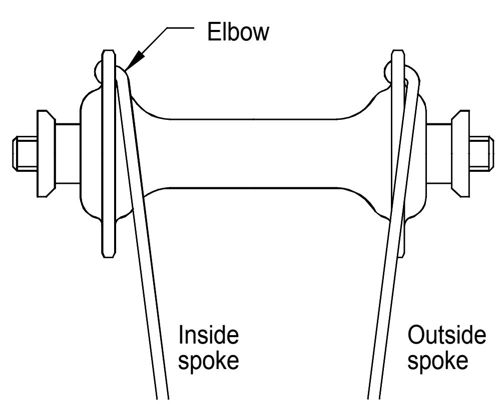


Figure 21 Inside and outside spokes

bows can be seen by taking a hub and passing a new unused spoke through to the outside then pulling the threaded end gently inwards towards the hub centre line. Try the same with an inside spoke and notice how it can easily swing into the central position with little or no bowing. The outside bows will be removed during the building stage (aligning the outside spokes). Figure 21 shows the spokes taking a straight line with no bows which is the ideal situation.

Pulling and pushing spokes

In a cross laced wheel where rotational torque is applied there are two spoke orientations, pulling spokes that radiate backwards and pushing spokes that radiate forwards. You will often hear the same spokes described as *trailing* and *leading*.

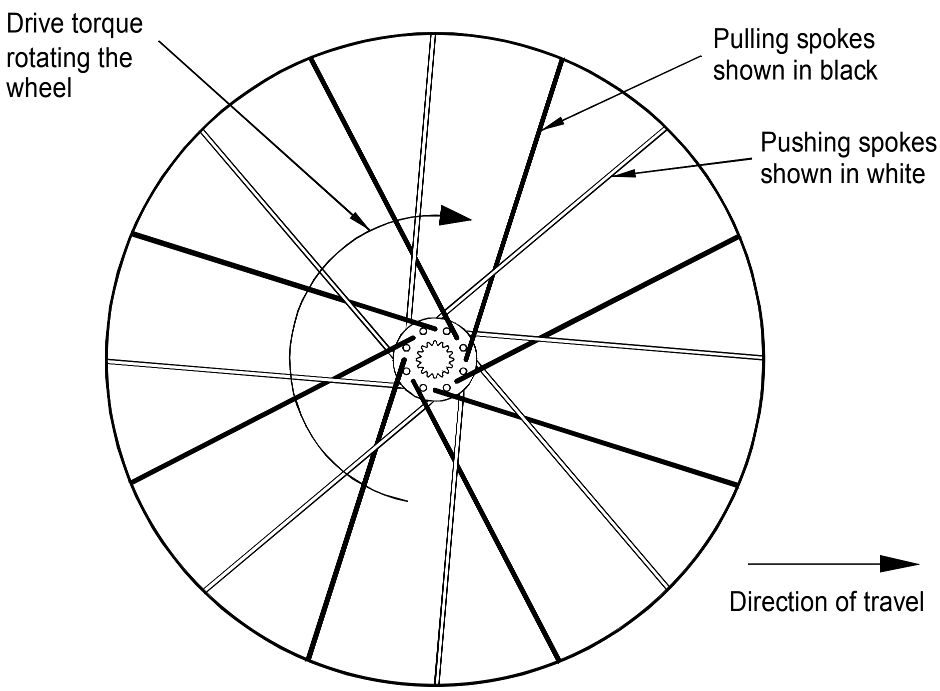


Figure 22 Pulling and pushing spokes

When drive torque is applied to the rear wheel shown in Figure 22 the force that makes the wheel rotate is transmitted *along the length of the spoke*; the pulling spokes increase in tension and *pull* the wheel around and the pushing spokes **contribute equally** as they *push* the wheel around and in doing so reduce in tension.

The *pulling* and *pushing* orientation is dependent on the direction the wheel is *attempting* to rotate and this is obvious in rear wheel shown in Figure 22 because the wheel is rotating clockwise due to the torque applied via pedalling. When a braking torque is applied to this wheel via a disc or hub brake the spokes have their pulling/pushing orientation reversed as they slow the wheel (and bike) down. Slowing the bike down via rim brakes does not create pulling and pushing spokes and is not relevant to this discussion.

How can a spoke push since there's nothing for it to push against, and if it did push then surely it would just push the nipple out of the rim? If it were wedged in like a wooden spoke on a wooden wheel then pushing is easily visualized, however a slender bicycle spoke works just the same. The pushing spokes are in tension and by pushing on them the tension reduces and because they are still in tension they remain seated in the rim. If it were possible to push the spoke sufficiently hard then the tension would reduce to zero and they would become loose and the nipples move away from the rim, but this is not possible because you cannot generate such a high force from pedalling or the application of a disc brake. For more reading on this do a search for *linear superposition* and by understanding this concept it will also explain how the vertical load (weight of the bike and rider) is supported by the spokes at the bottom of the wheel which means the hub does not hang from the upper spokes as many people mistakenly believe.

Where to place the pulling spokes

When building a wheel you can choose whether to place the pulling spokes on the inside of the hub flange or on the outside. In Figure 22 the pulling spokes are on the outside.

Looking at how the pulling spokes are arranged is one of the observations you will make when examining other wheels, not that it's important or that it determines how good the wheel is since there is no preferred option. If there was a preferred spoke orientation that made a better wheel then it would be common knowledge and all wheels would be built the same. There isn't a preferred option and consequently you will see all options in use and **all options work equally well.**

This discussion only applies to wheels where torque is applied; these are rear wheels with the torque from either pedalling or the application of a disc or hub brake, and front wheels with a disc or hub brake.

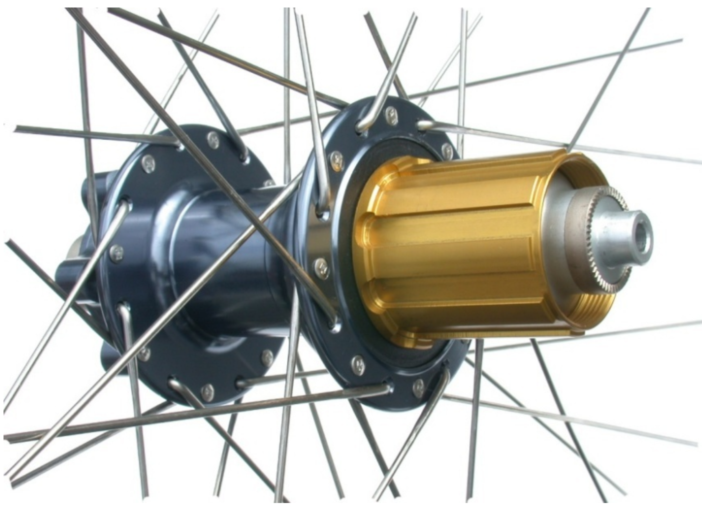
Once you start looking at other wheels you will see four options in use although 99% of the wheels will look like one of those on the next page. Rear wheels are shown but the same applies to front wheels although a front wheel is not subjected to pedalling torque (to visualise a front hub just put your thumb over the cassette carrier).

Option A

Pedalling action - the pulling spokes are on the *outside* of the hub flanges.

Applying the brakes (disc or hub brake) - the pulling spokes are on the *inside* of the hub flanges.

This is a symmetric pattern.

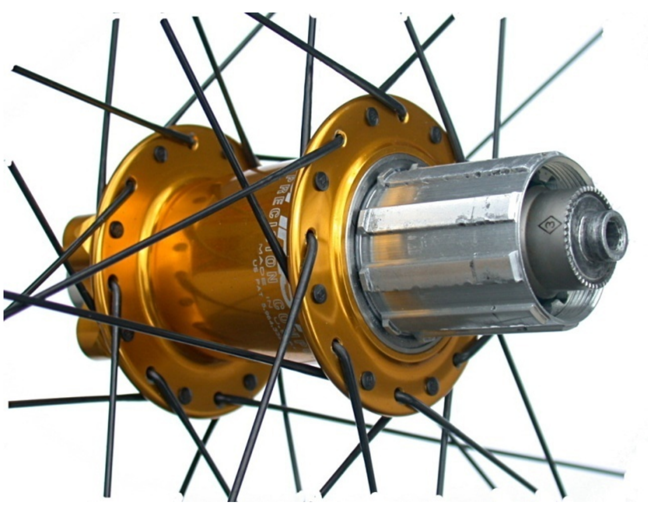


Option B

Pedalling action - the pulling spokes are on the *inside* of the hub flanges.

Applying the brakes (disc or hub brake) - the pulling spokes are on the *outside* of the hub flanges.

This is a symmetric pattern.



Option C

Matches the instructions provided by Shimano for lacing a **rear disc brake** hub.

This pattern is described in more detail on page 32.

This is an *asymmetric* pattern.

Figure 23 Inside and outside lacing options

Option A

When mountain bike disc brakes first appeared there was an advantage in building front wheels with *Option A* lacing. Look at the spokes where they interweave at the last crossing point, with Option A the pulling spokes from braking torque weave *over* at the crossing point and when the brake is applied they straighten and in doing so pull the crossing point and spokes inwards and away from the brake caliper. If the spokes were laced as option B then the pulling spokes would weave *under* at the last crossing point and when applying the brakes will straighten and pull outwards and hit the caliper and you would hear a clicking sound as each spoke hit the caliper. Hitting the caliper happened with early front disc brakes because the calipers were large and the gap between the caliper and spokes was small (rear calipers always had plenty of clearance so was never an issue). However calipers eventually became smaller resulting in plenty of clearance and it was not mandatory to use this lacing pattern. The documentation for Chris King disc hubs originally said:

> *The front ISO hub should be laced 3-or-more-cross with the rotor (left) side pulling spokes (relative to braking direction) heads out/elbows in (when laced 3-cross). The final cross of the pulling spoke must be on the outside so that, as braking force is applied, increased pulling spoke tension will pull the crossed spokes towards the center of the hub and away from the caliper. Lace the wheel symmetrically.*
>
> - The above quote translates to *Option A lacing*.

Shimano specifies that their **road wheels** should be laced as *Option A*.

The following diagram is taken from a Shimano road wheel instruction document.

http://cycle.shimano-eu.com/media/techdocs/content/cycle/SI/Wheel/MTB/SI_4SB0A/SI-4SB0A-002-ENG_t_v1_m56577569830749985.pdf

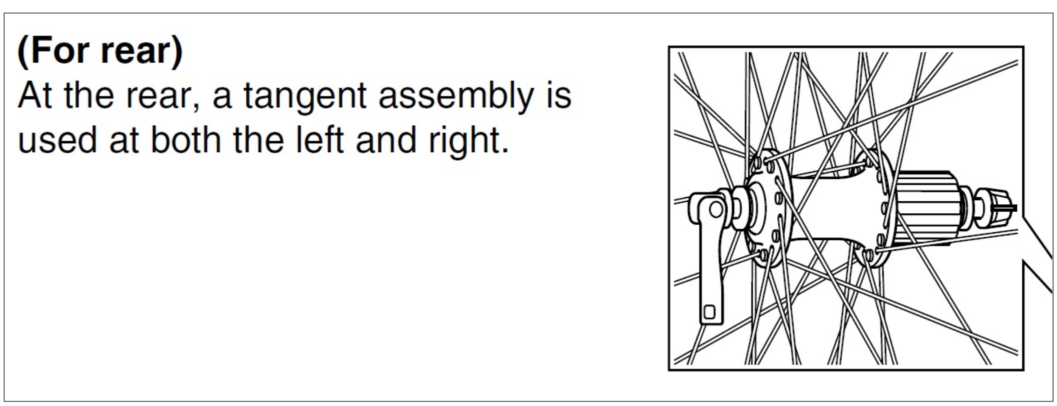


Figure 24 Shimano road wheel lacing

Option B

This is described in the book *The Bicycle Wheel* by Jobst Brandt and the logic is similar to that described for *Option A*, but here it prevents the spokes hitting the rear derailleur cage as opposed to the disc brake caliper. With *Option B* the pulling spokes from pedalling torque weave *over* at the last crossing point and when they straighten out under pedalling load they pull the spokes inwards and away from the derailleur giving more clearance (when the derailleur is positioned over the largest rear sprocket), done the other way then there's a chance that the spokes will hit it. This may have been applicable on old narrow spaced bicycles with tight clearances although I've never encountered it myself. In conclusion, this is what Jobst says:

> *Keep in mind that bending of the rear axle from the pull of the chain can also reduce clearance between spokes and derailleur. In fact, clearance effects are so small that they may not be sufficient reason to insist that all rear wheels be spoked with pulling spokes coming from between the flanges.*
>
> - *The Bicycle Wheel, by Jobst Brandt*

Option C

This is increasingly known as the *Shimano way* because it is described in the documentation supplied with Shimano **disc brake hubs.** The lacing instructions included with Shimano disc brake hubs is shown below and if you decipher it then rear disc hubs will be laced as Option C and front hubs Option B.

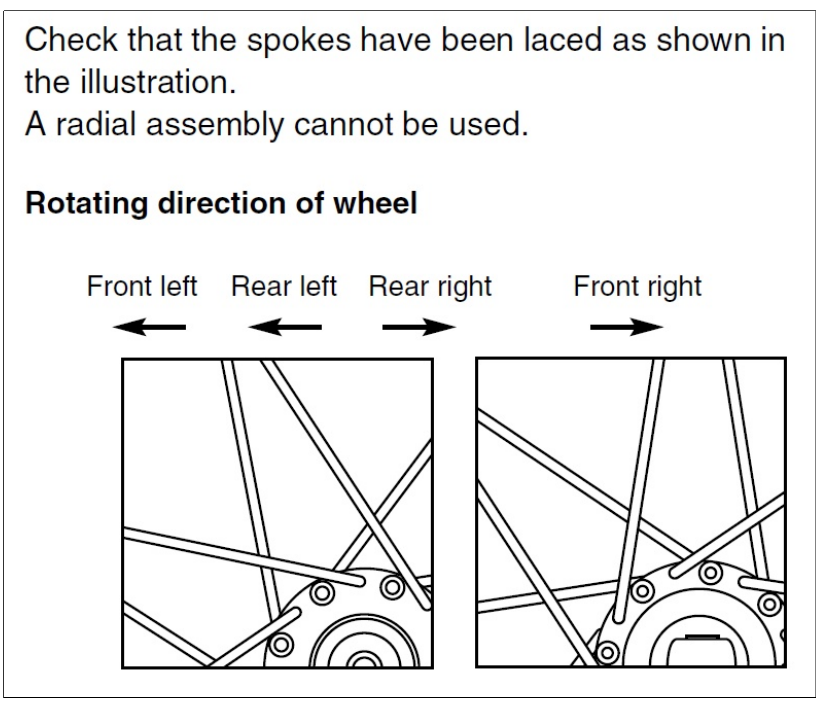


Figure 25 Shimano disc brake hub lacing instructions

Shimano place the pulling spokes from pedalling and braking on the outside of the hub flange and that is why you get the asymmetric pattern on the rear.

The same instructions tell you to lace the front disc hub with a symmetrical pattern (option B) so that the pulling spokes (due to braking) go on the outside of the hub flange on both sides of the hub. Some people even lace the front disc wheel as option C, for example the wheel on page 117 that was brought to me for truing was laced this way, there's no advantage in doing this (and no disadvantage) and certainly no logical reason.

Shimano have never justified their lacing approach. Independent arguments for this lacing method (not supported by evidence) include – *the pulling spokes are supported by the hub flange* and *the pulling spokes have a greater bracing angle*. Both of these statements are completely false.

Here is a reply from Jobst Brandt to someone who asked why Magura advised lacing rear disc hubs the same way as Shimano (in the current Magura documentation there are no longer any lacing recommendations).

```
Jose Rizal writes:

> This is in Magura's disc brake manual.
> Is there any merit to this recommendation?
```

"Use spokes with a diameter of 2mm/1,8mm which you cross three times. Head-inside-spokes (arc-outside-spokes) have to be pulled, i.e. these spokes point forward on the front wheel; on the back wheel these spokes point forward on the rotor side and backwards on the drive side."

```
Jobst Brandt replies:

No, and this is another example of people in charge not being aware of
the technology with which they are working.  Had they done an analysis
of forces involved, or read it in TBW ("The Bicycle Wheel"), they would
have known that braking torque doesn't present a significant spoke load
in comparison to the radial load of statically sitting on a bicycle.
They might also have noticed that the so called pushing spokes in fact
push, half the torque load being taken up by a light tension increase
and the other half by a tension decrease, so it doesn't matter which way
the spokes are oriented in the flange.  That is, all spokes of the wheel
are involved in transmitting brake torque from hub to rim (aka pedalling
torque to the rear rim).

The above taken from:

http://groups.google.com/group/rec.bicycles.tech/msg/741d6698406dcb5e
```

Where to place the pulling spokes – summary

Since it makes no difference to the wheels and how they perform you can lace the hub any way you want.

If you have a previously used hub then lace it the same way it was previously laced (the reason is given on page 10).

If you are using brand new hubs I propose the following:

- For your first wheels lace them as Option A. This is the default lacing described in the lacing section, so follow the lacing instructions as written.
- For your next set of wheels lace them as Option B.
- If you are a disc brake user, then lace your third **rear wheel** as Option C.

Instructions for lacing options B and C are given in the lacing chapter.

By doing this you will understand how to lace the different options and when you ride the wheels you will be able to prove that they all work the same.

One of the habits you will get into is that whenever you see a wheel you will look at it to see how it's laced and you will see examples of every option in use and no common theme.

Disc brake road wheels

Virtually all mountain bikes use disc brakes and have done so for many years and it's only a matter of time before disc brakes are used on road bikes. There's nothing special or different about building a disc brake road wheel, but I do want to give you a safety warning.

If your existing forks use rim brakes then you should not modify them by welding on a disc brake caliper mount. The forces exerted on the fork due to the application of a disc brake are different to those from rim brakes. With rim brakes all the force is taken at the fork crown and also shared between two fork blades and explains why forks designed for rim brakes are thicker at the crown where strength is required then tapering to a narrow cross section at the fork tip. With disc brakes there is a large reaction force at the caliper mount and if the fork is not sufficiently strong in this region then applying the brake will cause the fork blade to start folding backwards (sometimes called un-raking) and eventually the fork blade will break whilst riding and cause you to crash. Forks must be specifically designed for use with disc brakes, trying to adapt an existing road fork for use with a disc brake is very dangerous.

Chapter 4

Wheel design

The design of hubs, rims and spokes has evolved slowly over many years with today's components now benefiting from computerised design, better materials and better manufacturing techniques. This means that components from the major manufacturers, even low cost items, are capable of being built into top class wheels. Regardless of what you choose I hope you will have realised by now that it's the quality of the building which determines the success of the resulting wheel.

Each year the component manufacturers will introduce new hubs and rims and the sales literature always makes it very tempting 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, its components or developing new lacing patterns. The spoke manufacturers are also introducing 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 read through the marketing material and select components based on function rather than cosmetic features or features that offer no benefits to the performance of the wheel. 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, and choose a rim that is suitable for your intended riding.

Strong and durable

A well built wheel is seen as *strong* because it doesn't go out of true and can take a few knocks. If you want to make a stronger wheel then use a heavier and wider rim. A *durable* wheel is one that continues to perform over a long period of time and if you want a more durable wheel use more spokes. That's the theory, but today's modern rims are so well designed they are all very strong, even the lightweight ones. Spoke material is now very good at withstanding stress, so we tend to build strong durable wheels by default and those wheels that are problematic when used are usually caused by poor wheel building. Obviously, the super light rims are more susceptible to dents and flat spotting and you should always pay more attention to the maintenance of them by checking for rim damage and adjusting spoke tension where necessary, and if you are a long distance touring cyclist then keep away from lightweight components and low spoke counts.

Want to go faster?

Building your wheels with ultra light components will not make you go faster, it might do if you are a professional racing cyclist looking to save a couple of seconds, but the reality is that you won't notice much (if any) difference. When you add up the few grams saved it may sound an impressive figure, let's say you save 100g on components but when compared to 80,000 grams of rider (I weigh 80kg) plus the weight of the bike, say another 9,000 grams it sort of puts things in perspective. Light wheels may *feel* faster but it's very difficult to quantify any real improvements in covering a set distance in a faster time on a course that includes going up and downhill with plenty of cornering.

Deep section carbon rims are expensive but will not automatically give you a speed advantage. It's my understanding that they are only beneficial when you reach 30mph and if you ride below this speed then they offer no advantage. If you look at pro racing and the stage is hilly then you don't see too many deep section rims. Do your research.

Actually a set of standard wheels using standard components will allow you to ride faster and longer because they will take more abuse without letting you down. You often see people with ultra light 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 and faster down a rough track because their wheels are tough, plus they don't have 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.

One way to obtain more performance is to use better tyres, you will save weight, improve rolling resistance and have better grip. Mountain bike riders also need to select a tyre appropriate to the conditions where they ride and pay more attention to tyre pressure, suspension settings and suspension maintenance. Mountain bike riders who want to go faster should also improve their bike handling skills. An often neglected area is wheel bearings, keep them clean, greased and properly adjusted, they should be silky smooth because friction *will* waste energy. If you want to go a lot faster then train harder, or more specifically train more scientifically, there are plenty of articles on cycle training and nutrition.

Comfortable wheels

All you can do to make a more comfortable wheel is to choose a wider rim that takes a wider and therefore softer tyre. For example, a road race wheel may seem harsh but that's the result of a narrow race tyre pumped up to over 100lbs pressure.

The number of spokes, the type of spokes (plain gauge or butted) or the lacing pattern does not affect ride comfort. A 3 cross wheel and a radial wheel with the same tyre and same pressure will be indistinguishable. A 4 cross wheel will also be the same, to suggest that the longer and more tangential 4 cross spoke gives a springier ride is wrong.

Carbon fibre rims are very rigid especially when compared to aluminium rims, but they do not result in a harsh ride, they may feel different when riding but it's down to the added lateral stiffness which affects the ride characteristics. NOX Composites who make carbon fibre rims have done the calculations on vertical deflection and their conclusion is *"you can see that the difference in vertical deflection between an aluminum rim and a carbon rim is (at maximum) 0.009 inches. That's about the thickness of 9 human hairs! In short, it's just not possible for a rider to discern that small of a change."*

How many spokes

The spokes at the bottom of the wheel support the weight of the rider and bike. If you need to support a heavier load then more spokes are required at the bottom of the wheel and this is achieved by using a stronger rim which gives a larger stiffer span containing more spokes, or just use more spokes.

The majority of wheels are 32 spokes laced 3 cross and you will have to come up with a very good reason for doing something different. 28 spokes are fine for normal use and that includes mountain biking where even wheels with lightweight rims and 24 spokes are available. The factor determining the reduction in spoke count is for no other reason than a marketing ploy because the wheels look lighter and therefore faster. Touring wheels that are required to carry heavy loads over longer distances will benefit from 36 spokes.

Reducing the spoke count improves the aerodynamics (reduces the drag) but quantifying the benefit is difficult, but if you are a world class time trial athlete looking to save a couple of seconds over a 40km / 25mile time trial then it *may* help. Reducing the spoke count to save weight is really insignificant.

Putting fewer spokes in the front wheel may seem reasonable because it carries less of the rider's weight, but under braking the weight is shifted towards the front and under extreme braking where the rear wheel lifts off the ground the whole weight is taken by the front. So it's best not to reduce the number of spokes in the front wheel and keep it the same as the rear.

Carbon fibre rims are very strong and can therefore be built with fewer spokes because a strong rim allows more spokes to share the load and consequently 24 spoke carbon road wheels are popular, but there is a downside to this. If you are a powerful rider and exert strong lateral forces on the rear wheel, for example out of the saddle sprinting or climbing and generally throwing the bike sideways, the carbon rim being so stiff will remain flat and will try to tilt sideways. If there are insufficient spokes to resist the tilting then the rim will rub the brake pads (and no doubt some other noticeable effect with mountain bikes). An aluminium rim which is less stiff than carbon will locally deform at the road contact point and therefore not cause brake rub. The solution for carbon rims is to use more spokes, or stiffer spokes. This phenomenon is explained in the following web pages:

- www.slowtwitch.com/Tech/Debunking_Wheel_Stiffness_3449.html
- www.noxcomposites.com/wheel_building

Using different gauge spokes either side

On a dished rear wheel the left side spokes have a lower tension and with sufficient vertical load the tension in the left side spokes will reduce to zero before the right. Once the left spokes become slack the wheel will lose its lateral stability and the low tension will also cause the spoke nipples to loosen. The wheel can support more load before the left spokes go slack by making the right side spokes stiffer than the left and this is accomplished by using thicker (stiffer) spokes on the right and thinner (less stiff) spokes on the left. It's not the extra stretch of the thinner left spokes that maintains the tension (although this will give a small benefit), it's the difference in stiffness between the left and right spokes and the fact that stiffer right spokes will carry more of the load. The actual gauge of the spokes does not matter as long as one side is stiffer than the other.

It's difficult to quantify the additional load the wheel can support by stiffening up the right side, all that you can say is that in theory it will give you some benefit, but whether it makes a better wheel is not proven. I always use the same gauge spokes either side on dished rear wheels for the simple reason that the wheels work and I have no reason to look for a solution to a problem that does not exist. However, a poorly designed wheel using a flimsy aluminium rim, low spoke count and used by a heavy rider will cause problems, but using stiffer spokes on the right is not the answer.

Modifying the spoke tension

Changing the spoke tension does not alter the elasticity of the spoke which means reducing spoke tension does not soften the ride, and increasing the spoke tension does not make the wheel stiffer. Neither does higher spoke tension make the wheel more laterally stiff because once there is sufficient tension to make the spokes taut then the wheel is as laterally stiff as it's going to be. This means you do not use different tensions for different end uses such as touring wheels, road racing and mountain bike. I'll talk more about actual spoke tension in the building section when I describe final tensioning of the wheel.

How many crosses in a cross laced wheel?

If you are not familiar with the cross lacing pattern then take a look at page 73 which shows a 3 cross pattern, and page 77 for 2 and 4 cross patterns. Changing the cross pattern has no effect on performance, stiffness or strength. In a cross laced wheel the number of crosses to use is based on the number of spokes in the wheel, and if you are using a large diameter hub then that too has to be taken into consideration.

You must select an appropriate number of crosses to avoid the following two conditions:

1. Overlapping spoke heads

As the number of crosses increases, the spoke moves closer to the head of the adjacent spoke until it touches, then overlaps it which puts an unnecessary bend in the spoke close to the elbow and it also interferes when placing the spokes in the hub. For example the following diagram shows how a 32 spoke wheel can have a maximum of 3 crosses because once you go to 4 cross the spokes overlap.

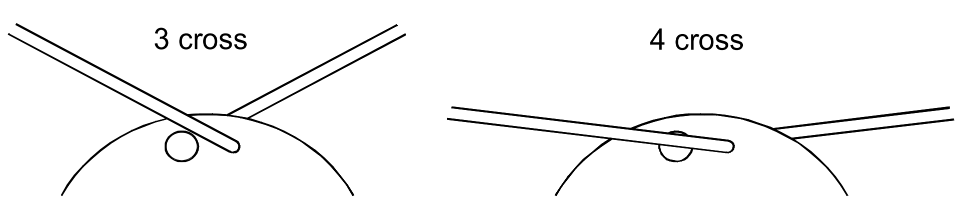
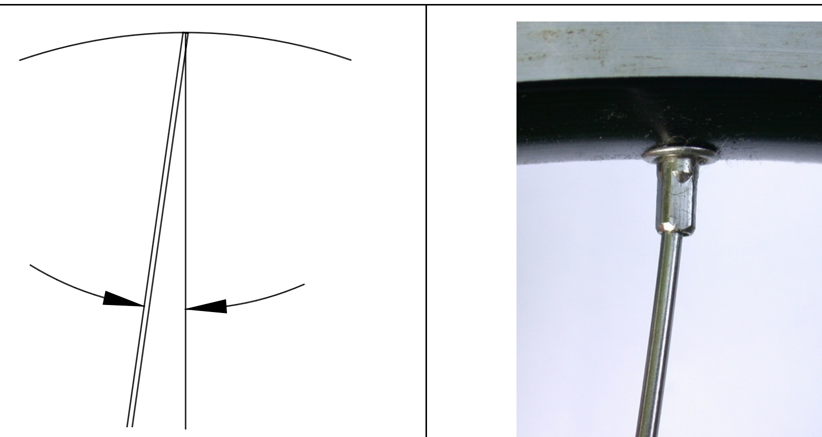


Figure 26 Overlapping spoke heads

The table below shows the preferred cross pattern for a given spoke count with an optional cross which gives you another spoke length choice. Any spoke count can be built zero cross (radial) but read the comments further down before considering a radial laced wheel.

Spokes	**Preferred**	**Optional**	
36	3	4	With 4 cross there may be a slight overlapping. The diagram on page 77 is drawn to scale and shows a 40mm (pcd) hub with 36 spokes built 4 cross and in this example the spoke barely touches the other spoke head.
32	3	2	3 cross is by far the most common option.
28	3	2	There's no real preferred option so use either 2 or 3 cross, the decision will be based on spoke length availability.
24	2	none	

2. Adverse spoke entry angle



Spoke entry angle

The nipple cannot swivel enough to match the spoke line

Figure 27 Spoke entry angle

As the number of crosses increases, the spoke entry angle at the rim will also increase and the nipple may not swivel enough to match the natural spoke line. The diagram on page 123 illustrates this. Standard nipples can swivel about 6 or 7 degrees, nipples with a spherical design such as the

Polyax nipple from Sapim and ProHead nipple from DT can swivel more (9 degrees for the Polyax). For hubs with a flange diameter up to 60mm the spoke entry angle will not be an issue, but you need to be careful with larger diameter hubs, for example internal gear hubs or hubs for electric bikes, or using small diameter rims.

The wheel shown in Figure 27 is a 36 spoke BMX rim with an ERD of 390mm laced to a hub with a flange diameter of 90mm (a non standard hub for a special application) built with a 2 cross pattern. Even with 2 cross you can still see the mismatch in angles between the nipple and spoke. In this example the spoke line is 10 degrees and borderline acceptable for this particular wheel, if it were built 3 cross the mismatch would be too great and the additional bending stress on the spoke could result in a fatigue failure with the spoke snapping at the thread.

How to check the cross pattern

Use the spoke length calculator at www.wheelpro.co.uk/spokecalc

Calculate a spoke table and hover the mouse pointer over a spoke length and it will show the angle the spoke makes at the rim and the spoke head clearance (the distance between a spoke and the head of the adjacent one).

Right			
1x	2x	3x	4x
249.0	256.5	267.0	278.2

Rim angle 4.4 degrees. Spoke head clearance 5.2mm

Figure 28 Cross pattern check

Radial lacing

Radial lacing can be used on any side of the wheel that doesn’t transmit torque, either drive torque from pedalling or brake torque via disc and hub brakes. For wheels using rim brakes the options for radial are both sides of the front wheel, and the rear left (non drive side). For wheels with hub or disc brakes the only option for radial is on the front wheel on the opposite side to the brake, but since the front brake provides the majority of the stopping power then it’s really better to have the wheel cross laced on both sides because on a well designed hub there is torque transfer to the non brake side with both sides sharing the brake torque. There are no performance benefits from using radial lacing but they do look different.

The radial pattern puts a lot of stress on the hub flange which can lead to fatigue fractures. For this reason many hub manufacturers do not recommend lacing their hubs radial and doing so could invalidate any warranty if the hub subsequently fails. If you want to use radial lacing always check to see if the manufacturer allows it otherwise you might build a wheel that could eventually fail due to a broken hub.

Alternative 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 but anything other than the standard cross pattern is likely to be cosmetic or an academic exercise to show that *this could be possible* but with no theory to backup any claims of a better wheel, and in most cases they build poorer wheels (without the builder realising it). If there were a better lacing pattern then we'd all know about it by now. I have never evaluated any of these alternative lacing patterns and I have no plans to do so. Please read the warning message below.

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.

Type of spokes

I've lost track of the available spoke options as the manufacturers keep introducing new variations which are only slightly different from the established designs, but the marketing material will make you think they are somehow special. For my own wheels the standard double butted spoke (2mm-1.8mm-2mm) DT Competition is all I need, all the other spokes will give me no benefits.

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 and a wheel that doesn't let you down. What is more important is that you actually build something that *you* are satisfied with. Use whatever components you want and you'll eventually discover your personal preferences.

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

Warning

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 you can do to confirm any theories other than to 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

Tools

I am not equipped with expensive or special tools that allow me to build better wheels or to make building them easier. My tools are pretty basic and you can put together a set of tools exactly like mine. Listed below are all the tools I use.

Spoke wrench

Many designs of spoke wrench exist and the choice comes down to personal preference. Spoke wrenches come in various sizes so make sure yours is correct for the nipples you are using, it must be a good fit to avoid damaging the nipples as you tighten them.

Figure 29   Spokey wrench

My personal choice is the standard *Spokey* wrench, I use the red one (size 3.25mm) for DT, Sapim, European and US nipples and very occasionally the yellow Spokey (size 3.4mm) with slightly larger jaws for when someone brings me a wheel to fix that uses oversized nipples found on Japanese wheels. I have never encountered a wheel that required something other than a red or yellow Spokey. There's also a *Pro* version of the Spokey but I've never tried one. The same design of wrench identical to the Spokey is available from other tool manufacturers such as the Cyclus wrench.

If you are just starting out building wheels then the biggest mistake is turning the wrench the wrong way. If you are prone to making this mistake then place a mark on one of the wings of the wrench (the black circle in the photograph) so that pressing the mark is the direction for tightening the nipple.

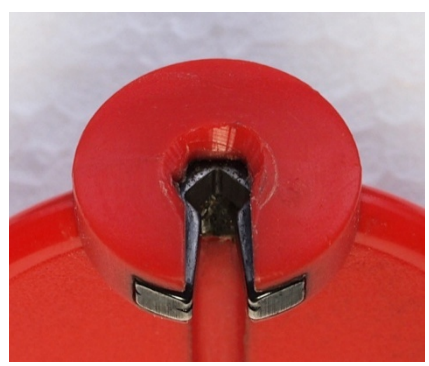


Figure 30
Modified jaws on the Spokey wrench

If you are using a Spokey wrench it should be easy to place on the nipple and this is a key requirement for building a wheel quickly, but sometimes a brand new Spokey will require a firm push to locate it and a pull to remove it. If this is the case then you'll find that the plastic on the top surface of the Spokey is interfering with the nipple and this is rectified by chamfering the plastic with a craft knife (see photo on the right). An unmodified Spokey will eventually ease up and people attribute this to the metal jaws wearing whereas it's the plastic that has worn away a little. I have never worn out a Spokey!

Wheel truing stand

The purpose of a truing stand is to hold the wheel whilst you tighten the spokes and it incorporates gauges to check the lateral and radial trueness.

Truing stands can be very expensive but that doesn't guarantee they are good. It's all down to personal preference and as a consequence I couldn't find anything that suited me. So I designed and built my own and I'll show you how to make one yourself exactly like mine. This is my personal truing stand shown in the photo and is what I use for all my professional wheelbuilding. Instructions for making it and how to use it are given in Appendix 2 on page 111.

One thing's for sure, a good wheelbuilder will be able to build a perfect wheel using whatever truing stand is available to them, even using the cycle frame, it's just that some stands enable the wheel to be built more quickly.

Figure 31 My personal truing stand

If you decide to purchase a truing stand then here are a few points you need to be aware of.

The stand should hold the wheel firmly and must not flex or wobble as the wheel spins otherwise delicate truing will be difficult.

The reference points for checking lateral and radial trueness should be easy and quick to adjust.

The stand must allow you to build wheels quickly which means it should be easy to place the wheel in and out of the stand. It should also be compatible with all the different hub axle designs, hub widths and rim diameters that you intend to build.

Some truing stands have a mechanism that checks the wheel dish as you build the wheel, however you should ideally check the dish with a separate dishing gauge because it's a more accurate method, and once you've used the separate tool you can then decide whether or not to use the dish checking facility built into the stand.

Wheel dishing gauge

A dishing gauge, sometimes called a centering tool, is used to check if the rim is central between the ends of the hub. The gauge is placed on one side of the wheel and the indicator positioned so that it touches the hub face. It is then placed on the other side of the wheel and the indicator without any adjustment should touch the other hub face and if it doesn't then the rim is not centred, but it's easily corrected during building. If you are building a wheel for an offset frame you'll need to make a small modification to this technique as described on page 20.

For many years I used the Park Tools WAG-1 (shown on the right) because it was a very good design, although it's now discontinued by Park. This gauge now struggles with today's wheels that use wide rims because there's insufficient adjustment of the pointer so I now use a homemade gauge which is actually better then the WAG-1.

I made the gauge shown in Figure 34 from 9mm plywood although any rigid material is suitable. The gauge covers wheel sizes from mountain bike to road wheels. If you are building smaller wheels then just make something smaller.

The feet of the gauge are made from 1 ½" x 1/8" (40mm x 3mm) aluminium T section.

The indicator is a 150mm steel rule sliding on a piece of magnetic strip. Magnetic strip is a low cost item easily available, or take some from a fridge magnet. I also polished the back of the ruler removing the graduations and placed some sandpaper on the front to give some additional friction where your thumb rests. Adding a drop of oil to the magnet makes it silky smooth to adjust and extremely precise and fast to use. The ruler slides between two guide blocks (I cut mine from a spare piece of the aluminium T section). I've profiled the end of the ruler so that it reaches underneath a hub skewer.

I'm not using the ruler to measure anything because the check for dish is just a visual assessment of the gap.

Everything (feet, guide blocks and sandpaper) is attached using double sided tape.

Figure 32 Wheel dishing tool

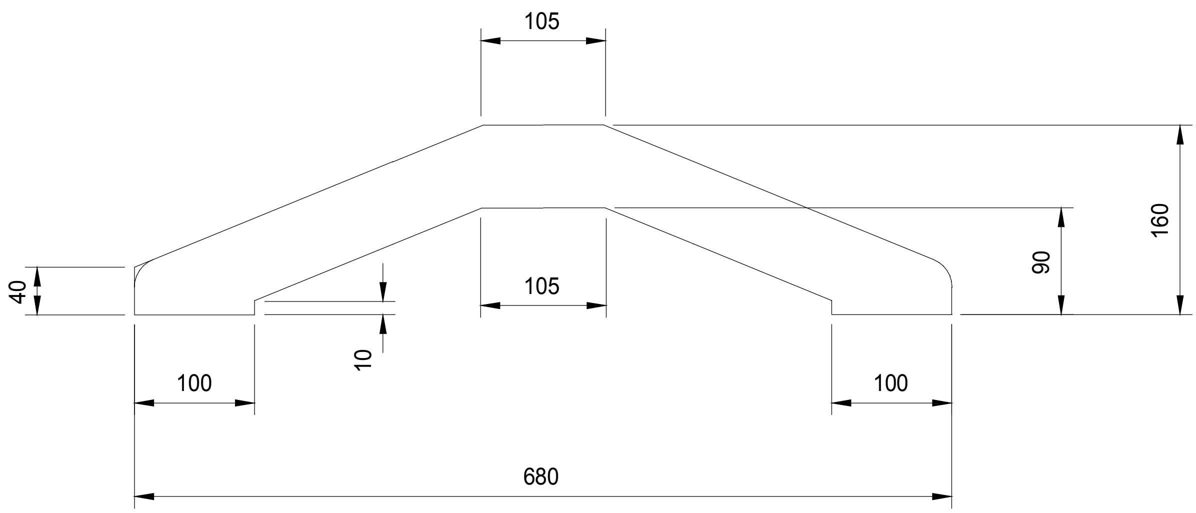


Figure 33 Dishing tool dimensions

To help you make the gauge I've put a download template in the support section on the Wheelpro website at www.wheelpro.co.uk/support

Figure 34 The dishing tool

The top right photograph shows the guide blocks and magnetic strip

The nipple driver

The nipple driver is an indispensable tool and I never build a wheel without using one. After lacing the wheel the next step in the building process is to quickly screw down the nipples to the same thread engagement. Using a nipple driver you accomplish this task quickly, with the added benefit that it makes the wheel close to radially true with little thought or effort.

Figure 35 The nipple driver

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 screw the nipple down the top of the spoke releases the blade and the blade spins freely with no further turning of the nipple. If you are struggling to see how this tool works then make one and try it out.

Purchase the cheapest screw driver you can find and hopefully it will be made from low quality steel that is easy to bend, if not then you'll need to heat it up in order to bend it. Cut away the handle of the screw driver to reveal the complete blade then file the end profile and bend it in two places to form the cranked shape as shown in Figure 36. Purchase a standard file handle available from any good hardware store or engineering supplier (mine is size 1, 110mm long) 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, you hold both handle and blade with one hand when locating the tool then the pressure exerted whilst turning keeps it in place. The procedure becomes intuitive and fast after a short time.

In the diagram in Figure 36 the 3mm point is important because this determines the amount of tightening and if you build a lot of wheels then it could wear down, so periodically measure and reshape it again if necessary.

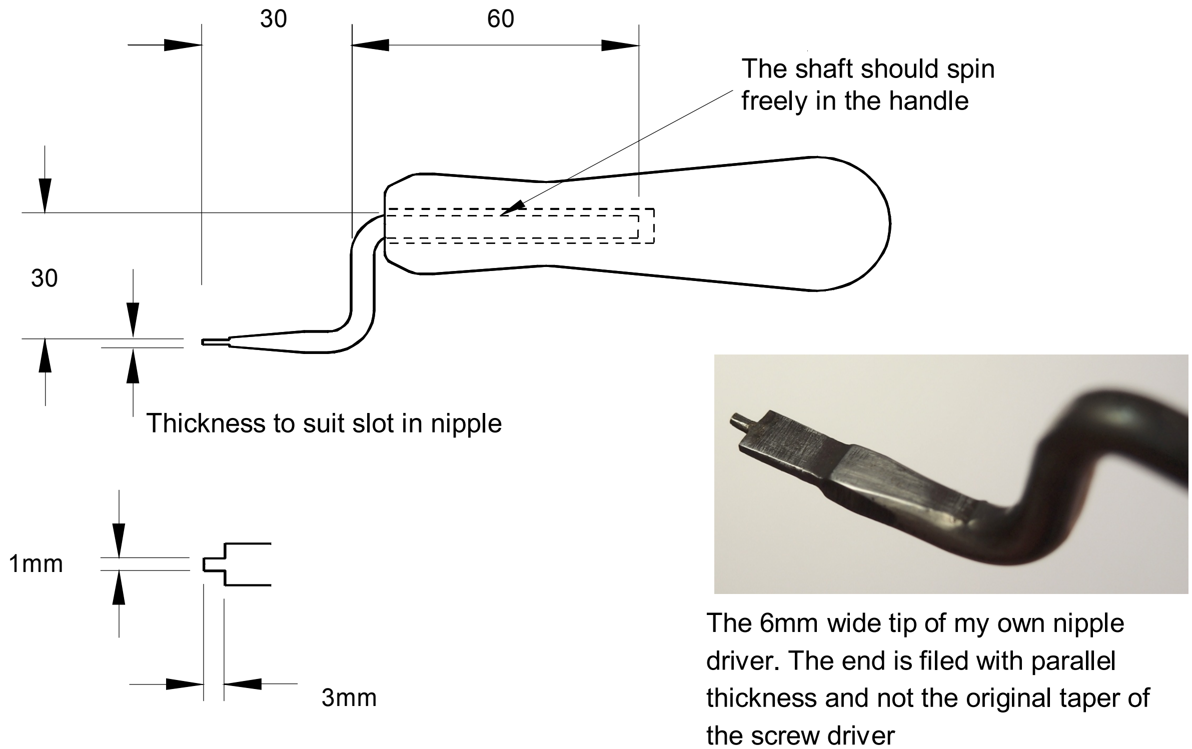


Figure 36 Making a nipple driver

Nipple drivers can be purchased but they don't work as well as the one described here. I find the proportions of the cranked profile are 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 a short point will tighten the nipples too much in the early stage of building.

Some wheelbuilders use a power drill with a straight bit using the same end profile as shown for the nipple driver, but I never use a power drill. 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.

The nipple driver described here is only suitable for conventional shallow rims and cannot be used on deep section carbon rims. The aim is to tighten all the nipples to the same engagement point so on deep rims you should initially tighten the nipples so that they just cover the visible spoke threads.

Nipple holder

When lacing a wheel you can usually place the nipples into the rim with your fingers. As the rim section gets deeper this becomes more difficult and you must avoid accidentally dropping a nipple into the rim cavity because it's awkward and time consuming to get it out.

If you look on the websites of Sapim and DT you will see they supply tools to help placing nipples into rims. I've tried one of thee but found it cumbersome to use and preferred to slice a cotton bud at an angle (as a wheelbuilder you will always have cotton buds in stock because they are used to oil the rim eyelets prior to lacing the wheel). Push the end into the nipple and you can easily place it into the rim then grasp the protruding nipple and pull off the holder, then use the nipple driver to spin the nipple onto the spoke a couple of turns.

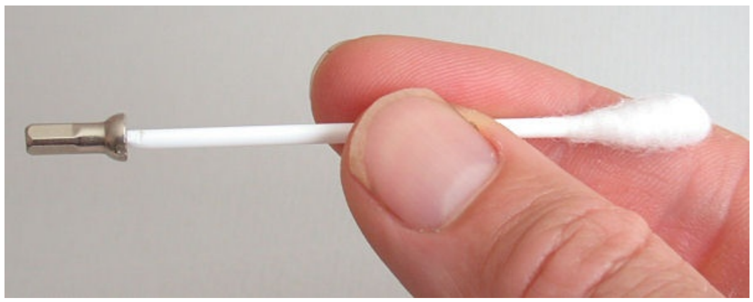


Figure 37 Nipple holder

A more durable nipple holder is made from a spoke by cutting off the thread and filing a very gradual taper onto the spoke which then pushes into the nipple and holds the nipple very securely. To give you an idea of how gradual the taper is, it's similar to the taper found in the butted section on a DT Competition spoke. It works extremely well and can even be used to screw down the nipple, then releasing it by pulling it out. The other advantage of this design is that you can make longer nipple holders that are required on deep section rims. If you prefer to purchase a nipple holder then the *Mulfinger Nipple Loading Tool* gets good reviews, although I've not tried one myself.

Leather gloves

You need a thick pair leather gloves to protect your hands because several times during the building process you are required to grasp and firmly squeeze the spokes when stress relieving them. I'll explain stress relieving in the building section.

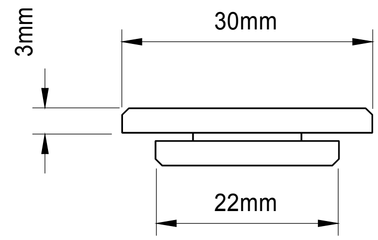
The ones I use are made from canvas and reinforced on the palms and fingers with thick leather and surprisingly they are very cheap.

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

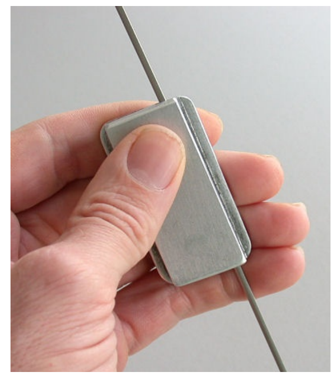
Figure 38 Leather gloves

Bladed spoke holder

Thin bladed spokes twist very easily which makes tensioning them difficult, especially the Sapim CX-Ray and DT Aerolight spokes with a cross section of 2.3mm x 0.9mm. 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 use. The cross section profile is shown on the right and it is 50mm long. The one shown here is for bladed spokes having a thickness of 0.9mm. I used a piece of 0.9mm feeler gauge sandwiched between two pieces of aluminium. The stepped design is important because it makes locating the tool on the spoke very easy. Initially it was bonded together using a high strength adhesive but the joint failed after a few months so I had it riveted together.



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 39 Bladed spoke holder

Tensiometers

A correctly tensioned wheel can be built without using a tensiometer because there's a broad range of acceptable tension and it's easy to drop into this zone and end up with a perfect wheel. Obtaining the correct tension is described in the building section, but please also read the notes about the effect of spoke tension on page 38.

If you purchase a tensiometer remember that the best tensiometers that are based on the Jobst Brandt design shown here are only accurate to +/- 10% and all other tensiometers will be less accurate. Without a means of checking them a tensiometer can only give you an approximation of the numerical tension which is usually sufficient when it comes to wheelbuilding.

Figure 40 Spoke tensiometer

If you build your wheels without a tensiometer and they are working and do everything expected of them then you don't need a tensiometer. If your wheels are not working as intended then a tensiometer is not a magic cure for obtaining good wheels.

Chapter 6

Spoke lengths

Building wheels with the correct length spokes makes things a lot easier. If the spokes are too short you will struggle with tight spokes too early in the building process and if they are too long the spokes will tighten through the nipple and be harder to turn. If you get your spoke lengths wrong it can often mean the wheel is impossible to build and it will be an expensive and time consuming mistake.

The technique for calculating spoke lengths is to measure the rim and hub and use a spoke length calculator. At a later date if you wish to rebuild this wheel with a different rim then it's even easier to calculate the spoke lengths as I explain later.

When gathering the components for your chosen wheels it's very tempting to purchase the hubs, rims and the spokes together, either to save time or save postage, however you should obtain the hubs and rims first so you can calculate the spoke lengths and then order the spokes. You cannot simply ask someone else for the spoke lengths, or make a calculation based on hub and rim data found on the Internet because that information is often wrong and your calculated spoke lengths will also be wrong. When I require a spoke length I always calculate my own and so should you, it's not difficult and the method I describe will allow you to work out spoke lengths for any hub and rim combination.

Measuring rims

The only rim dimensions that matter for spoke length purposes are the *Effective Rim Diameter* commonly referred to as the ERD, and if the rim has a large left/right stagger commonly found on fatbike rims then the distance between the two sets of spoke holes is required, all other rim profiles and dimensions are irrelevant.

The ERD is the rim diameter measured at the spoke ends in the finished wheel.

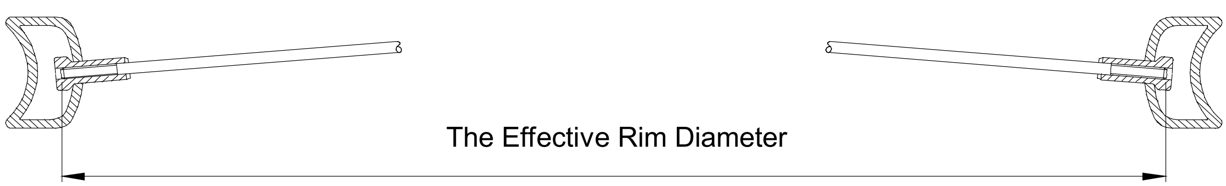


Figure 41 Effective Rim Diameter

Rim manufacturers often provide the ERD but you should never use it because the ERD is not a strictly defined term and I've seen far too many errors to trust ERD data from *any* source. You should always measure the ERD yourself since the ERD has the biggest effect in spoke length calculations. For example, if you calculate your spoke lengths using an ERD that has a 4mm error then your spoke lengths will be wrong by 2mm which could mean the wheel is difficult or even impossible to build.

Measuring the rim ERD

If you look at Figure 41 you will see that ERD depends on the nipples you use and your preference for where you want the spoke ends to finish in relation to the nipple. For standard 12mm nipples I like the spokes to finish somewhere between the top surface of the nipple and the bottom of the nipple slot.

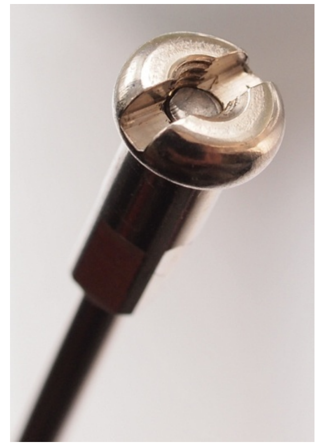


Figure 42
Position of the spoke in the measuring tool

Take two spokes and cut off the elbow and file them down accurately to 200mm. Screw a nipple onto one of them so that the spoke end is flush with the bottom of the slot. Secure it in position by crimping the square flats or gluing the nipple threads. If your wheel uses nipples longer than 12mm or internal nipples or some other design of nipple then see the discussion on non standard nipples on page 60.

Join the ends of the spokes with a piece of elastic. You'll need to experiment to get the correct length of elastic so that it pulls the spokes taut when they are placed in the rim. If you prefer to hold the spokes without using elastic then make sure the spokes leave the rim straight with no tilting otherwise you will get a measurement error.

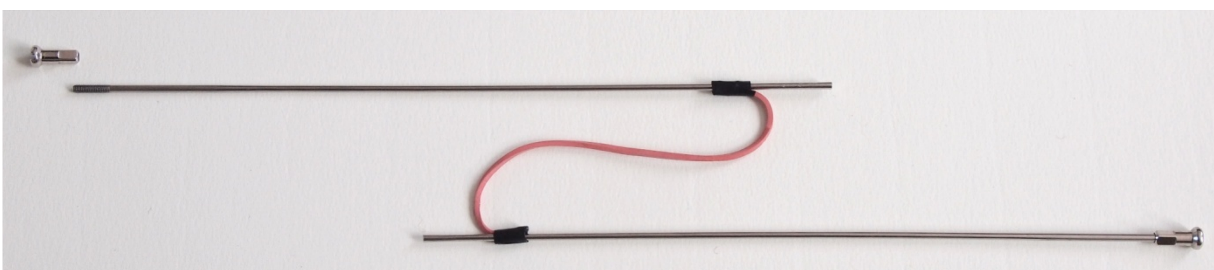


Figure 43 ERD measuring tool

Place these spokes through the rim making sure they go through exact opposite holes because it's easy to be off by one. Attach the other nipple to the same thread engagement. Measure the gap between the spoke ends and add 400mm to get the ERD. Average several diameters. If you need to measure rims less than 400mm in diameter use shorter measuring spokes, for example 2 spokes at 100mm, measure between the ends and add 200mm.

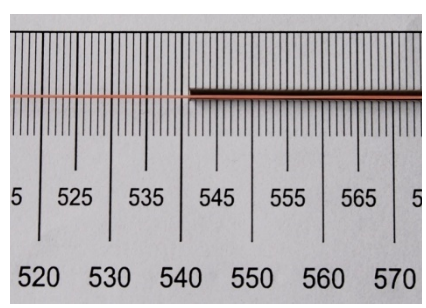


Figure 44 Custom ERD ruler

I've created a direct reading custom ruler to speed up the rim measuring process (when using 200mm measuring spokes), for example the rim on the right measures 541mm.

I've provided the ruler and instructions in a separate document at www.wheelpro.co.uk/support

Measuring the erd in a built wheel

This technique is useful when swapping a rim and you don't know the erd of the rim in the existing wheel (page 103).

Measure the outside diameter of the rim by rolling the wheel one revolution on a flat surface, measure the distance travelled and divide by 3.142 to get the outside diameter. Measure from the outside to the top surface of the nipple (dimension X) and subtract twice this from the outside diameter. The position of the spoke in the wheel you are measuring is irrelevant since the erd is always 1mm below the top surface of the nipple, so subtract 2mm (2 nipples at 1mm each). If you are measuring the erd of a rim using the standard technique described previously then give this method a go for practice and see how the two erd's compare, they should be the same.

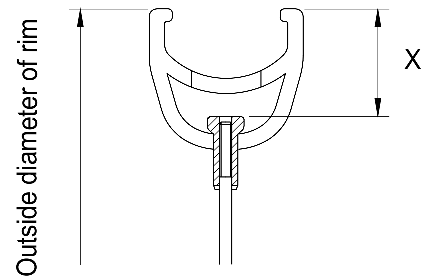


Figure 45 ERD of a built wheel

Rims with a large hole stagger

The spoke holes in rims are normally drilled with a small left/right stagger which does not affect the spoke length. If there is a visually large stagger, for example on fatbike rims, then this has to be taken into account when calculating the spoke lengths, see page 57.

Measuring hubs

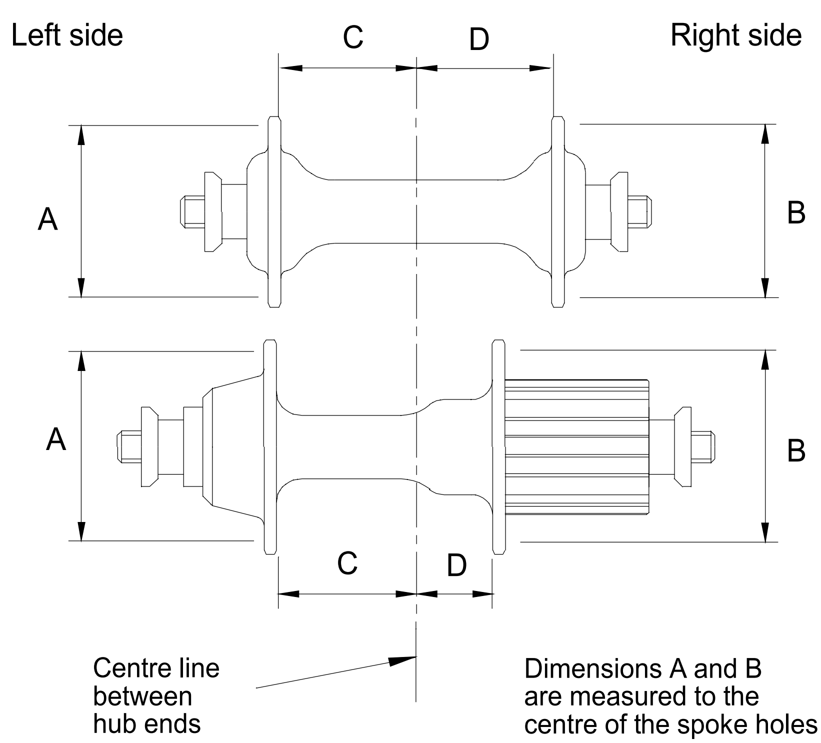


Figure 46 Hub measurements for spoke length purposes

Initially I said that you should never trust data from other sources but you can safely use the information supplied by the *hub manufacturer* (but not from anyone else) because unlike rims the hub measurements are to fixed points on the hub with no ambiguity (apart from the Shimano website where the data is either confusing, missing or sometimes wrong). Manufacturers will often refer to dimension C as *centre to left flange* and dimension D as *centre to right flange*. If you use the manufacturer's data then make sure you select the correct hub because sometimes it's not easy identifying what's in your hand with those listed on their website. I always measure my own hubs because it's quicker than searching the manufacturers websites and the dimensions I obtain will always be accurate.

Hub measuring method

Measure the hub diameters A and B (see Figure 46) from spoke hole centre to centre using a pair of spring dividers which are low cost tools and easily available.

Figure 47 Spring dividers

For symmetrical front road hubs obtain the flange distances (dimensions C and D) by dividing the flange width by two. For rear hubs, front disc hubs and other non symmetrical hubs use the following technique to measure dimensions C and D, a rear hub is shown but the technique is the same for all hubs.

C = z - x

D = z - y

z = Half the hub width

See measuring x and y below

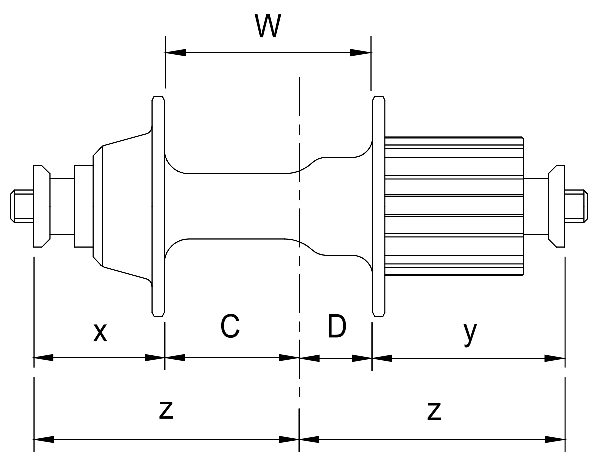


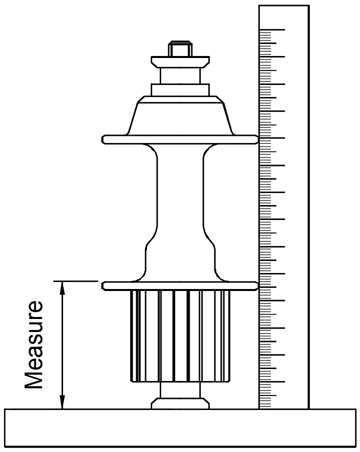
Figure 48 Measuring the hub flange distances

Always check your calculation, measure between the flanges with a ruler (dimension W) and it should be the same as C + D.

I always measure to the inside faces of the hub flange because it's easier to do, if you measure to the centre of the flange then it won't make much difference (try it and see the effect on spoke length using the spoke calculator).

Measuring x and y

Place the hub face against the edge of your desk and take the measurement with a ruler or to gain greater accuracy let the hub stand upright on its end (for quick release hubs you'll need to use a piece of wood and drill a hole so that the hub rests on its locknuts).



You can also use a piece of card and mark the position then measure separately.

Figure 49 Measuring x and y

Spoke length calculators

Once you have your hub and rim measurements put them into a spoke length calculator. All spoke length calculators use the same formula so there's no need to check your calculation across several, there may be small differences between different calculators which is due to the implementation of the formula and whether they use any compensations. You need to choose one calculator and stick with it so you'll become familiar with it and be confident in selecting spokes based on its output, I'll recommend my own, www.wheelpro.co.uk/spokecalc because I wrote it and use it all the time.

Rounding the spoke lengths

The spoke lengths from the calculator are to one decimal place and you should always use this precision when determining your actual spoke lengths. Based on this length you can go 1mm either side to find a suitable spoke length. Very soon you'll be able to look at the length to 1 decimal place and quickly make your decision.

Some spokes are only made in even lengths and even though they come in 2mm increments you will always be able to select a suitable spoke length. Here are some examples to show how I would choose an even and odd size based on the calculated size.

Calculated	Even	Odd	
292.3	292	293	For the even size I couldn't use 294 because it's 1.7mm too long and the odd size at 291 is 1.3mm too short. You can only go + or – 1mm. If both sizes are available then the even size at 292 is closer to the calculated figure but the alternative 293 is still okay.

265.6	266	265	You can use 265 or 266. The 266 spoke will be easier to find since most sellers only stock even lengths.
295.1	296	295	The odd size is obvious. For the even length I'd take a spoke 0.9mm long (296) rather than 1.1mm short (294). If I did choose the 294 spoke then I'd use a 1mm longer point on the nipple driver otherwise the short spoke would tighten too early in the build process.
261.0	?	261	The options for the even size are 1mm too long or 1mm too short. I would choose 262 for standard spokes and 260 for thin spokes (DT Revolution) since they will stretch a little more. Alternatively make sure you measured the rim ERD correctly, a 1mm error in ERD means the spoke length changes by 0.5mm which could make your decision easier.
290.5			Determine the selection yourself. The answers are given at the bottom of page 62.
181.8			

Record your data

The technique for calculating spoke lengths required you to measure your hubs and rims and **you need to write these measurements down**. You also need to write down calculated spoke length (to one decimal place) and lengths you actually used to build the wheel. In the future these notes will be valuable wheelbuilding information and believe me you will kick yourself if you didn't record your data.

Figure 50 Spoke length data

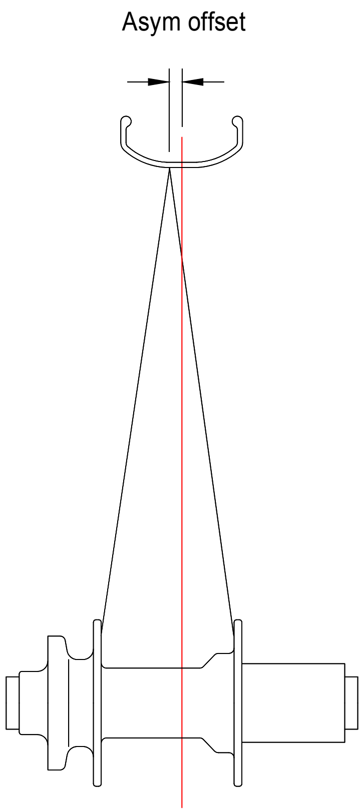
When you've finished building the wheel examine where the spoke ends finished, your initial selection may not have been perfect so you may need to revise the lengths for future wheels. Based on the observation you should always write down two sizes. The first is the preferred size and the other is an alternative size that would still build the wheel. This gives you the option of saying in the future when you build the same wheel *"well I haven't got the preferred size in stock, but I know the alternative will still enable me to build the wheel"*.

I've made recording the data easy for you. Use the Wheelpro spoke calculator, calculate your spoke table and print the spoke length page to get a specially formatted print. Record your data and keep the sheet somewhere safe. Shown here are some of my own notes, the older notes were written on plain paper then I added the print facility to the spoke calculator and started using that.

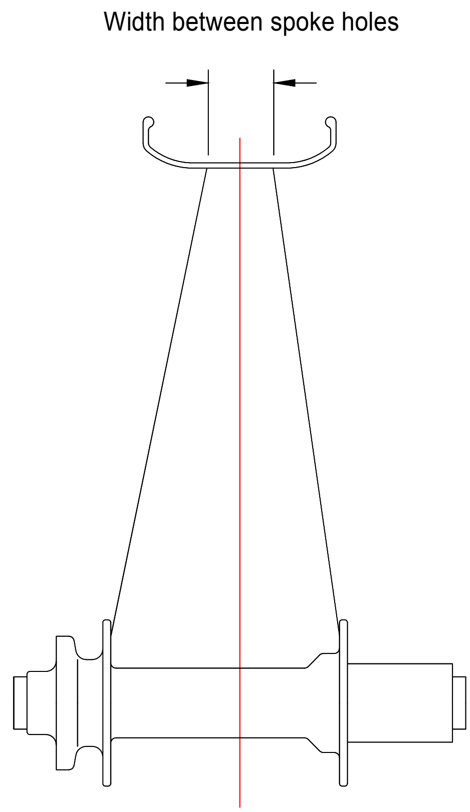
Spoke lengths for offset rims and offset frames

The method for working out spoke lengths for offset rims and offset frames involves adjusting the left and right flange distances of the hub and using these adjusted versions in the spoke length calculator. In the following diagrams the red line is the centreline of the cycle frame (and rim).

Offset rims



Offset one side



Offset both sides

These are asymmetric rims (often abbreviated to ASYM) where the spoke holes are positioned over to one side. The rim manufacturer will specify the offset value which is typically around 4mm.

For the rear wheel shown here the ASYM value is subtracted from the left flange offset and added to the right flange offset.

For a front disc brake hub the ASYM value is added to the left (disc) side and subtracted from the right.

This is either a rim with a very large left/right hole stagger, or a fatbike rim with two rows of spoke holes. Conventional rims have a very small left/right stagger that does not affect the spoke length, but if the stagger is over 4mm then you should take this into account when calculating spoke lengths.

The width between the spoke holes is divided by 2 and subtracted from both the left and right flange offsets.

Shown here is a 170mm fatbike hub.

Figure 51 Offset rim spoke calculation

Offset frames

The lower hub is shown as it would appear in a symmetrical frame and note how the same hub in an offset frame reduces the left hub flange and increases the right side.

With an offset frame you subtract the frame offset from the left side and add it to the right. The frame manufacturer will specify the amount of offset.

Fatbike wheels and offset frames

If you have an offset fatbike frame you need to take the calculation one stage further.

The diagram shows a 135mm hub placed in an offset frame, the dimensions relate to a Surly Pugsley frame which has a frame offset of 17.5mm and a Surly Marge Lite rim with 25mm between the two rows of spoke holes.

Fatbike offset frames require a fatbike rim with a double row of spoke holes. The spokes must be laced to the right set of rim holes (the left set cannot be used because the left side spokes would be vertical). So add half the width between the rim spoke holes to the left side and subtract it from the right.

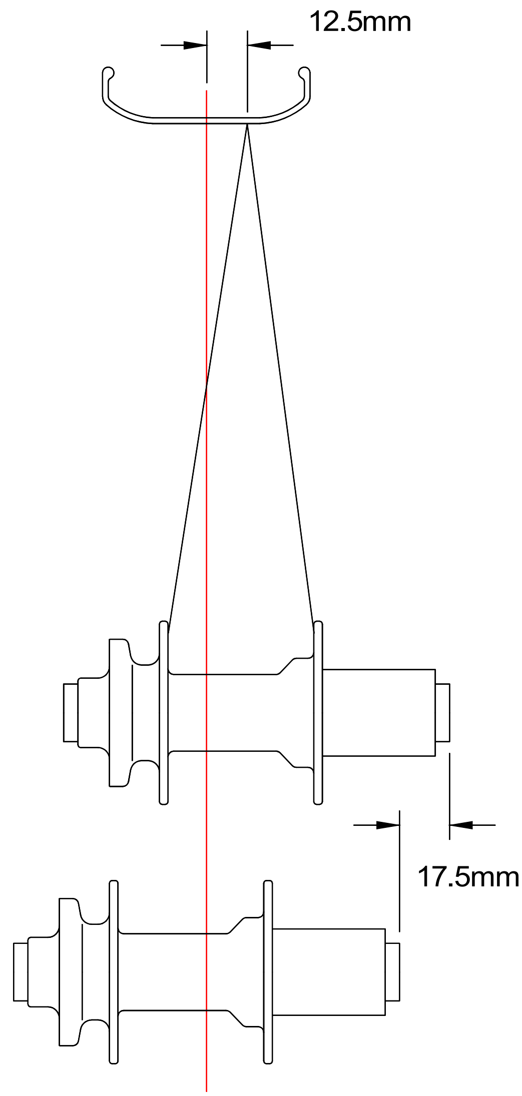


Figure 52 Fatbike offset frame

Here's the full calculation:

Shimano Zee hub	**Centre to left**	**Centre to right**
Original flange offsets	33.5	20.5
Pugsley 17.5mm offset frame	-17.5	+17.5
Surley Marge Lite rim	+12.5	-12.5
Modified flange offsets	**28.5**	**25.5**

The modified left/right flange offsets should be within a few mm of each other, if they are a lot different then you are advised to check your calculation. Another check is to add together the modified offsets and the result should be the same as adding together the original offsets.

How nipple length affects spoke length

Longer nipples are only required when the standard 12mm nipple does not protrude through the rim enough to locate the spoke wrench. It's very rare that a rim requires more than 12mm, the only time I use a longer nipple is when I build a Mavic UST mountain bike rim because this rim has a unique design which requires a 14mm nipple, for every other rim I use 12mm nipples.

With longer nipples the spoke length is *sometimes shorter* than the lengths used for 12mm nipples and is based on how the manufacturer designs the threaded portion of the nipple. When DT makes a longer nipple they also increase the length of the internal threading which requires an adjustment to spoke length. Sapim keeps the thread length constant so no spoke length adjustment is necessary. I'll take a closer look at the DT nipples to show why the 14mm nipple requires a spoke 1mm shorter, and the 16mm nipple requires a spoke 2mm shorter.

DT-Swiss nipples

I've made some cross sections of 16, 14 and 12mm DT nipples shown on the next page. The ruler is in 1mm increments. The red lines indicate the start of the thread in the nipple and the black lines mark the end of the thread 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. The blue lines mark the top of each 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.

Spoke lengths for DT 14 and 16mm nipples

Measure the rim ERD using the measuring tools described on page 52 (using a 12mm nipple) and calculate the spoke lengths. If the wheel is going to be built with 14mm nipples subtract 1mm from the spoke lengths and for 16mm nipples subtract 2mm. The DT-Swiss spoke length calculator automatically subtracts 1mm if you specify a 14mm nipple and subtracts 2mm if you specify a 16mm nipple.

Spoke lengths for other makes of long nipples

There's an easy way to check if compensations are necessary. Take one of the long nipples you intend to use and screw it on a spoke with light finger pressure until it goes no further and look at where the spoke end finishes up. If the end is just above the top surface of the nipple (the same as a 12mm nipple) then for spoke length purposes they are identical to 12mm nipples and no compensation is required, if not then make some ERD measuring tools with the nipples you intend to use as described on page 60 for non standard nipples.

If you are using a longer nipple and the nipple design requires a shorter spoke then take this into account when using the nipple driver to take out the initial slack since the 3mm point normally used on the nipple driver will benefit from being longer.

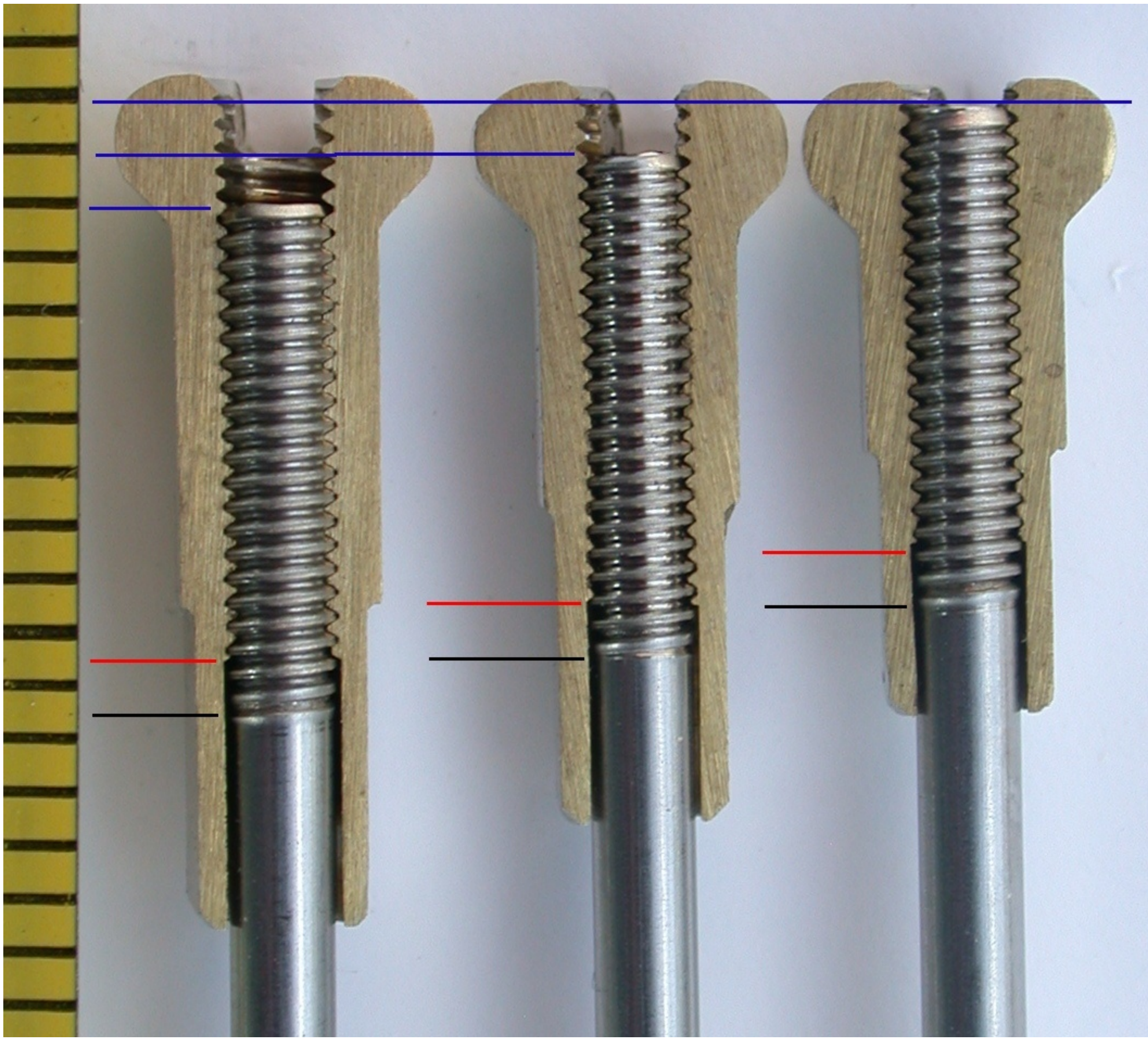


Figure 53 DT-Swiss Nipples
From left to right 16, 14 and 12mm

Spoke lengths for non standard nipples

If you build with something other than 12mm nipples you will need to modify the rim measuring tools and replace the 12mm nipples with those you intend to use. You will need to do this with internal nipples and *may* need to do this with 14mm and 16mm conventional nipples as previously discussed on page 59.

Screw the nipple you intend to build with onto each measuring spoke using light finger pressure until it stops, then unscrew the nipple 2mm and that's your ideal position and since the spoke thread is 56 threads per inch, 2mm equals 4.5 turns.

Spoke lengths for a different rim

Once you have built a wheel and later decide to build another wheel using the same hub, same spoke count and same lacing pattern but this time using a *different rim* then calculating spoke lengths is very easy. All you do is compare the rim ERD diameters and modify the spoke lengths you previously used.

For example, I have already built a wheel that required 262mm spokes and now want to build a similar wheel using a different rim. The previous rim had an ERD of 540mm and the ERD of the new rim is 544mm so the spokes need to be 2mm longer and I will use 264mm.

All I did was use half the difference in rim diameters to modify my existing spoke lengths. If my new rim was smaller in diameter I would be subtracting rather than adding. I use this method all the time since I tend to build the same hub onto lots of rims and it provides fast and very accurate spoke lengths. You must have a record of the previous wheel, you need the rim ERD and the spoke lengths you used which are taken from the notes you made whilst building the previous wheel.

Another example, the ERD of the next rim I build on this hub is 7mm smaller, so the spokes are 3.5mm shorter. The exact spokes for this wheel are therefore 258.5mm. So I could use either 258mm or 259mm, the 0.5mm error is insignificant.

If you have the same hub but with a *different spoke count* or require a *different lacing pattern* then you cannot compare the rim diameters and must use a spoke length calculator.

You must also use a calculator if your existing data is based a standard rim and the next rim is an ASYM offset rim. Once you build the wheel and determine the exact spoke lengths they become your standard, and for the same hub built onto other ASYM rims (which have the same offset) just compare rim diameters as before.

The spoke length formula

I've put the proof of the formula in the Appendices on page 119.

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

where :

R = Rim ***radius*** *(half the ERD)*

H = Hub flange ***radius*** *(half of dimensions A and B on page 53)*

F = Hub flange offset (dimensions C and D on page 53)

X = Numeric value of the cross pattern (0, 1, 2, 3, 4)

h = Number of spokes in the wheel

ϕ = Diameter of spoke hole in hub

Notes when using the formula

1. You need to do separate calculations for each side of the hub.
2. For radial wheels the number of crosses in the calculation is zero giving identical spoke lengths regardless of the number of spokes you specify.
3. Many spreadsheets and programming languages use angles in **radians**. The value of 720 in the formula is in **degrees** and is converted to radians by multiplying by 2π/360.

Test calculation

If you intend to use the formula in your own calculator then use the following data to check it because 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.

For example purposes the wheel consists of a 540mm diameter rim, a hub with a flange diameter of 38mm and flange offset of 36mm with 32 spokes built 3 cross.

R	270
H	19
F	36
X	3
h	32
ϕ	2.5

Substitute these values into the spoke length formula

$$\text{Spoke length} = \sqrt{270^2 + 19^2 + 36^2 - 2 \times 270 \times 19 \times \cos\left(\frac{720}{32} \times 3\right)} - \frac{2.5}{2}$$

Spoke length = **264.51** mm

The online spoke calculator at www.wheelpro.co.uk/spokecalc uses a fixed spoke hole diameter of 2.5mm. It also subtracts 0.2mm which I find makes the results accurate in the real world. In the above example it calculates a spoke length of 264.3. If you want to check this with the spoke calculator then A and B are 38, C and D are 36 and the rim diameter is 540.

Here are the answers to the spoke length rounding questions on page 56.

290.5	–	290	–	291
181.8	–	182	–	181

Straight pull spoke lengths

You **must** use a spoke length calculator that is compatible with straight pull hubs because the spoke length formula for a straight pull hub is slightly different. If you use a normal calculator your spoke lengths will be wrong! The Wheelpro calculator is straight pull compatible (and at the time of writing, the DT Swiss calculator is also compatible). The measurements for a straight pull hub are as follows:

Flange diameter

The measurement is taken at the extended crossing point of two spokes. If the spokes are close to tangent then the diameter can be measured to the centre of the spoke holes, if they are not tangent (as shown in this diagram) then it's the midpoint between the diameters of the spoke entry and exit holes. A small error when measuring the diameter will not affect the spoke lengths.

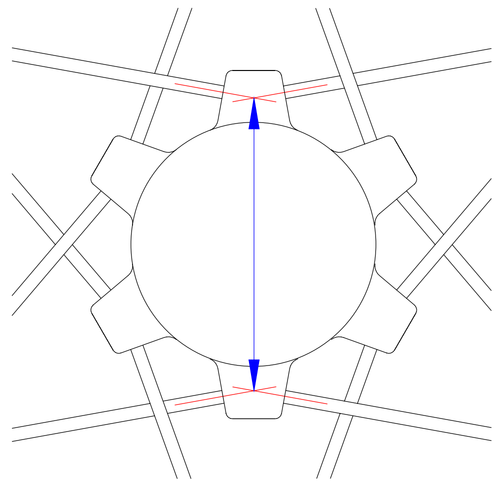


Figure 54 Straight pull flange diameter

Flange distance

With a straight pull hub each side can have two rows of spokes, if so then take the measurement to the centre of the rows.

Spoke offset

This is the measurement from the centre line to where the spoke head seats. It can be either positive, negative or zero depending on the hub design. Measure the offset carefully because it has a direct effect on the spoke length, for example a measuring error of 1mm will result in a 1mm error in the spoke lengths.

The measurement is taken at the point where the conical head of the spoke starts (which is the position where the spoke length for a straight pull spoke is taken).

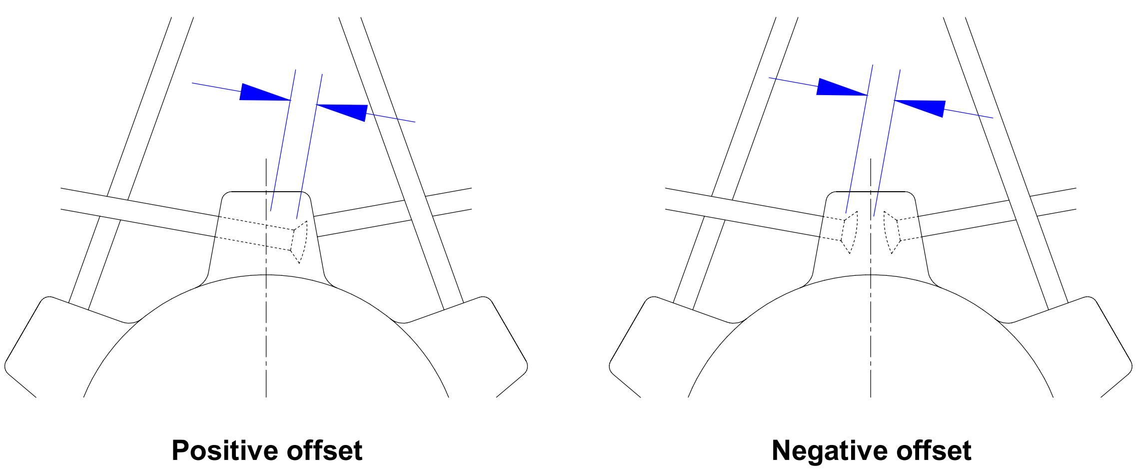


Figure 55 Straight pull spoke offsets

Measuring the spoke offset

With negative offset hubs the spokes usually locate in open slots and the position where the spoke heads locate is easily seen, so measure between the two location points and divide by two.

Where the spoke location is hidden you need to make some measuring tools. Take a straight pull spoke and cut the threads off, then cut the spoke into two pieces around 120mm long and accurately file the lengths as shown in Figure 56.

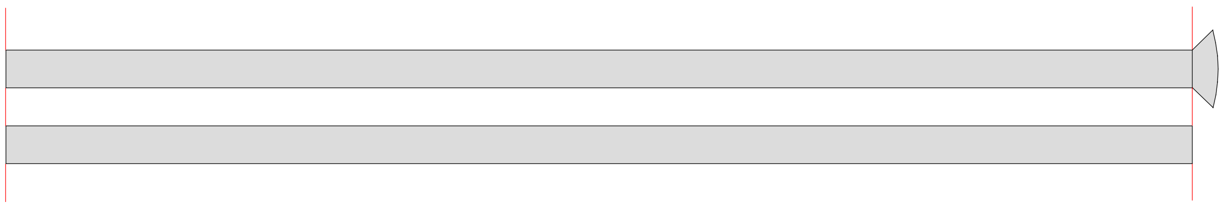


Figure 56   Spoke offset measuring tools

Mark the centreline of the hub. Place the spoke into the hub and lay the other piece adjacent to it with the ends touching and tape the spokes together. The measuring spoke must be placed on the side of the hub to avoid measuring errors. Pull the spoke taut and measure the offset relative to the centreline. The example below is the left side of a Hope Pro4 front hub, the Hope data sheet on their website lists the offset as 1.7mm. With these tools it's difficult to get that level of precision and I measured the offset at 1.5mm which is good enough for the spoke length calculation. Since this is a positive offset the Hope figure would yield a spoke length 0.2mm longer.

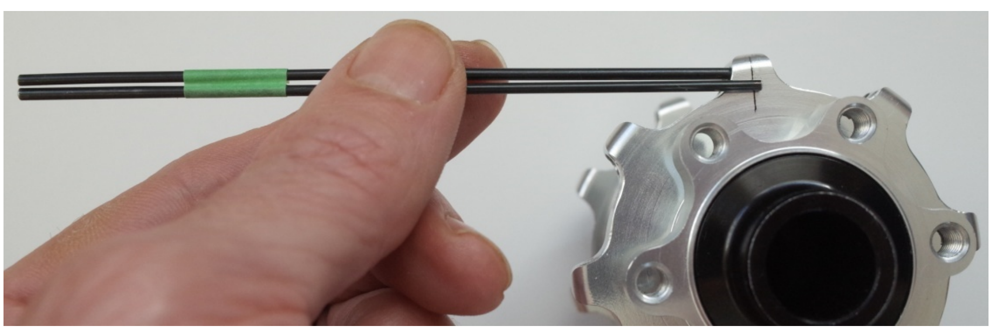


Figure 57   Measuring the spoke offset

You can also ask the manufacturer for the straight pull hub dimensions for diameter, flange distances and spoke offsets. To avoid any ambiguity give them a link to the help page for straight pull hubs in the Wheelpro spoke length calculator which shows the dimensions required. If they do supply the dimensions you are still advised to assess them to see if they look reasonable, for example if they quote a spoke offset of 10mm it's likely to be wrong.

www.wheelpro.co.uk/spokecalc/help-sp-hub.html

An example of a straight pull wheelbuild including the spoke length calculation is shown in Appendix 5 on page 129.

Chapter 7

Lacing the wheel

The following instructions show you how to lace a 32 spoke wheel with a 3 cross pattern. The **same procedure** is used for all spoke counts, for example with 36 spokes the only difference is you have 4 spokes extra to lace. For different cross patterns (including radial which is zero cross) it's the **same procedure** except for a small change in lacing step 7 (described on page 77).

Record your data

Measure your hub and rim and record this information along with the spoke lengths you are using. The reason for recording this information is described on page 56.

Hub and rim checks

Make sure you know which is the left and right side of your hub. All the lacing diagrams are shown looking on the right side of the hub.

If you have a previously used hub then you should try and lace it the same way as it was originally laced, see page 10. The following instructions will result in option A lacing (page 30), if your original pattern was different you'll need to make some minor changes as described on page 79.

Look at your rim and check if the rim holes are staggered (page 12). If you have a carbon fibre rim then make sure you correctly identify the stagger, read the section on page 13 which describes spoke holes that are drilled on an angle.

If the rim holes are a normal type 1 stagger or the holes are positioned centrally then use the lacing instructions as written. If your rim has a type 2 stagger which is quite rare, then there are two slight modifications shown in steps 2 and 4.

Label your spokes

If your wheel requires two sizes of spokes then make sure they are kept separate, for example put them on individual pieces of paper with their **intended location** written on. If you are building a rear wheel label your two sets *Drive* and *Non drive*, if it's a front disc hub then label them *Disc* and *Non disc*. If you accidentally mix these spokes up, or choose a spoke from the wrong set during lacing you will have a lot of problems when you start tensioning the wheel and finding the spokes you incorrectly laced and rectifying the situation is not easy.

Figure 58   Label your spokes

Oil your spokes and rim

Spokes assembled completely dry will be difficult to bring to the correct tension due to friction in the spoke threads and where the nipple seats in the rim. Without oil the spokes will be more prone to twisting, the wrench will be harder to turn and the nipple will grab and release on the thread making fine truing difficult. The oil I use is motor oil which is anything that goes into a car engine or gearbox.

The purpose of the oil is to reduce friction and allow the nipple to be tightened to achieve the correct spoke tension; the oil will not subsequently cause the nipples 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.

Spoke prep and adhesive are not necessary and I've put some notes on this on page 79.

If you want to practise lacing up and 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 are ready to complete the wheel.

Oil the spokes

Take each bundle of spokes in turn and tap the spoke threads on a flat surface 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 want them to be lightly coated and not swimming in oil which is messy and unnecessary.

Oil the rim eyelets

Oil the rim eyelets using a cotton bud dipped in oil. Do this for all rims, those with eyelets and those without. You also oil carbon fibre rims.

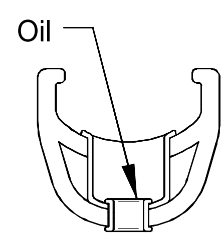


Figure 59   Oil the rim

Lace the wheel

The lacing procedure is described in 9 steps. 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. You'll soon know if you are lacing it wrong because the symmetry of the wheel will be lost and in most cases it will be impossible to complete the lacing.

When lacing, the nipples should only be attached a couple of turns to hold them on the spokes. I always stand up when building a wheel and I also like the room to be quiet.

Lacing step 1

The lacing starts on the right side hub flange.

- For rear hubs this will be the drive side flange.
- For front disc hubs this will be the flange opposite the disc brake fitting.

Align the hub label (optional)

In the finished wheel it's nice to have the rim valve hole aligned with the hub label (see page 76). This is purely a cosmetic exercise but it's generally recognised as a sign that the wheelbuilder has shown attention to detail. One benefit is that it makes finding the valve hole easier when building the wheel.

Look at the centre of the hub label and identify the spoke hole to the left of it (hole 0), then count to the left the same number as the crosses being built.

Since I'm showing you how to lace a 3 cross wheel count 3 holes to position 3 and place a spoke through this hole from the outside. If you build a radial wheel use hole 0. Keep hold of this spoke, it will be the first spoke you place in the rim in step 2 (next page).

If you have a previously used hub it might not be possible to align the label because the existing indents in the hub may prevent you from selecting the desired hole. It's more important that you match the original lacing so you may need to skip this cosmetic exercise.

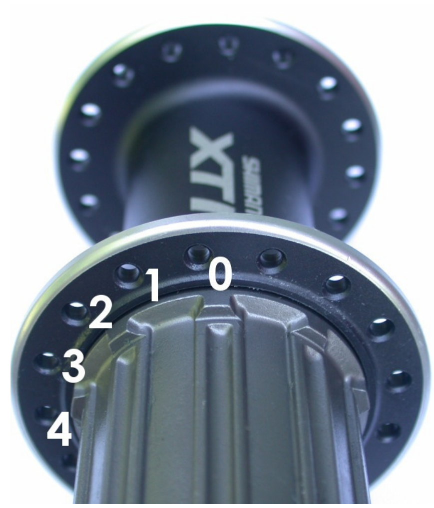


Figure 60 Aligning the hub label

Take 7 more spokes (or start here with 8 spokes if you are not aligning the label) and place them through the right side hub flange from the outside using alternate holes.

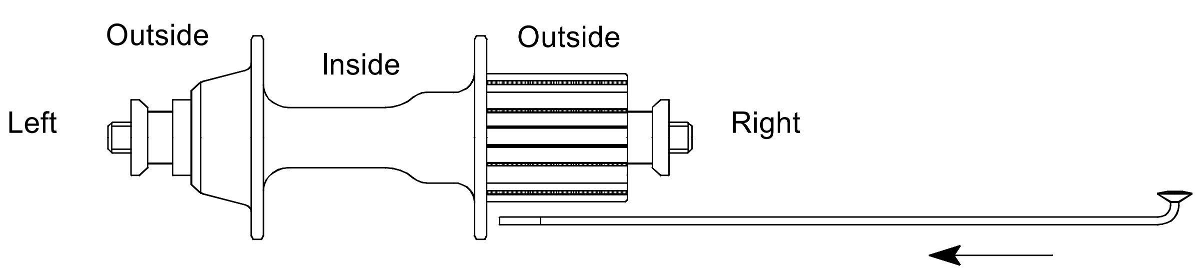


Figure 61 Lacing step 1

Lacing step 2

If the rim has a manufacturers label then it's good practice to ensure it's readable when looking on the right side of the bike (see page 76) although these days most rim labelling is symmetric. Turn the rim over if necessary.

Regardless of the rim label, if your rim has offset spoke holes (an ASYM rim) then make sure the rim is the correct way around, for a front disc brake wheel the offset is away from the disc side, for a rear wheel the offset is away from the cassette side.

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

If you are aligning the valve hole this is the spoke you initially identified on the previous page.

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

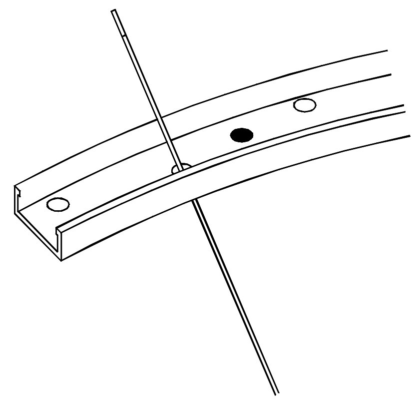


Figure 62 Lacing step 2

It is important to get this first spoke correct because it determines the placement of all the other spokes in the wheel.

To make sure your first spoke is correct it should look like this photo (type 1 rim shown).

For clarity only one spoke is shown, your hub will have 7 spokes hanging loose. A piece of tape marks the position of the valve hole with the spoke placed through the rim hole immediately to the left.

Figure 63 The first spoke (visual check)

Lacing step 3

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

Your wheel will look like the diagram shown below with the spokes protruding straight through the rim. There are three rim holes between the spokes.

One of the spokes is directly to the left of the valve hole (for type 2 rims it will be 2nd left).

The diagram is drawn semi 3 dimensional looking on the right side of the wheel.

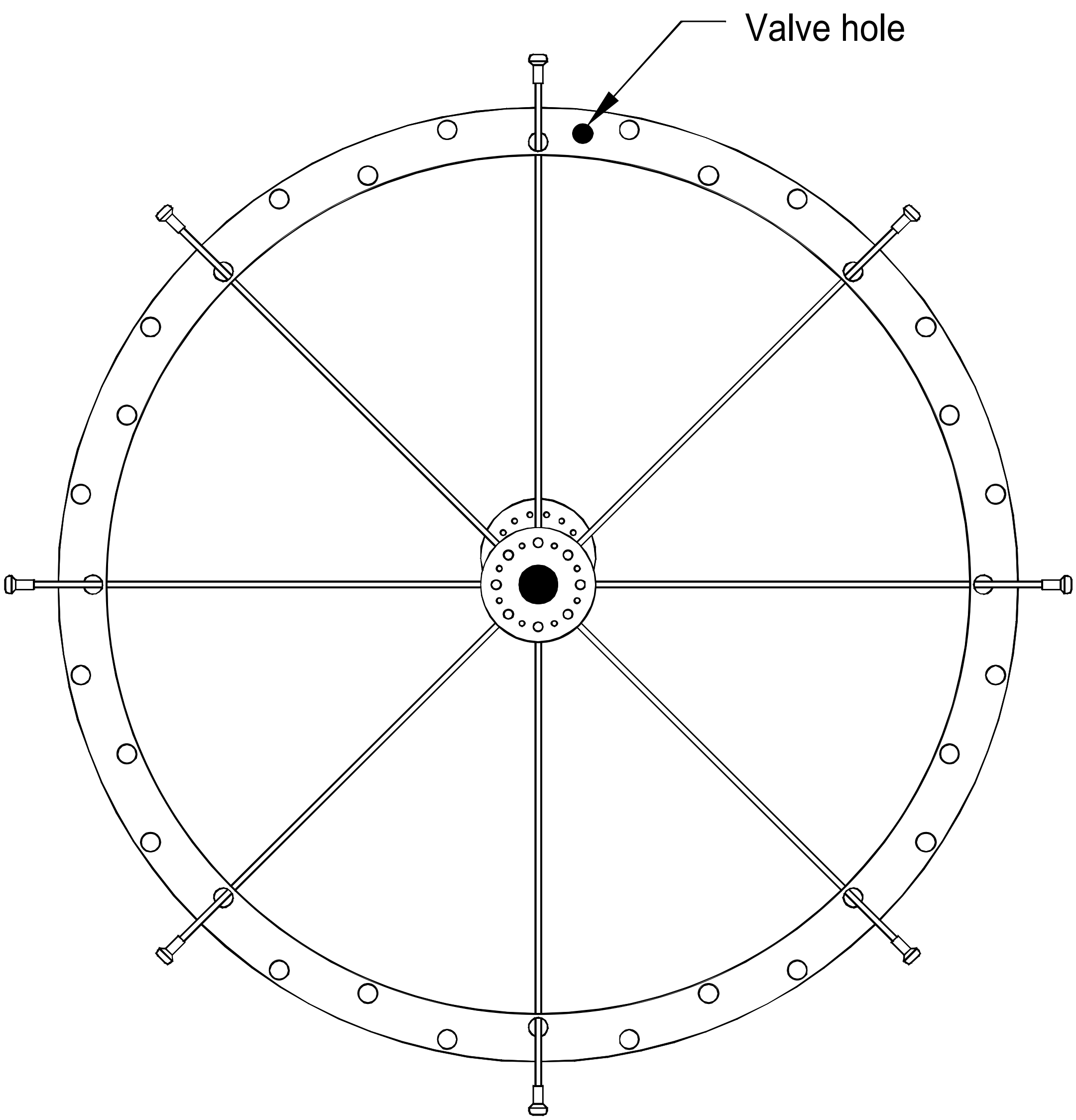


Figure 64 Lacing step 3

Lacing step 4

Look at one of the spokes, any spoke will do, and where it passes through the hub. Using this hole look across the hub and notice how the holes on the other flange are offset, there is one hole either side.

Select the hole to the **left**.

Take a spoke for the opposite side and pass it through this hole from the **outside** and place it in the rim immediately to the **left** of the sighting spoke.

Caution : if your wheel requires two sizes of spokes make sure you select the correct one.

Type 2 rims select the hole to the right and place it in the rim to the right of the sighting spoke

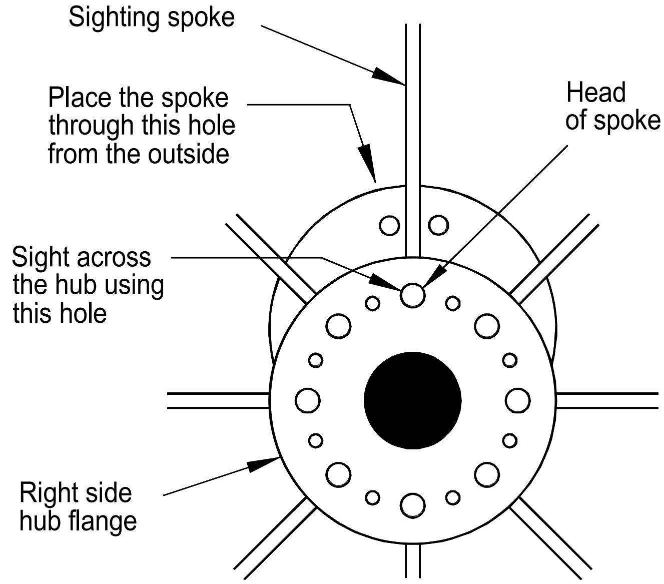


Figure 65 Lacing step 4 (hub placement)

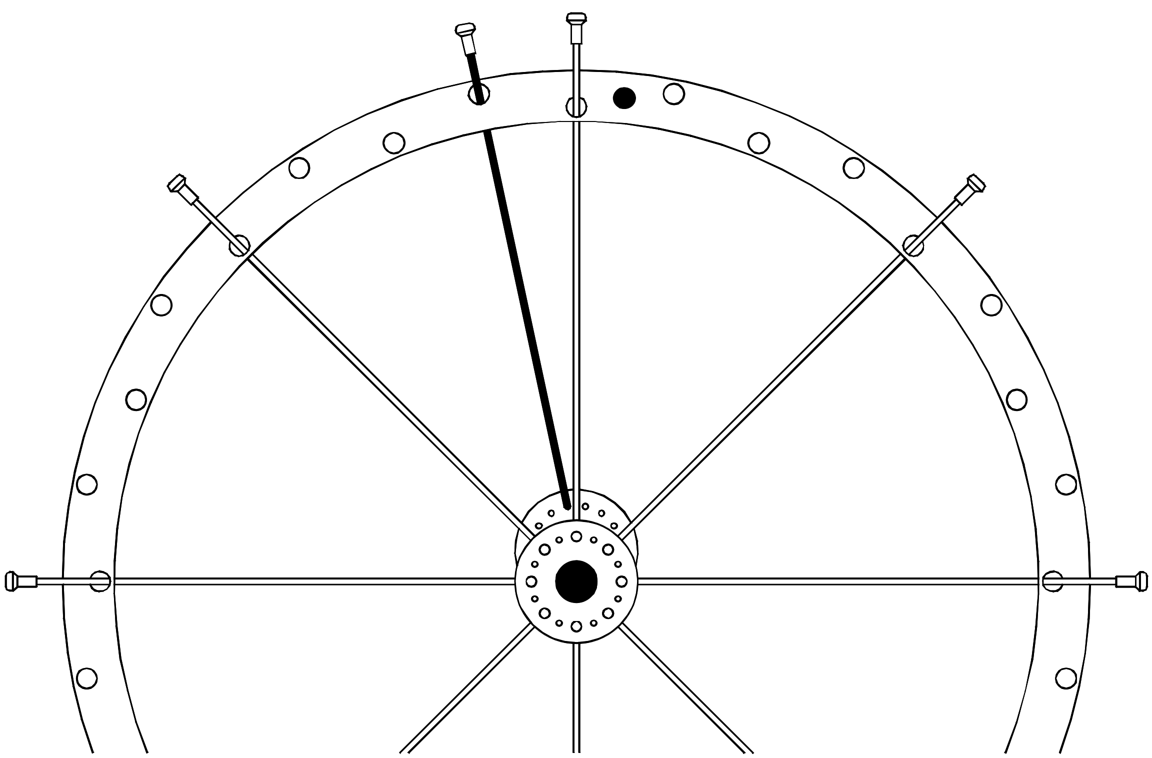


Figure 66 Lacing step 4 (rim placement)

Lacing step 5

Continue on the other side with 7 more spokes. There is no need to repeat step 4.

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 the diagram below.

The quick way is to hold the wheel flat and drop these 7 spokes through the hub, then with the wheel stood upright place them very quickly adjacent to the spokes on the right side.

The second set of spokes is now in and both sets lie on the **inside** of the hub.

Your wheel will look exactly like this, the spokes shown in black are on the opposite side flange.

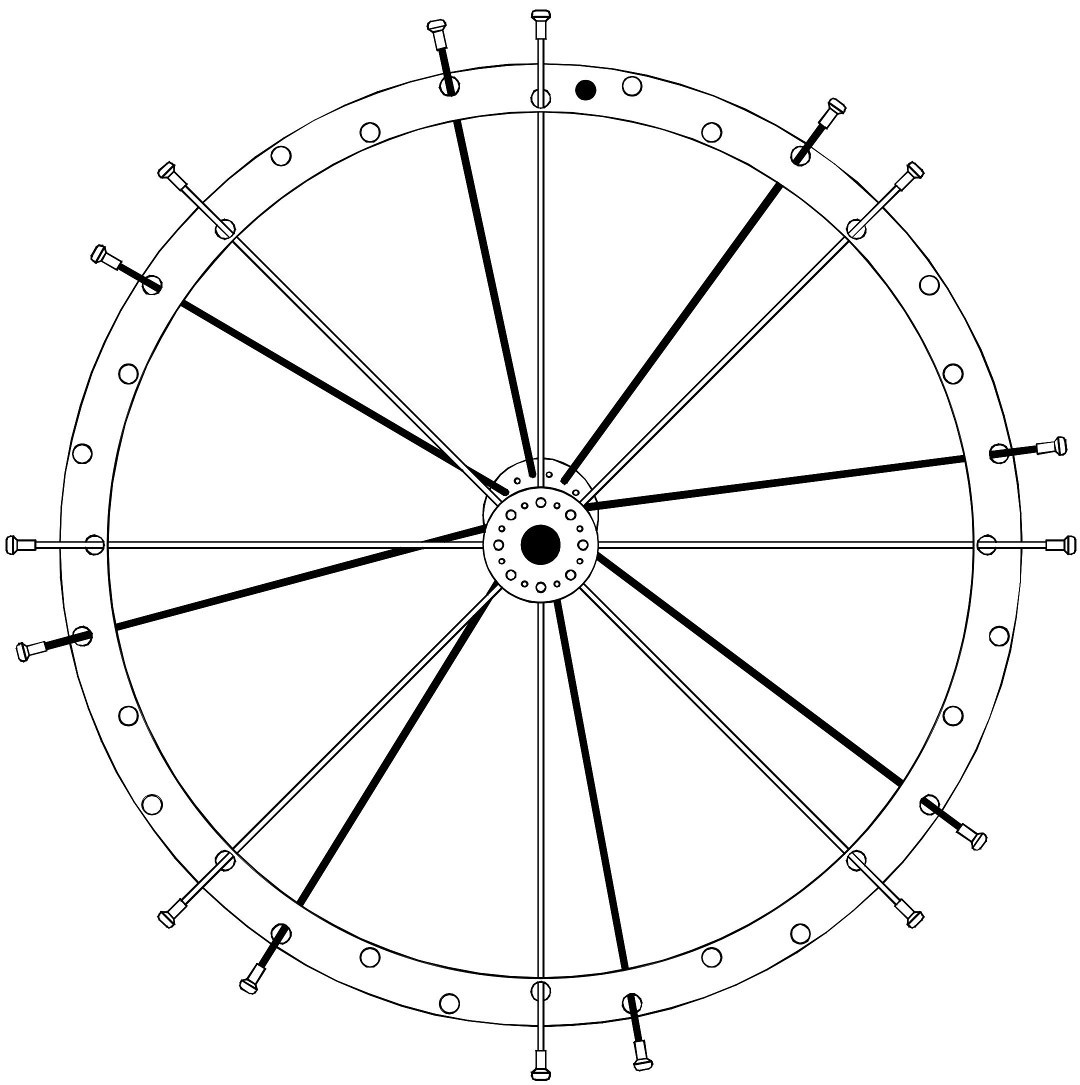


Figure 67 Lacing step 5

The following diagrams show a more realistic side view of the wheel looking on the right side. For clarity only the spokes in the near side (right side) are shown.

Lacing step 6

Grip the hub and rotate in the direction shown. The two spokes adjacent to the valve hole will slope away from it (the diagram only shows one of the spokes).

If the spokes are a tight 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 twist the hub, you may even have to start the spokes moving tangentially by pushing each spoke in turn close to the elbow. Alternatively the spokes may be a loose fit in the hub and it will not hold its rotated position and you will have to carry out this exercise again whilst starting step 7.

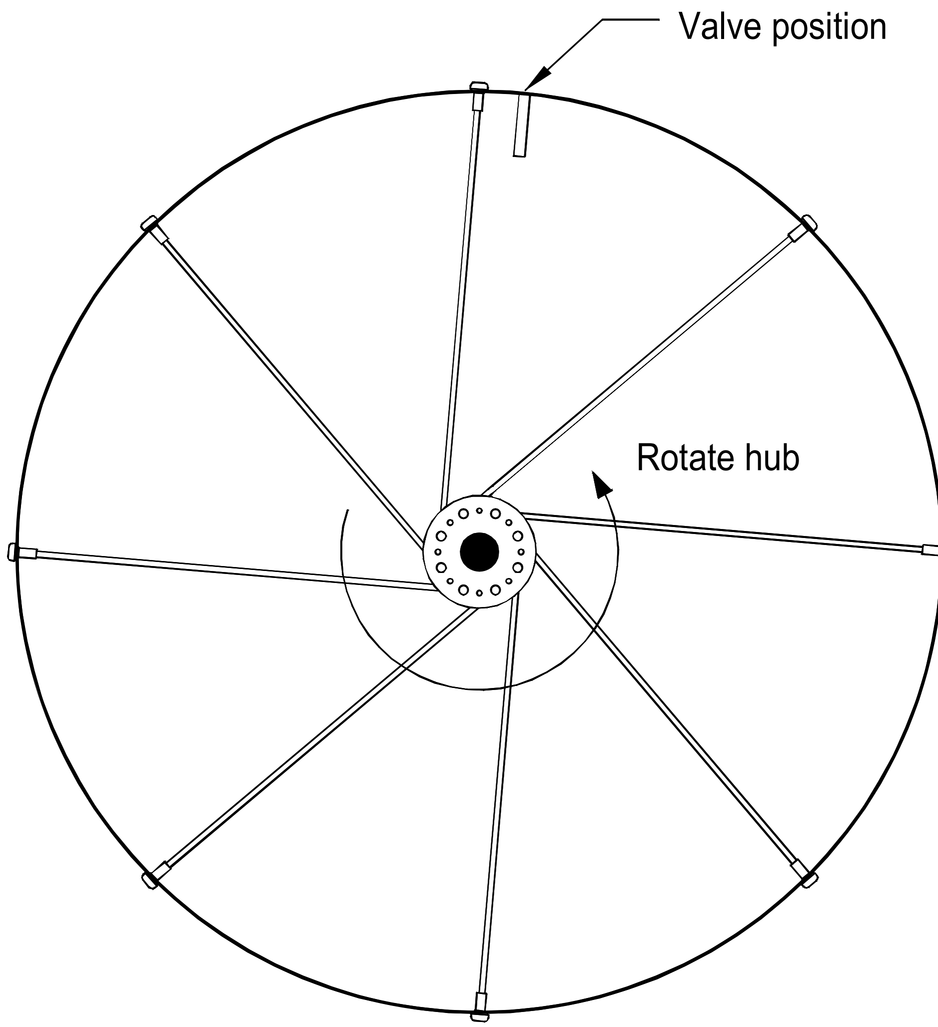


Figure 68 Lacing step 6

Lacing step 7

Take a spoke for the right side and pass it through the hub from the inside 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 this is a 3 cross wheel the spoke will cross 3 other spokes before entering the rim.

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 scratch the rim with the threaded end of the spoke.

There are two available rim holes for placing the spoke but it must go through the rim hole which is central between the two spokes on the same side. 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, the hub is fully rotated and you have selected the correct rim hole.

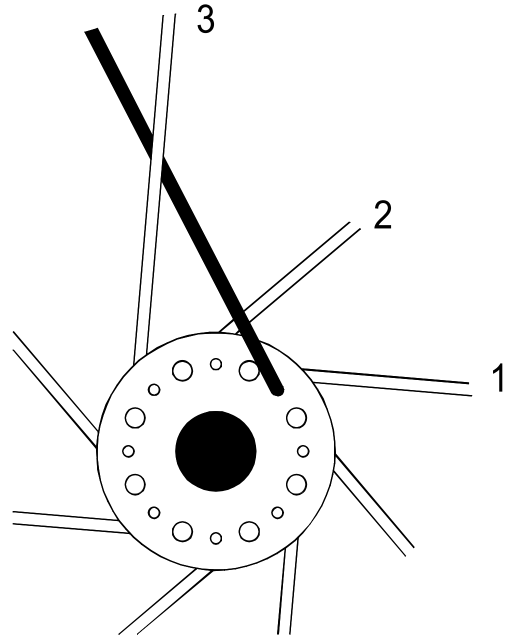


Figure 69 Lacing step 7 (3 cross)

You'll need 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 spin with the nipple driver as you bring the spoke towards the nipple.

If the rim has a cavity be careful not to drop the nipple into it because it can be awkward to get it out. If you have difficulty placing the nipples then use the nipple holder shown on page 48.

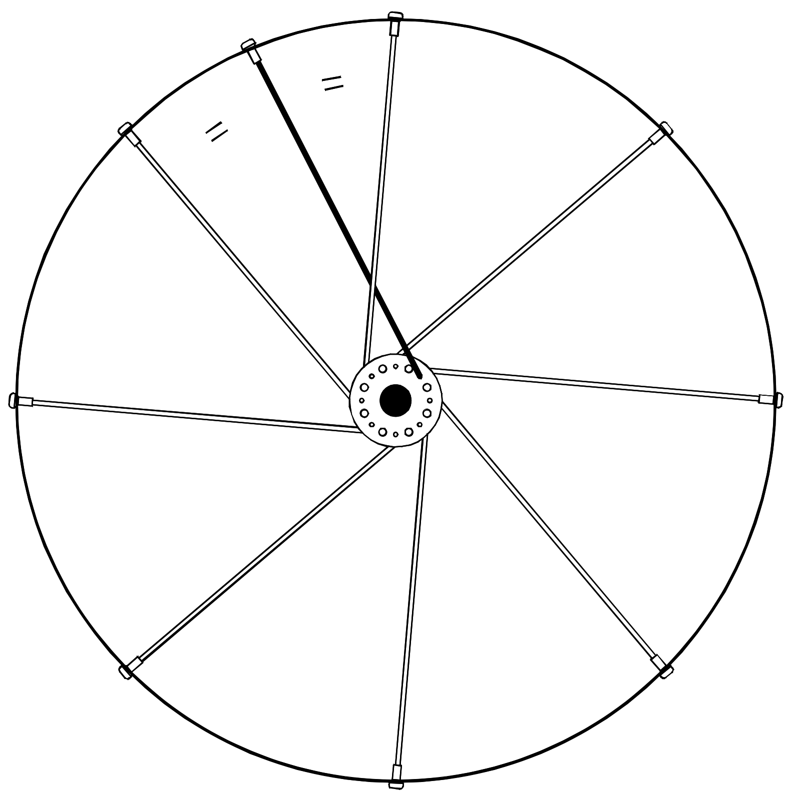


Figure 70 Lacing step 7

Lacing step 8

Continue with 7 more spokes, weaving each spoke *over, over, under and in* using the nipple driver to attach the nipple. The 3rd set of spokes is now in. The quick way is to put all 8 spokes into the hub when starting Step 7 but initially you should do it one at a time until you become familiar with the process.

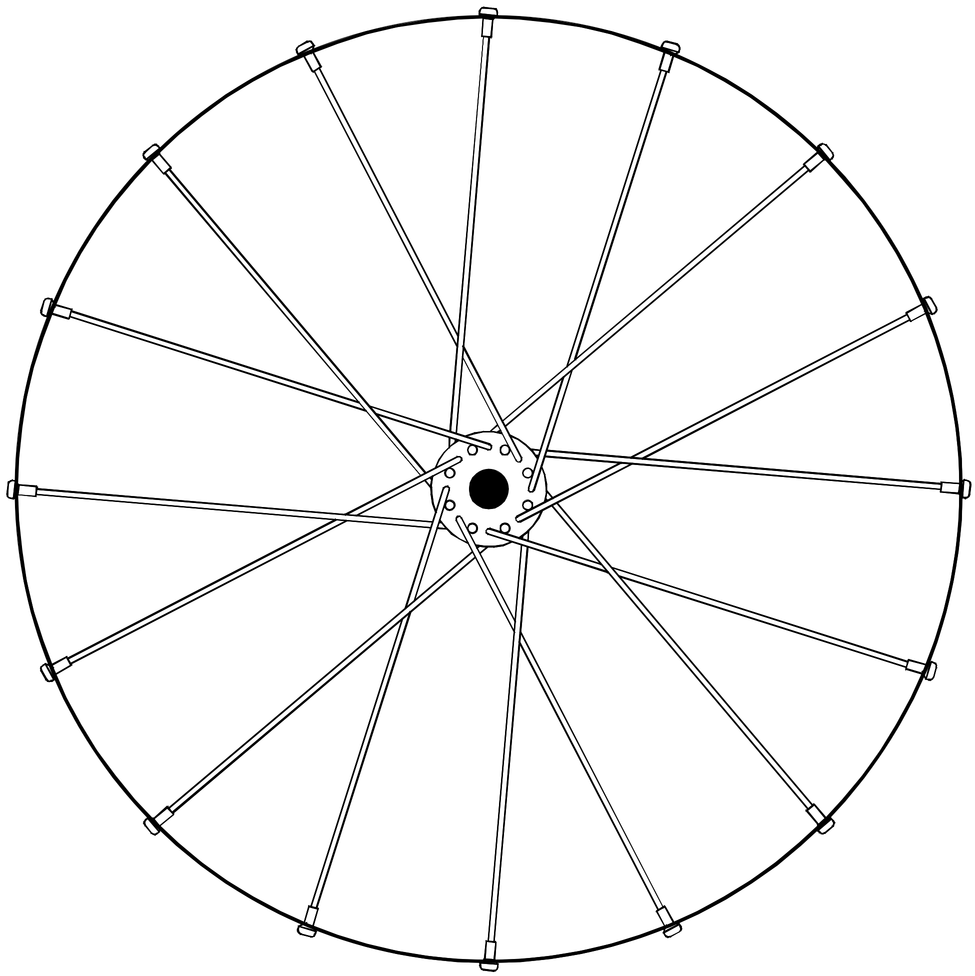


Figure 71 Lacing step 8

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 through 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 loose.

Lacing step 9

Complete the other side of the wheel in the same manner.

The 4th set of spokes is 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.

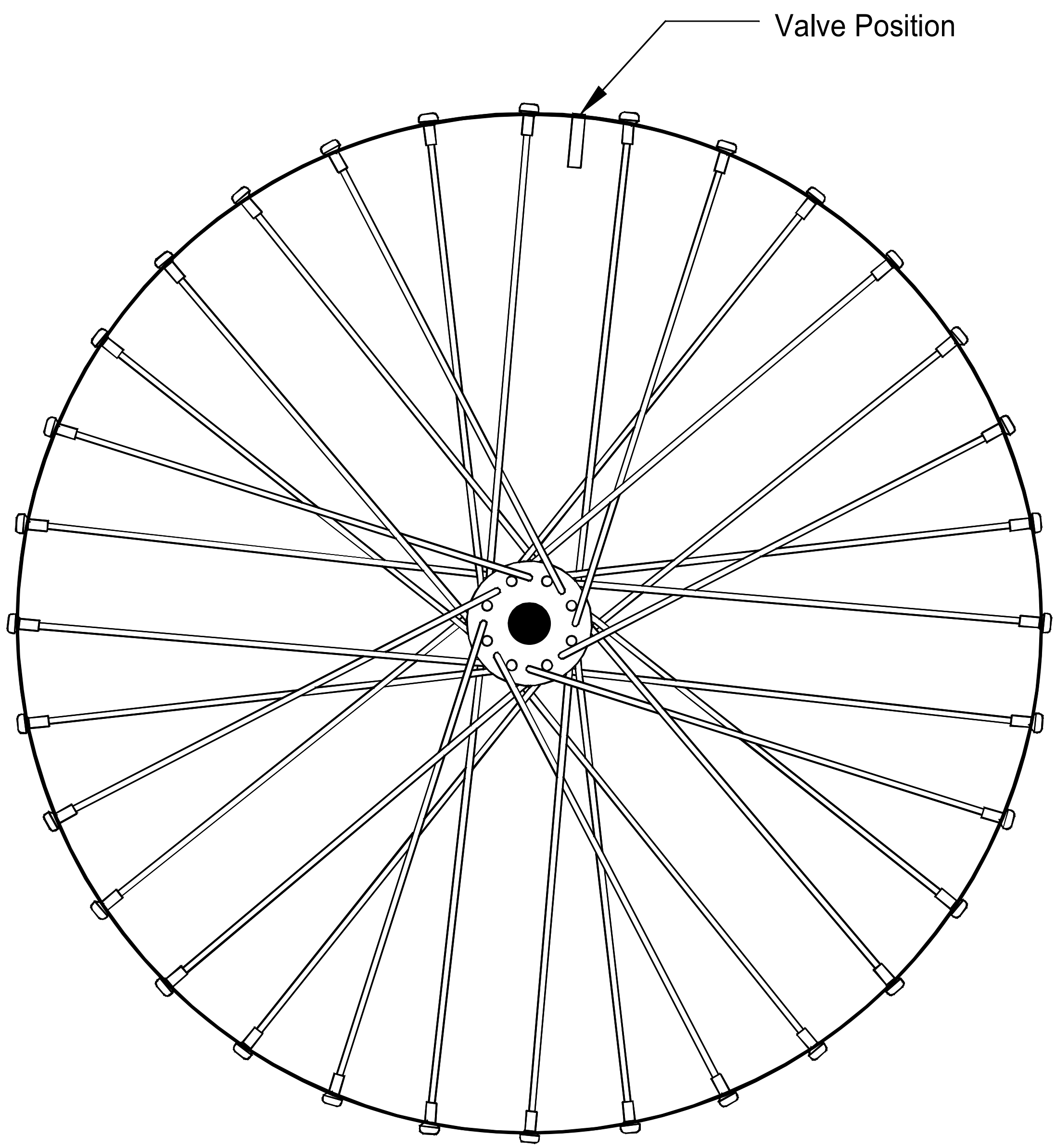


Figure 72 Lacing step 9

There's a video in the support section on the website (www.wheelpro.co.uk/support) showing the lacing procedure with text on the video to mark the individual lacing steps previously described.

Check your wheel

It should have a regular even pattern and 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 have a left/right stagger then the spokes should be connected to the correct side of the hub. If your rim has offset spoke holes (an ASYM rim) then make sure the rim is the correct way around, for a front disc brake wheel the offset is away from the disc side, for a rear wheel the offset is away from the cassette side.

If you want to dismantle the wheel and re lace it for practice the spokes will no longer be perfectly straight but the gentle bends in them are harmless. If you are using two sizes of spokes then make sure you keep them separate.

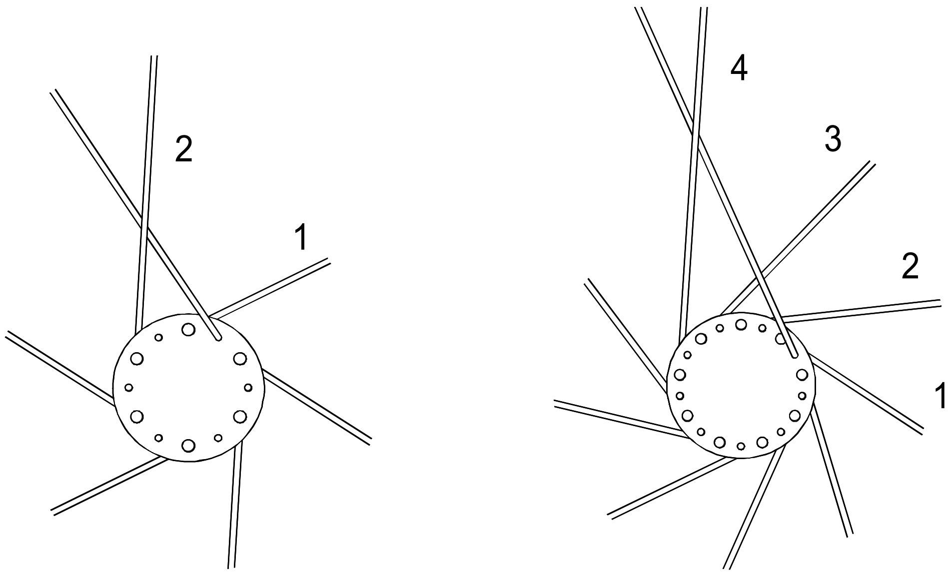
Here is a wheel with the valve hole pointing at the hub label and the rim label is readable from the right hand side. Don't worry if the wheel you just laced didn't turn out this way, it's not important because it's only a cosmetic exercise.

Figure 73   Cosmetically perfect

The rest of this chapter describes some different lacing patterns, if you want to finish your wheel you can skip to the next chapter starting on page 81.

How to lace 2 and 4 cross wheels

To lace a wheel using a 2 or 4 cross pattern you need to make one change at Step 7 in the lacing procedure on page 73 and substitute one of the drawings below. When counting the crosses remember to include the first cross which is very close to the hub. You will of course require the appropriate spoke lengths because changing the number of crosses changes the spoke length.



2 Cross
Over spoke 1 and under the 2nd
24 spoke wheel shown.

4 Cross
Over 3 spokes and under the 4th
36 spoke wheel shown.

Figure 74   2 and 4 cross lacing patterns

Lacing a radial wheel

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. Not all hubs can be radial laced, see page 40 for further information. The only decision on placing the spokes is whether to have the spoke heads on the inside or outside. Using *heads in* to achieve a wider bracing angle and a laterally stiffer wheel achieves nothing since there's more than enough stiffness already. The manufacturer of this hub specifies that heads in radial lacing should not be used on their hubs because it puts additional stress on the hub flange as the spoke is pulled over at a point where there is minimal hub material. I always lace heads out.

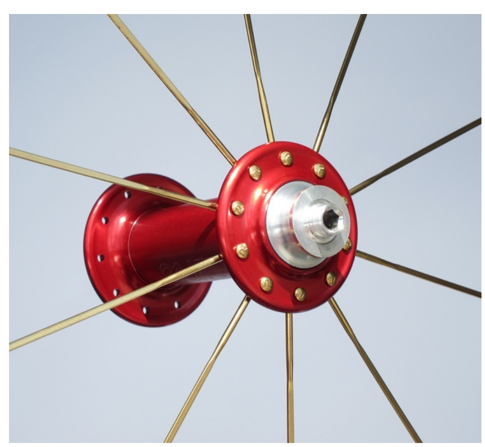


Figure 75   Heads out radial lacing

Cross combinations on the same wheel

You can use different cross patterns either side of the wheel, for example you could build a 32 spoke wheel with one side 3 cross and the other side 2 cross. The only reason to do this would be to give more spoke length options. In reality there is only one combination worth considering where one side has a cross pattern and the other side radial, known as a half radial wheel. It's going to be interesting to build but only another wheelbuilder is likely to notice and there are no performance benefits in doing this. If you plan to use half radial then read the discussion on page 40 and lace your radial side spokes heads out.

If you want a different cross pattern on the opposite side of the wheel then Lacing Step 4 on page 70 (placing the first spoke on the opposite flange) requires a small change.

In Figure 76 *Normal* represents the standard placement when using the same number of crosses either side. If you want to increase or decrease the number of crosses then select the appropriate hole. 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** (3cross-**1**=2cross) and for radial you would place it through the hole marked –3 (3cross-3=0 crosses or radial). The spoke is placed in the rim as described in Lacing Step 4, always to the left of the sighting spoke. Complete the lacing by following the remainder of the lacing procedure as written.

This diagram is for use with rims that have a type 1 hole stagger or are centrally drilled (see page 12). The type 2 rim stagger is rare so I'm not going to include a diagram for this, but if you do find one of these rims then modify the diagram by shifting the hole pattern clockwise one hole so that *Normal* is on the right side of the spoke.

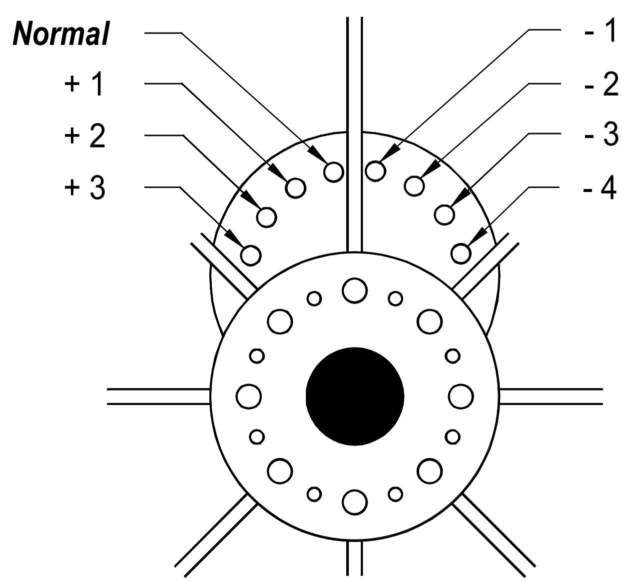


Figure 76 Different cross patterns either side

Option A, B and C lacing

As discussed on page 29 there are other ways of arranging the spokes on the hub flange and to summarise the discussion it makes no difference, they all perform the same. If you follow the lacing steps previously shown you will end up with option A lacing. If you want to lace the other options, perhaps to confirm that they all work the same or match the lacing of a previously used hub or to just try something different then here's what you do:

How to lace option B

In Lacing step 1 on page 67 start by placing the spokes through the **left side** of the hub then follow the remaining steps exactly as written, the lacing diagrams are now looking on the left side of the wheel.

How to lace option C

Follow the lacing steps 1 to 3 as written.

At lacing step 4 perform the sighting as shown but place the spoke through the hub from the **inside** and place it in the rim as shown. After completing step 5 your wheel will look similar to the diagram on page 71 except that the spokes shown in black will lie on the **outside** of the hub.

Twist the hub then stay on the **left side**. Take each spoke one at a time and pass it through the hub from the outside, it's going to get caught up in the spokes on the other side and will require some gentle flexing to manoeuvre it into place but on a 32 spoke wheel there are only 8 of these to do. Be careful not to scratch the rim with the spoke threads. Weave it over the last crossing point and place it in the rim. Once the left side is complete put the last set of spokes into the right side which is easy since the spokes cannot get tangled up.

Other lacing patterns

I only use radial and the standard cross patterns described in this chapter. For more information please see *Alternative lacing patterns* on page 40 in the Wheel design chapter.

Spoke prep and adhesive

If you encounter problems with your wheels then don't immediately reach for spoke prep, adhesive or self locking 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 consider your wheel is well built and still has problems, in particular spokes loosening, then make sure the rim is strong enough for its intended use. A lightweight aluminium rim subject to heavy loads, rough ground or a strong and powerful rider (with a less than smooth riding style) will cause the rim to deflect and unload the spokes and there will be insufficient tension to prevent the nipples from loosening. If you dive straight in and go with adhesive without first looking at your building technique or wheel design all you'll end up with is a poorly built wheel held together with adhesive that may perform a little better than previously.

My own personal wheels are built with oil and you should be using oil for your wheels. You will be monitoring your wheels and be fixing any problems resulting from riding incidents before they develop into something more serious. Chances are you will never have to touch them.

Loctite 222

I actually use *Loctite 222* threadlock on *customer wheels* because if these wheels take a few knocks then a local flat spot in the rim could cause a loss of spoke tension and a chance for the nipple to unscrew, and then the neighbouring spokes would lose tension leading to a slowly degrading 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 make sure their wheels last as long as possible.

Loctite 222 threadlock adhesive is a low strength standard engineering product for securing threaded fasteners and is available in small 10ml bottles. It has lubricating properties so achieving the 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. Do not use anything other than 222 since the other Loctite products are likely to be high strength permanent adhesives.

For completeness this is how I use Loctite 222:

Prior to lacing **do not** put oil on the spoke threads. Oil the rim eyelets as described.

- After lacing the wheel place a small amount of Loctite 222 on each of the visible spoke threads then spin the wheel in the truing stand to force the adhesive over the exposed threads and into the nipples.
- Tension and finish the wheel as described. Loctite 222 will start to cure after 30 minutes so you need to be finishing the wheel in less than an hour.

Chapter 8

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.

Make sure you understand what I've written above otherwise you'll arrive at the fine-tuning stage with an egg shaped wheel with some severe side to side waves 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 a little more effort to get the wheel finished. A used hub will not cause you any problems.

Your 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. It's far better to be slow and methodical on your first build so that you understand the logical progression.

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 hard to identify lateral trueness errors.

You will also need some paper based tape such as decorators masking tape because it adheres well to the spoke and it's easy to tear a piece off the roll when required. I have a few pieces of tape stuck on the truing stand ready for use.

Completing the wheel is described in 8 stages, if you wish to take a break from building then complete stage you are currently on and resume at the next stage when you get back.

The wheel is now placed in the truing stand.

1. Take up the slack

Take up sufficient slack so that the spokes are not loose. There will be just enough tension for the spokes to point in a direct line between the hub and rim. There will be a slight bow in the outside spokes as they leave the hub. ***The spokes should not be tight.***

Use the nipple driver to screw down all the nipples equally to the same position. The main problem new builders have is keeping the wheel radially true (round) and this simple tool which is described on page 47 is easy to use and quickly tightens the nipples to the same engagement point.

If it's not possible to use a nipple driver, for example on deep section rims, then tighten each nipple so that they just cover the exposed spoke threads. If you are doing this then you can skip the next two paragraphs which describe how to use the nipple driver.

When using the nipple driver I normally apply a little sideways pressure to the spoke with the fingers of my other hand so that the spoke enters the rim at 90 degrees allowing the nipple driver blade to release more precisely. 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 spoke starts to tighten before the nipple driver releases do not try to force it because you will be tightening the spokes too much at this stage. Neither should you take the nipple driver out because the spoke won't be tightened enough and certainly not the same as the previous spokes. If the spokes are obviously too short then mark where you are up to with a piece of tape and use the wrench to back off all *previous* nipples two turns (see the comment in the box below). 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 spoke lengths are correct then the spokes at this stage will still be a little 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 will start going out of shape, it loses its roundness and gets some severe side to side waves 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 43.

When using the wrench make small adjustments 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 when taking up the slack is one half turn of the wrench, a large adjustment is 1 - 2 full turns.

Before using the wrench I usually make a quick check on the wheel dish and remove any large dishing errors whilst taking up the slack. It could be that I need to give one side more than the other particularly if I'm using less than ideal spoke lengths and it's better to do it now while there's little tension in the wheel. Don't try to get the dish perfect since a 2-4mm error at this stage is normal. See Step 7 on page 86 for guidance on adjusting the dish.

Start at the valve hole and tighten each nipple one turn, go completely around the wheel and repeat if necessary, perhaps using a half turn. It should only need 2 or 3 turns, 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 when 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 spoke you are working on 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 will create a lot of unnecessary work for yourself. I always have a couple of pieces of tape stuck on the truing stand ready to grab one and place it on the spoke.

If you notice a regular pattern of alternating tight and slack spokes in a cross laced wheel it means your hub isn't fully rotated but it will soon sort itself out once more tension is applied. If it doesn't sort itself then you may have made a mistake in Lacing Step 4 (page 70), or there's a quality issue with the hub where the holes in the hub flanges are not offset exactly one half pitch (page 8).

2. Align the spokes

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.

Aligning the spokes increases their fatigue life and I also find it makes tensioning them easier because you are not working against the natural spring of the spoke. If the spokes had been over tightened in the previous stage then the spokes would have been pulled straight with no apparent misalignment (but they are still misaligned).

Aligning the spokes applies to new spokes. If you are reusing old spokes and placed them in the hub the same way they were removed from the previous hub they will already have the correct alignment and will not require any modifications, but it does no harm to check and re align if necessary.

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 harm to the spoke, remember making a spoke is brutal process and what you are doing here is very mild in comparison. Sight along the spoke to make sure it is straight.

Be careful 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.

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

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.

Next we are going to improve the lateral and radial trueness of the wheel and take out any dishing errors. You need to do this now while the spokes are not too tight because it's very difficult trying to remove large errors when the wheel is nearing completion and the spokes are reaching their final tension.

4. Improve the lateral trueness

Give the wheel a spin in the truing stand and it should look reasonably true side to side (lateral trueness). If you have some severe lateral trueness errors then you weren't careful enough using the nipple driver and taking up the slack, or if you were using two lengths of spokes I hope you placed the correct spokes in either side of the wheel and not misplaced one or two.

Now turn the wheel slowly in the truing stand and position the lateral gauge close to the side of the rim and identify the largest error, the rim may touch the reference or be well away from it. Examine the spokes in the immediate vicinity of the error. Slight variations in spoke tension will be causing the out of true and **you need to be methodical and determine the exact spokes to adjust**.

Use tone to assess the relative tensions between adjacent spokes on the *same side of the wheel*. Pluck spokes close to the nipple to get a more pure sound.

In this example the rim touches the reference. To correct this:

- A spoke on side A may require tightening. Pluck the spokes on side A to identify any looser ones and tighten them a little.

- A spoke on side B may require loosening. Pluck the spokes on side B to identify any tight ones and loosen them a little.

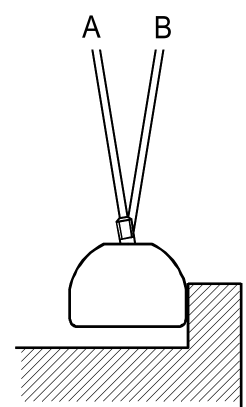


Figure 77
Fixing lateral trueness

Make small adjustments and gradually pull the rim into shape.

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

Tightening a spoke will pull the rim towards the reference 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. You'll know if you turn the wrench the wrong way because the out of true will get worse. Once you fix this error move onto the next largest error and continue until the wheel has a fairly good lateral trueness, not perfect, just good.

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 spokes to adjust – **no guesswork**, get the exact ones.

5. Adjust the radial trueness

The wheel must be round with no low spots or high spots. If you have been careful in the previous stages when taking out the slack then the radial trueness will not be far out, if it's more than 2 mm out of round on a new rim then take more care next time.

Place the radial trueness gauge close to the outside edge of the rim and turn the wheel slowly and look for high spots where the rim touches the gauge. The gauge will touch at the midpoint of a wave in the rim that may span several spokes or more. All the spokes in this region will require tightening to pull the rim closer towards the hub thus reducing the high spot. Remember to feather out the tightening by gradually reducing the amount of tightening as you approach the outer edges of the wave.

If the rim is round except for a low spot where there is a gap between the rim and the gauge then spokes in this region will need loosening a little to allow the rim to move further away from the hub, again make sure to feather the adjustment.

When correcting the radial trueness on a dished wheel (rear wheel or front disc wheel) care is needed to maintain the lateral trueness. The rear drive side and front disc side spokes have steeper angles and pull sideways on the rim slightly less, so slightly more adjustment should be made to these spokes to preserve the lateral trueness.

Make the adjustments to the radial trueness 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 maintain similar spoke tensions and tolerate a small localised radial error which will not be noticeable when riding the bike.

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 trueness* on page 92. After adjusting the radial trueness re-check and adjust the lateral trueness.

6. Equalise the spoke tensions

After completing stages 4 and 5 you will have a reasonably true wheel but closer examination can reveal spoke tensions all over the place. It may appear laterally true but you can have the situation where low tension spokes are balanced by spokes that are too tight and when the wheel is used the lower tensioned spokes will become looser and the trueness you thought you had will soon disappear after a few rides.

For a reliable wheel it is important to have all the spokes sharing the tension equally.

With dished wheels work on **one side** of the wheel at a time since each side has a different tension and consequently a different tone. Even on dishless front wheels I still do one side at a time because it's less complicated this way.

Start at the valve hole and pluck a few spokes on the *same side* to gauge the average tone the spokes make.

If you find a low tension spoke you'll no doubt find that one or both the neighbouring spokes are too tight. The neighbouring spokes are on the *same side* of the wheel and not the immediate neighbours which are from the opposite side. So tighten the slack spoke and reduce the tension on any of the neighbouring ones that are too tight. If the lower tension spoke has just one tight neighbour then back it off the same amount you tightened the slack one, if it has two tight neighbours then back each off half as much. The adjustments made here are of the order of fractions of a turn of the wrench. You might want to read about spoke twist on page 88.

Similarly, if you find a tight spoke then back it off a little and tighten one or both of its neighbours.

It will take at least two passes around the wheel to equalise the tensions. 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 too much and always use tone to identify the spokes to adjust so you don't introduce any more spoke tension imbalances.

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 finishing the wheel.

7. Check the wheel dish

The wheel dish should be checked regularly from now on to ensure the rim in the finished wheel is central between the ends of the hub.

When checking the dish for the first time on a dished wheel (different spoke lengths either side) expect some error and the amount depends on 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 your two sets of spokes were near to the ideal length then the dish will be perhaps 6mm out (or closer). If you had to compromise when selecting your spokes then the dish will be out a lot more.

I actually do a quick check on dish prior to using the spoke wrench in stage 1 on page 81 and remove any large dish error 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 used two sizes of spokes and believe your spoke lengths were correct and have a very large dish error (around 15mm) 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. This takes some getting used to and you can easily adjust the wrong side which makes the dish go worse. 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 it.

It's normal to correct dish by *tightening* one of the sides but if you are concerned about getting the spokes too tight then you can slacken the spokes on the other side to achieve the same result.

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.

In this example the dishing tool was first placed on the opposite side of the wheel and adjusted so that it just touched the face of the locknut. It is now shown here on the other side of the wheel and for correct dish the pointer should once again touch the locknut face. In this example there is a dish error which is corrected by tightening the spokes on this side. The error looks large but it is corrected with half a turn of the wrench.

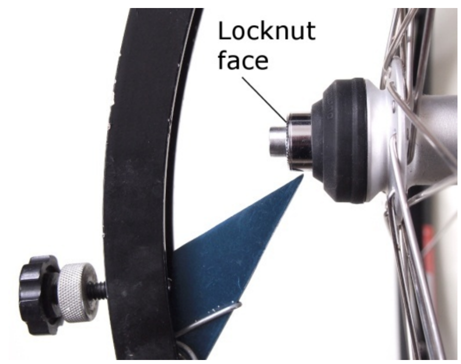


Figure 78 Checking the wheel dish

Once the dish has been corrected, which is quite easy when the spokes are not too tight, you must be careful because the dish can easily change as you continue to bring the wheel up to its final tension, especially on dished wheels. Tensioning dished wheels is described in the next stage which covers final tensioning.

At this stage the wheel 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 trueness and dish.

Once the spokes are approaching their final tension it will be difficult (or impossible) to correct any large errors in trueness or dish so make sure your wheel is in good shape before moving on to final tensioning.

8. Final tensioning

Before you start the final tensioning you need to understand two important things:

i) Spoke twist

If you don't understand spoke twist then final tensioning and delicate truing will be a time consuming and frustrating process.

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. You need to check if the spokes are twisting so you can compensate for it during tensioning.

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 it interfering with the wrench forming a flag.

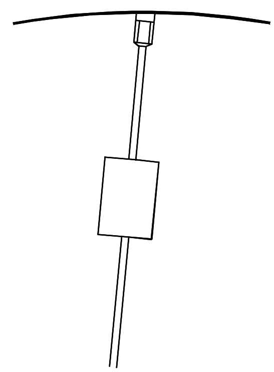


Figure 79 Checking for spoke twist

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 allow the nipple to turn (relative to the spoke) and thus tighten the spoke. At this point you can turn the wrench the required amount to tighten the spoke. Then 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 on each side of the wheel will react similarly and you just repeat the same amount of tightening and backing off, but since it is easy to do, replace the flag every couple of spokes to monitor the twist.

The amount of twist depends on the type of spoke and how tight they are. Slender butted spokes will twist more than plain gauge ones, thin bladed spokes such as the Sapim CX-Ray twist very easily and require a special tool (page 50) to physically prevent them from twisting and without using this tool they would be impossible to tighten.

Prior to final tensioning if you suspect your spokes already have some residual twist in them or would like to check, then 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.

Leaving spokes twisted in a finished wheel is not good practice because they will untwist when the wheel is first ridden (with a tinkling and pinging sound) and as the spokes readjust themselves the thread engagement in the nipples will change resulting in the wheel losing some lateral trueness.

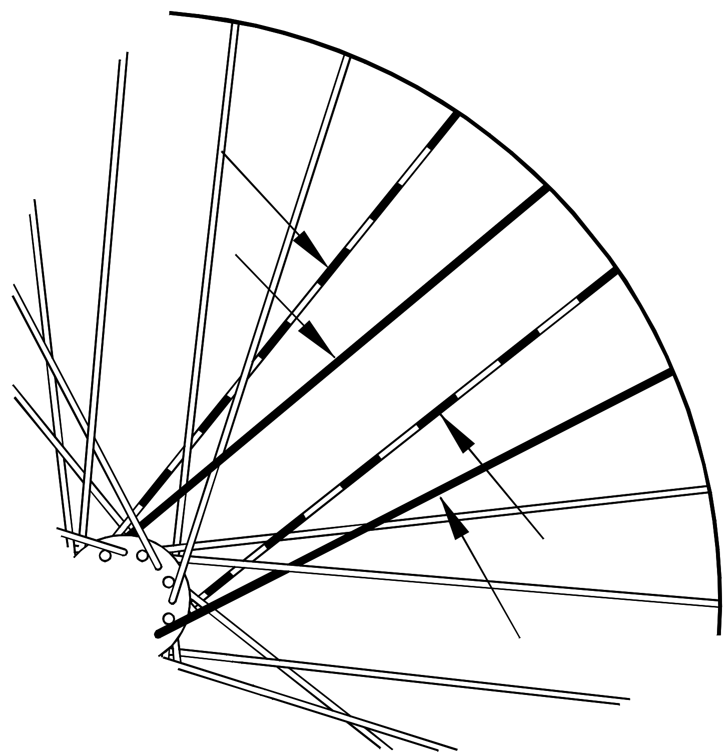
ii) Stressing the wheel (stress relieving the spokes)

Stressing a wheel briefly increases the tension in the spokes and makes sure the nipples and spoke elbows are firmly seated in the rim and hub. More importantly the procedure increases the fatigue resistance of the spoke elbows.

Stressing is performed several times during final tensioning (stressing is not required in the previous stages 1-7). After the first stressing operation the wheel will probably lose some of its lateral trueness which will need correcting, 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 below going all round the wheel squeezing in groups of four, you'll need a thick pair of gloves to protect your hands.

You will not break or damage any of the spokes unless they were faulty to start with or were old spokes previously damaged, so don't look into the rim channel or point the wheel at someone else because if a spoke breaks it will fly out of the rim at high speed.



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, for example count 8 separate squeezes on a 32 spoke wheel (8 * 4 spokes per squeeze).

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

Figure 80 Stress relieving

The other method to stress the spokes is to lay the wheel down on the floor resting on its axle and press down on the rim diameter with your hands either side and 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. 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 and many people attribute the tinkling sound to the stresses being relieved which is of course false, in fact they should make no sound at all if you have tightened the spokes correctly and compensated for the spoke twist during building. I don't use this method and prefer squeezing. If you use the pushing down technique then be very careful not to apply so much force that the wheel collapses, this is easily done on lightweight wheels because wheels are not designed to handle high forces in this direction.

Complete the final tensioning

Start at the valve hole and tighten each spoke half a turn and make sure you go completely around the wheel. You need to keep going around the wheel until you consider the wheel is sufficiently tight. Watch out for spoke twist. With each rotation of the wheel always check and adjust the lateral trueness and check the dish. 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. During final tensioning you will stress the wheel a couple more times.

Tensioning dished wheels

The spokes on the rear drive and front disc require slightly more tightening to maintain the dish due to the steeper angle of these spokes. When tightening a rear or front disc wheel I do it in two halves. For a rear wheel I'd have the drive side facing me (I stand in front of the truing stand slightly to one side) and I'd tighten the nipples on that side say half a turn then flip the wheel around in the truing stand and tighten the others a fraction less to maintain dish. I do it this way because it's easier to do rather than alternating between two amounts of tightening. A typical ratio would be half a turn on each drive side spoke, flip the wheel around, and then one third on the other side spokes.

How tight should the spokes be?

There's a broad range of acceptable tension and it's easy to drop into this zone and end up with a reliable wheel. Going beyond this and trying for higher tensions does not make a better or *stiffer* wheel (see page 38). Low tension wheels are pretty obvious because they will feel looser than any of the other wheels you examine and a loose wheel will be problematic when used because it will get looser and go out of true easily.

Modern rims tend to be well designed and can take the spoke tension with ease but be careful with lightweight non-aero road rims or if you are building older rims as part of a restoration project. As you tighten and stress the wheel there should be little change in lateral trueness. If you have a lightweight, shallow section road rim and it goes significantly out of true after stress relieving in the latter stages of final tensioning then it's likely the spokes are too tight and the rim has reached its compressive limit (see the discussion on rim compressive force on page 16). 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. You will never buckle any 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, and the same is true for deep section road rims and robust touring rims.

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 rim with a similar weight and cross section.

When comparing a dished wheel choose a pair of almost parallel spokes on the reference wheel on the *tight side* which is the rear drive side or front disc side and flex them at mid point and make a comparison with your own wheel. Don't bother checking the other side, you need to learn what *tight* feels like, get the tight side correct and the other side will automatically be correct.

Be careful when checking bladed spokes because you are flexing them across the broad stiffer section and they will feel tighter than they actually are.

As you build more wheels you just get to know what is tight and what is slack. To help build up your own knowledge 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 to build a wheel with spokes at a lower tension and you will come across many examples of these.

I do not use tone to quantify spoke tension. I'm emphasising this because too many people think I obtain the correct tension by tone, I don't. I only use tone to identify relative differences in tension between spokes, i.e. one spoke is tighter than or slacker than another. Based on this feedback I can better judge which spokes to adjust when performing truing operations or balancing spoke tensions.

Tensiometers

The alternative is to use a tensiometer. When using a tensiometer you check the spoke tension in the *tight side* of the wheel and the other side just happens to be whatever it is in order to ensure the correct wheel dish. If you want a numerical tension then I always aim for around 125kg and this applies to deep section carbon rims with low spoke counts (the manufacturers of carbon rims will quote tension figures of around 120kg even though these rims are massively strong and can take extremely high spoke tension). The manufacturers of lightweight rims sometimes specify a tension below 125kg and so for those rims I drop my tension down a little.

Nearly done

The last adjustment to lateral trueness will require a fraction of a turn on the occasional spoke. Checking for spoke twist is even more important when performing delicate truing, you may think you've tightened the nipple ¼ turn but you can easily have just twisted the spoke ¼ turn with no tightening at all.

If you are using bladed spokes then carefully examine each spoke and un-twist any misaligned ones otherwise the aerodynamic benefits will be wasted.

The wheel is finished

Take a look at how good your spoke length selection was and where the spokes finished up in relation to the top of the nipple, were the spoke lengths good or if building the wheel again would you choose a different length? Record your spoke length observations on the sheet containing your hub and rim measurements and initial spoke length calculations.

The individual stages for building a wheel are summarised on page 109 and will serve as a reminder when building future wheels since you may be tempted to skip reading this chapter and miss out an important operation.

Wheelbuilding accuracy

A wheel with zero errors is impossible to achieve, so how accurate 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 has high accuracy 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 installed and the wheel placed in the bike the errors will be insignificant and will certainly go unnoticed by the rider especially when you factor in the movement from the cycle frame flexing.

The following measurements are a guide to good trueness (the measurements are the maximum gap at the reference point). Lateral trueness 0.2mm, radial trueness 0.5mm, dish 1mm. With dish the 1mm error is distributed 0.5mm either side which is insignificant because your wheel will be far more accurate than the bike frame and dropout alignment. When I build a wheel I don't take any measurements, I measured just once out of curiosity using engineering feeler gauges just to check a good wheel (and give you the figures quoted above). For me, a visual sighting is enough, if it looks true then that's good enough.

Don't try for 100% perfectly balanced spoke tensions because it will require very tiny adjustments and this level of accuracy is not required for a good wheel, it's the big tension differences you need to avoid and it's easy to balance these out. Plus we are never starting with rims that are made 100% true so these will need a pull here and there to obtain a true wheel. My spoke tensions are pretty close but never 100% equal.

Some wheels take longer to get true and I never get them as perfect as I'm accustomed to. Examples of these are wheels using superlight rims which react very easily to spoke adjustments and wheels with 24 spokes and fewer because you have fewer spokes to work with in the region you are trying to true.

You should always build a true wheel so that it's easy to see if it goes out of true when ridden which is a sign something has gone wrong and needs investigating. So my advice for all wheels is to build them true to whatever standard you set 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 you are aiming to build a wheel that you are satisfied with and the time it takes to build is not important. My advantage is that I know when to stop, I know when the wheel is finished and cannot be improved by spending more time on it, I know what to do in a given situation and I *never* turn the spoke wrench the wrong way! But all this comes with experience that you will start to gain. Don't be impressed by anyone who comments on 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.

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.

Testing your wheel

As a new builder you should be monitoring your wheels and inspecting them frequently.

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 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 test would be:

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 which may cause the wheel to lose some of its lateral trueness.

After a short distance of gentle riding

If the wheel loses its lateral trueness then the spokes were not properly stressed during building, or the spokes may have had a poor tension balance or insufficient tension. If the wheel was built with far too much tension then hard braking using *rim brakes* can overload the rim and cause it to go out of true in a similar way to stress relieving during building, however stress relieving during building would have already identified the wheel was too tight (this only applies to rim brakes because applying a disc brake does not alter the rim compression).

After a few rides

If this is your first wheel you may have to make some *minor* lateral trueness 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.

Lots of problems!

If you have lots of problems when using your wheels then make sure they are suitable for their intended purpose. It would be unreasonable to expect a lightweight road rim with 28 spokes to withstand rough use by a strong rider, and for lightweight road wheels to carry heavy loads over long distances. A lightweight mountain bike wheel being subjected to high drop-offs and poor landings won't last too long either.

Retensioning your wheel

A new wheel does not need to be re-tensioned after a few rides and I have never re-tensioned any of my wheels. If you think your wheel is a little low on tension and believe it wasn't tensioned sufficiently during building then by all means tighten it up, but start with half a turn and see the effect.

It's likely the spoke tension will drop a little when a tyre is installed and inflated, but this is something that has never bothered me, or caused me to add more tension. I've seen reports where the spoke tension has dropped just by installing a tight fitting tyre on a lightweight rim without even inflating it, and the tension drops further when the tyre is inflated, it's certainly not common and if you experience this you can always ask the manufacturer (who will probably say increase the spoke tension a little).

Chapter 9

Repairing wheels

It’s surprising the amount of 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.

Checking a wheel

Lateral trueness is a good indicator of the general state of the wheel, if it’s out of true then something is wrong and needs a closer look to find out what’s happened. It’s better to make regular checks rather than wait until the wheel is badly out of true, so every few rides give the wheel a spin whilst it’s still in the bike and check the trueness against some reference point. Then examine the surface of the rim and look for uneven markings and cracks on the braking surface and other regions of the rim particularly around the rim eyelets.

Flat spots

Check for any flat spots in the rim resulting from impacts. You might not actually see a flat spot, but a couple of adjacent spokes will be noticeably loose and will indicate the presence of a flat spot where the rim has been pushed in causing the spokes to lose tension. If you put the wheel in the truing stand you will no doubt see a large radial error which cannot be fixed using a spoke wrench (and you shouldn’t even attempt it). Trying to beat out the flat spot is not easy and you can easily make things much worse. I have never tried fixing flat spots by trying to bend the rim back into shape.

All you can do is tighten the slack spokes to a similar tension as the others and it’s important that you do this otherwise adjacent spokes will start to lose tension leading to a gradual deterioration of the wheel. If it’s a severe flat spot you may not have enough threads on the spokes to do the necessary adjustment so a new rim should be considered.

Although the flat spot will remain in the rim it will not 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 brake pads to chaff the tyre causing an early tyre sidewall failure.

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 the photograph of the spokes on page 23).

The situation you should avoid is dropping the chain between the largest rear sprocket and the hub whilst changing gear, or bouncing the chain off on rough ground. The chain-drop in the photograph happened during a cross country MTB race, the chain hit the shoulder of the lightweight double butted spokes of the 2mm 1.5mm type and two spokes snapped immediately and the others were severely gouged. If you have dropped your chain replace any severely damaged spokes and others with only slight damage can be left alone since spokes are pretty tough these days and things often look worse than what they are.

Figure 81   Chain drop

Make sure the stops on your rear derailleur are correctly adjusted so it prevents over shifting the chain from the top sprocket and down into the spokes.

Spoke protectors aren't popular and I'd guess it's because they are an ugly piece of plastic often found on entry level bikes. If they looked a little more high-tech then I'm sure more people would consider fitting one. I haven't evaluated their usefulness and there may be a reason why they are not used on high end bikes, however I saw this one at a mountain bike race around the year 2002.

Figure 82   Spoke protector

Rim wear and damage

Rims eventually wear out and they have a limited life and like tyres they are consumables. It's not a major issue throwing out an old rim and since you will be doing the replacement work yourself the only cost to you is a new rim every now and then. 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. Beating out indentations or trying to bend a crash damaged rim back into shape is troublesome and can often make things worse and is not something I ever do.

Some aspects of cycle sport such as off road riding are hard on rims so it may be advisable to use a cheaper rim which is good quality but with no expensive features such as surface treatments and fancy colours and replace it when the expected damage occurs. Keeping a couple of spare rims in your garage means you can wreck a rim on a Saturday ride then pop a new one in ready for Sunday.

If you use rim brakes then check the rim for concave sides, cracks and non uniform markings on the braking surface which suggests the metal has almost worn through. The sidewall of this rim was so thin it led to a failure 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.

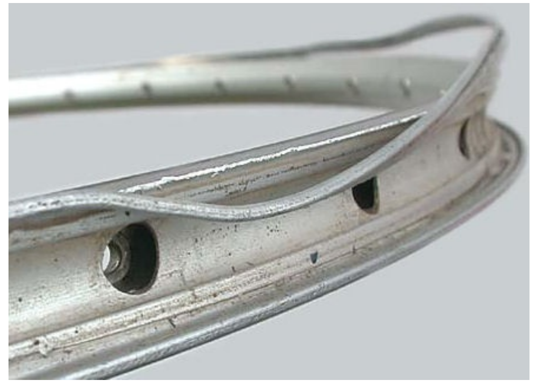


Figure 83   Rim sidewall failure

Rims with cracks around the spoke holes where the spoke appears to be 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 leads to fatigue cracking. A rim that has cracks will need replacing. The crack in this rim was interesting because it 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 a mountain bike tyre at a lower pressure it would be fine (which it was). Over inflating mountain bike tyres can cause the rim to split and the split can be visible as shown here, or it can be hidden on an internal surface under the rim tape. If your wheel has some odd bulges, or runs out of true for no apparent reason, then you should carefully inspect the rim for cracks.

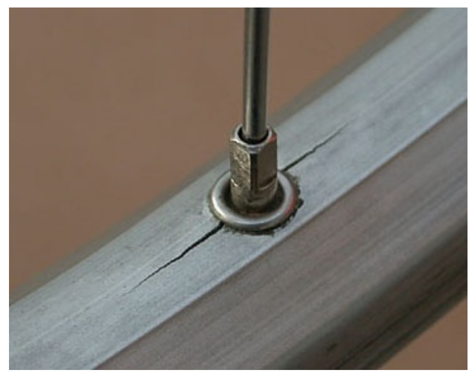


Figure 84   Rim spoke hole failure

Truing a wheel

If the wheel is excessively out of true due to a damaged and bent rim then no amount of spoke adjustment is going to fix it. For example, a mountain bike rider going through a corner with an out of control front end slide puts a massive side load on the wheel and even the best made wheel can fail with the rim severely bent. 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 tension balance will be way out with some excessively tight spokes and some very loose ones. Some people have managed to straighten bent rims with reasonable success although I have never attempted this myself so can't give any guidance, but the rim and spoke tension balance are never going to be perfect.

The rest of this procedure is for truing a wheel that has lost some of its lateral trueness through **normal riding**. I'm going to assume it's a wheel built by yourself and you originally built it with equalised spoke tension. If you are fixing a wheel built by someone else then I've given the procedure its own heading which is described on page 104.

Once a wheel is being used I only check the lateral trueness, I'm not concerned about the radial trueness because under normal conditions (no impact damage) it's not going to change from the accuracy of the original build.

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. Always look for one or two slack spokes first.

Do not dive straight in and adjust spokes at random without giving careful consideration because you will make things a lot worse.

Spin the wheel and identify where the out of true is. A wheel losing some of its lateral trueness is usually caused by a spoke losing a little tension and quite often it's only one spoke.

In Figure 85 the wheel is being trued whilst still in the bike using the brake pads as a reference and in this example the rim needs pulling back into the central (true) position. In the area where the out true is look for a spoke with low tension, spokes with a lower tension will make a dull sound in comparison to adjacent spokes on the same side of wheel when plucked close to the nipple. 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.

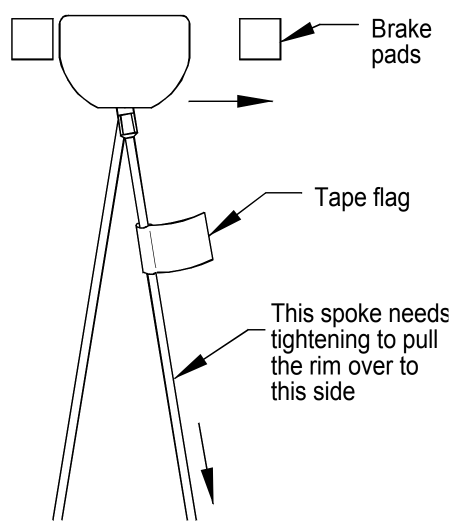


Figure 85 Truing a wheel

Before using the spoke wrench make sure you know which direction to turn it – which way to tighten and which way to loosen, it becomes second nature after a time but you can easily turn it in the wrong way which makes the trueness even worse.

The use of tape flags was described within the discussion on spoke twist on page 88 and you should read it again because it's important to check if the spoke is twisting rather than tightening. You may think you've tightened a spoke ¼ turn but in reality only twisted it ¼ turn with no tightening. Once tightened remember to release the spoke twist,

Identify the single worst (slackest) spoke and always apply a flag by firmly wrapping a piece of tape over the spoke to prevent it flying off, then tighten the spoke a small amount, say ¼ turn. It will probably require more tightening but if you tighten a little at a time you'll start to see the effect of your changes and in doing so start to learn more about the truing process, plus it reduces the danger of over tightening. If you do over tighten the spoke it will cause the wheel to go out of true in the opposite direction. The mistake then would be to start tightening on the opposite side to pull it back which although improving the lateral trueness will cause an error in radial trueness 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 stuck 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.

If there are no loose spokes then look for a tight spoke on the side of the wheel where there is deviation towards your truing reference point. Apply a flag and loosen the spoke, observe the flag since the spoke can just as easily twist as before and will require untwisting.

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.

Because you are truing one of your own wheels using small adjustments to pull it back into shape you will not affect the wheel dish so it's not normal to check and adjust this.

Nipples that will not turn freely

If you need to tighten a spoke you first apply a tape flag and start to adjust the tension. The spoke will *always* twist and hence the flag will *always* rotate. The flag will stop rotating when there is enough torsional resistance in the spoke to allow the nipple to move relative to the spoke threads and tighten the spoke. Once the adjustment is made you untwist the spoke by returning the flag to its starting position. It's exactly the same if you wish to loosen a nipple. All this assumes the nipples are able to move freely, however they don't always react as I've just described.

Whilst turning the wrench the spoke friction may suddenly release with a crack with the tape flag moving back to its original position and the spoke will have been tightened an amount based on how far the wrench was turned. You might find this condition on used wheels where the nipple has become firmly attached to the spoke threads, particularly if the previous builder did not use any oil on the spoke threads.

If the flag rotates more than half a turn then the nipple is probably stuck on the spoke threads and further turning can result in the spoke snapping. If you suspect the nipple is stuck then untwist the spoke and leave it. If you were attempting to tighten the spoke then try an alternative strategy such as tightening two adjacent spokes (on the same side of the wheel) or even loosening an opposite side spoke. It's a compromise but it's your only option.

The previous builder could have used strong adhesive on the threads and adhesive is often used on factory made wheelsets. If the nipples won't turn and you suspect adhesive has been used then gently warm the nipple using a disposable cigarette lighter to break the adhesive bond allowing the nipple to be turned. Once adjusted the nipple will stay in place because the adhesive residue is still there but wasn't really necessary in the first place.

If the nipples are stuck and nothing can be done to release them and if the out of true cannot be tolerated then it will need rebuilding with new spokes and nipples.

Spoke breakages

Figure 86 Spoke fatigue failure

A spoke can break for no apparent reason with a clean break across the spoke elbow or spoke threads. 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 slowly propagate across the spoke ultimately leading to a fracture. A spoke does not break due to the power exerted by the rider, it's because the spoke was 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 building technique as described in this book (aligning the spokes and stress relieving).

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 other spoke elbows. In Figure 86 the wheel had a broken spoke due to a fatigue failure and on closer inspection hairline cracks were seen on many other spokes. If you cannot see any cracks and want to check if other spokes are ready to break then stress relieve the wheel using the spoke squeezing technique described in the building section on page 88. If this causes other spokes to break then the wheel should be rebuilt with a complete set of new spokes.

There are other factors that can influence fatigue failures, if the hub has excessively large spoke holes then read the discussion on spoke holes on page 8, if the hub has thin flanges then read about flange thickness on page 8. If the spoke broke at the threaded end and you are using spokes with a 1.8mm thread then read the discussion on page 25. If the wheel was built by someone else they may have used a poor wheelbuilding technique that resulted in the spoke failing from fatigue and this also applies also to machine built wheels.

Even though you make an excellent job of building the wheel and follow all the correct procedures there's always the chance of a manufacturing defect in the spoke material that subsequently causes it to fail although it's rare these days. If a single spoke has broken and no obvious signs of other fatigued spokes then just replace it.

Replacing a broken spoke

If the spoke has broken at the hub end you can usually install a new spoke without removing the tyre which is a bonus if you have a tubeless setup. If you are keeping the tyre on then bending the old spoke at 90 degrees will give more leverage as you use the spoke wrench to unscrew the nipple leaving it in the rim. Make sure the nipple you are working on is at the top of the rim to preventing it from dropping into the rim cavity.

When lacing the new spoke don't worry too much about bending it along its length as you push it through and work it around the opposing spokes, but don't put any kinks in. You can easily straighten the spoke with gentle flexing and any remaining small bends will be pulled straight with no harm whatsoever to the spoke.

Oil the spoke thread and attach the nipple (if the tyre is still installed you might need to use pliers to pull down and turn the nipple until the spoke threads catch), then oil the rim eyelet. Mark the new spoke with some tape because it's usually only this spoke that requires tightening to true the wheel and marking it makes it easier to locate. Take up the slack and if it's an outside spoke align the elbow (page 83), then tighten the newly installed spoke. The wheel should true up to the same accuracy as it was before the spoke snapped but you won't know how good it previously was, so get it as good as possible by tightening the new spoke then you may have to adjust one or two others to make the wheel perfect. Finally stress the new spoke (page 88) by squeezing the two pairs of parallel spokes that contain the newly placed spoke.

If you are a touring cyclist I recommend taping some spare spokes somewhere onto your cycle frame, perhaps the chain stays, so that if a spoke breaks whilst touring you will have the correct replacements easily available. You'll also need some basic tools for removing the rear cassette, and if you use disc brakes then some tools for removing the disc rotor.

Replacing all the spokes

If you are continually replacing broken spokes then it's usually better to rebuild the wheel with a complete set of new spokes. Before taking the wheel apart you must first remove any cassette sprockets or disc brake rotors from the hub otherwise you will have difficulty removing them later.

Release the spoke tension using the same method as described for a rim transfer on page 103. You then have the option of using wire cutters to quickly take out the spokes or continuing with the wrench and nipple driver to completely dismantle the wheel.

If you dismantle a wheel by cutting the spokes then **always** back off all the spoke tension using a spoke 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.

The cutters I use are C.K. 4371A which 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 87 Cutting spokes

When lacing the wheel with a new set of spokes make sure the spoke elbows match the previous indentations in the hub flange, see *previously used hubs* on page 10.

Reusing spokes

A set of spokes will last a long time and will easily outlast many rims, if they haven't broken in the current wheel then they will not break in subsequent wheels, so there is no reason to throw used spokes away because using new ones has no advantage, and neither do you retire your spokes after they've done a certain mileage. Spokes are now a significant cost which is a good reason to reuse old spokes where possible.

I only reuse the spokes if the original wheelbuild was my own because I would know the complete history of the spokes, I would know the spokes were good quality and they were not damaged through bad building. If you want to reuse the spokes from a wheel built by someone else and the wheel has been reliable then they should be okay, if it was a problematic wheel that had one or two broken spokes replaced then don't use them because more will break when used in the new wheel. I would not use the spokes taken from a machine built wheel, even a brand new one, because I see too many reports about spokes breaking in machine built wheels indicating that the method of building them has caused the spokes to fatigue.

If you take the spokes from a wheel you should keep the spokes segregated. The spoke elbows will have taken a particular bend and they need replacing in the new hub the same way to prevent putting new bends in the elbows which can lead to fatigue issues. For a rear wheel there will be four sets, the inside spokes (left and right side) and the outside spokes (left and right). A symmetrical front wheel will have two sets, inside and outside and a front disc wheel four sets. If you get the inside and outside spokes mixed up then providing they were good quality spokes it shouldn't matter too much, but get into the habit of keeping them separate.

If you want to reuse the existing spokes then use the following techniques when replacing the rim or hub.

Reusing nipples

The old nipples are fine providing they are brass. Aluminium nipples always look worn and scored around the nipple seat and don't inspire confidence.

Replacing the rim

If the existing spoke lengths are suitable then replace the rim using the transfer method. This method does not require dismantling the wheel and so keeps the spokes in the same orientation on the hub flange.

Identical rim

If you are replacing the rim with an identical one (same make and same model) then the spoke lengths will be okay, but you should always examine the original wheel to see how accurate the lengths were and if they were less than ideal then take this into account when rebuilding. For example, if one side were too long (or short) then expect a lot of dish error that should be corrected early when tensioning the wheel. If one or both sides are excessively short then you'll need to use a nipple driver with a longer point.

Different rim

If you are rebuilding using a different rim then measure the ERD of the new rim to see if it's the same as the old one. If you don't have an accurate ERD for the old rim then use the technique in the spoke length section for measuring the ERD of a built wheel (page 53). If the ERD's are the same then for wheelbuilding purposes it's an identical rim. If the new rim differs by up to 4mm there's still a chance you can use the old spokes. Use the following examples to assess the suitability of the existing spokes, once you understand the logic you can make a better judgement of your own situation.

New rim is smaller
If the new rim is 4mm smaller in diameter then the spokes need to be 2mm shorter. Look into the rim channel and check where the spoke ends finish in the old wheel. With the new rim the nipples will need screwing down a further 2mm. If the spoke ends are 1mm or more below the top surface then it's possible. If they are flush with the top surface or above then it's not possible. When building the new wheel it doesn't matter too much if the spokes protrude through the nipple 1mm.

New rim is larger
If the new rim is 4mm larger in diameter then the spokes need to be 2mm longer. If the spokes are protruding above the top surface of the nipple then it's possible. If they are flush with the top of the nipple you can still use them but the spokes will be a fraction short in the new wheel but still okay. If the spokes are beneath the top surface then it's not possible to re use them with the existing nipples, the only option is to use DT 16mm nipples which require spoke lengths 2mm shorter (this only applies to 16mm nipples made by DT, see page 59).

Rim transfer method

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 each nipple one turn, then a couple of turns until all the tension is released. The aim is to reveal 2mm of spoke threads beneath the nipple on all spokes (2mm is not critical).

On a dished wheel start by releasing tension in the spokes opposite the tight side, these spokes being less tight are easier to undo and will make the other previously tight side easier to undo.

Tape the new rim to the side of the old rim so that the valve holes line up.

Oil the inside of the eyelets on the new rim.

Place the wheel in the truing stand. Use the nipple driver to remove a nipple from the old rim, oil on the spoke thread using a cotton bud and transfer the spoke across and into the new rim. If you are using brass nipples use the same nipple again and attach it a couple of turns. When all spokes are transferred remove the old rim and tension it as normal, you won't need to press out any spoke bows on the hub flange but you will still need to stress relieve it.

Figure 88 Rim transfer

Replacing the hub

Before taking the wheel apart you must first remove any cassette sprockets and disc brake rotors from the hub otherwise you will have difficulty removing them later.

You will be using the same rim and the existing spoke lengths will be suitable providing the new hub has a similar geometry. Hub geometry has a small effect on spoke length so if the replacement hub looks visually similar then it will be fine, however if the spoke lengths were wrong in the existing wheel then they will be wrong with the replacement hub.

If the two hubs look totally different you'll need to calculate the spoke lengths for your existing hub and those for the replacement hub to one decimal place and find the difference in spoke lengths (for this exercise you don't need an accurate rim erd, use anything you want). If the lengths are up to 2mm different then follow the logic described previously for replacing the rim to see if the existing spokes are suitable.

Release the spoke tension using the same method as described for a rim transfer on page 103. Remove the spokes from the **rim only** leaving the spokes still in the hub and untangle the spoke crossings. This keeps the spokes nicely segregated and when you rebuild the wheel pull a complete set of spokes out of the appropriate side. If the lacing procedure requires inside spokes make sure you take the inside spokes, it's not as obvious as you think.

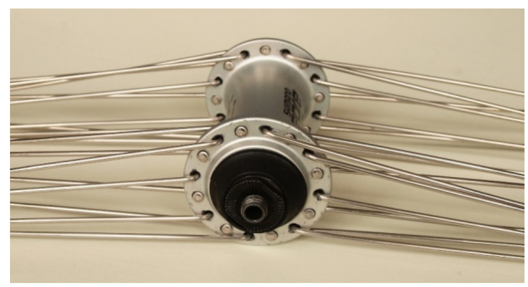


Figure 89 Keep the spokes in the old hub

Truing a wheel built by someone else

If a wheel built by someone else needs truing you may need to fix some additional building errors as well. You could easily adjust a few spokes to make it true but as a wheelbuilder you are now in a position to make the wheel a lot better.

Start by improving the lateral trueness by following the procedure for truing a wheel on page 97, there's no need to make it perfect at this stage. The procedure on page 97 assumes a well built wheel but the one you have may not be so good and will often require more adjustment on a greater amount of spokes that are either too tight or too slack. Use tape flags to monitor the spoke twist because the previous builder may not have lubricated the threads and there is the real possibility of twisting and snapping a spoke, see *nipples that won't turn* on page 99.

Equalise the spoke tensions as described on page 85 then lateral true again.

Check the radial trueness. If there's a single large error and an obvious dent in the rim then it could be impact damage that cannot be fixed with a spoke wrench, read about *flat spots* on page 95. If the radial errors are due to building then you may wish to improve the wheel a little although it's usually not worth the effort especially if the spokes are tight because fixing radial errors when the spokes are tight is very difficult. Perhaps make it a little better.

Check and adjust the wheel dish, see page 86.

Stress relieve the wheel by squeezing the spokes as described on page 88 but don't use as much force as normally used on a new build. You only want to pull things together and make sure everything is fully seated and bedded in. If a spoke snaps then it was in a fatigued state and was going to snap pretty soon whilst riding the bike so it's better it happened now. Snapping the spoke was not your fault and if you are truing a wheel belonging to someone else you need to emphasise the fatigue issue. Lateral true again. If the previous wheelbuilder had never stress relieved the wheel then doing it now will drop the tension a little.

Assess the spoke tension and increase it if necessary. First check if the spoke lengths are correct, remove the tyre and rim tape and take a look, ideally the spokes should finish flush with the top surface of the nipple or just above as a maximum. If they are too long it will be difficult to add tension to a slack wheel.

Stress relieve again and true. The wheel will now be in good shape and will remain that way.

Appendices

Appendix 1 : Wheelbuilding Checklist

Appendix 2 : Making your own truing stand

Appendix 3 : Spoke length formula

Appendix 4 : The geometry of a wheel

Appendix 5 : Example of a straight pull hub wheelbuild

Appendix 1

Wheelbuilding Checklist

Preparation and Lacing

Measure your components and record the data including the spoke lengths being used.

Oil the rim eyelets and spoke threads. Lace the wheel then complete the wheel in 8 steps:

1. **Take up the slack** - page 81

   Tighten the nipples using the nipple driver. If the spokes are still loose then tighten them a couple of turns with the wrench. You can also take out any large dishing error here. The spokes must not be tight.

2. **Align the spokes** - page 83

   Press down the bows in the outside spokes. Inside spokes are normally okay.

3. **Take up all of the slack** - page 83

   The spokes will make a tone when plucked close to the nipple. Don't make them too tight.

4. **Improve the lateral trueness** - page 84

   Make the wheel laterally true, the closer the better. Check and adjust the lateral trueness again after each of the following steps.

5. **Adjust the radial trueness** - page 85

   Make the wheel radially true.

6. **Equalise the spoke tensions** page 85

   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 86

   Take out most of the dish error and check regularly from now on and aim to get it perfect during final tensioning.

8. **Complete the final tensioning** - page 88

   Watch out for spoke twist.
   Stress the wheel several times.

   When finished check how accurate the spoke lengths were and whether they require modifying if building the same wheel in the future and if so then record this information.

Appendix 2

Making your own truing stand

This is my own personal truing stand.

The stand is suitable for all wheel diameters from BMX to road wheels and 29'er wheels, and all hub widths from 100mm to 170mm (see the notes later on for other hubs widths and rim diameters). Hub axles can be solid axle, quick release and hollow axles (10mm, 12mm, 15mm, 20mm, etc).

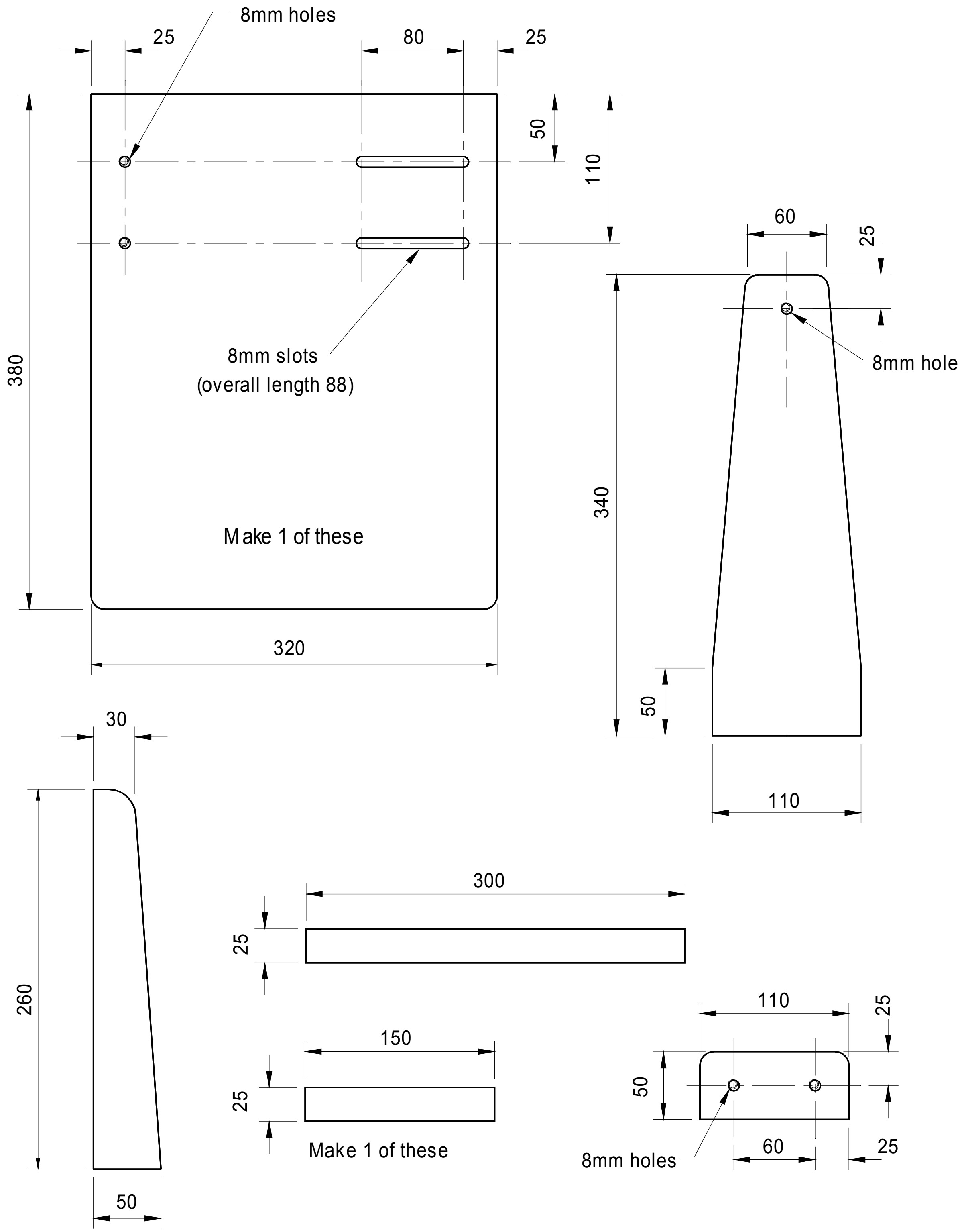
The stand is made from wood because it makes a very rigid structure. Wood also has excellent resonance properties and makes the sound from plucking the spokes during building the wheel more precise.

Everything is made from 18mm thick MDF although other types of wood will be suitable, the 18mm thickness is not critical and you can use 16mm or 20mm without altering any of the dimensions. If you look at my finished stand you'll see I've used some hardwood for the lateral and radial gauges and a couple of other pieces within the main stand (the non white items). The 3mm black plastic can be obtained from a sign maker, they usually have some off-cuts.

I used white laminated MDF for my stand but painting the base of the truing stand white is just as good (search online for information on painting MDF). A white or light coloured stand is important because it makes a clear bright working zone and gives excellent contrast when used in conjunction with the black reference plates on the lateral and radial gauges. If you build a white rim then place a piece of yellow paper on the baseboard to give good sighting contrast. Assemble the wooden pieces using adhesive and 3mm x 35mm countersunk head wood screws.

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

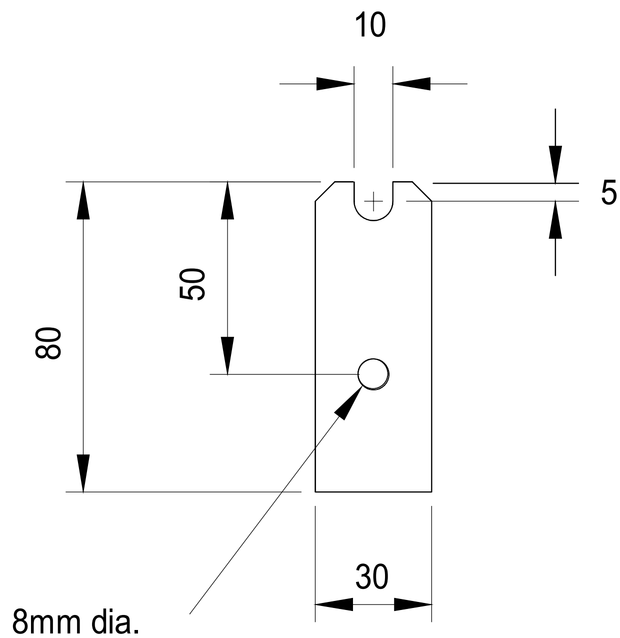


Make two of everything except where shown.

Axle jaws

The jaws are made from 6mm steel. Use a 10mm drill and drill through and trim the sides. The 8mm hole is countersunk for an M8 countersunk screw.

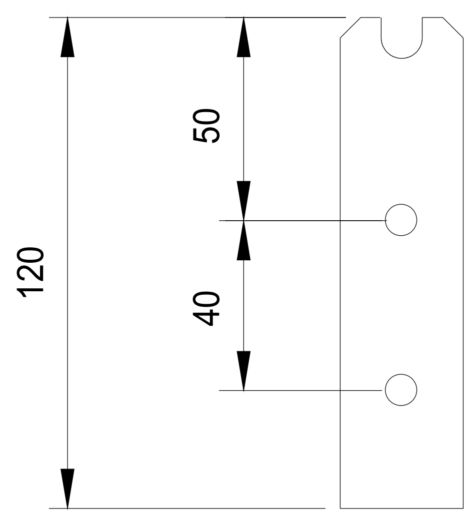
I've used steel for the jaws but due to the light clamping action when securing the hub the jaws can be made from plastic to the same dimensions.



29'er Mountain bike wheels

With a 29'er wheel placed in the stand there will be 40mm of clearance between the edge of the rim and the baseboard. If you intend to true a 29'er wheel with a mountain bike tyre installed there will be insufficient room and it will not be practical to remove the tyre if you are using a tubeless setup.

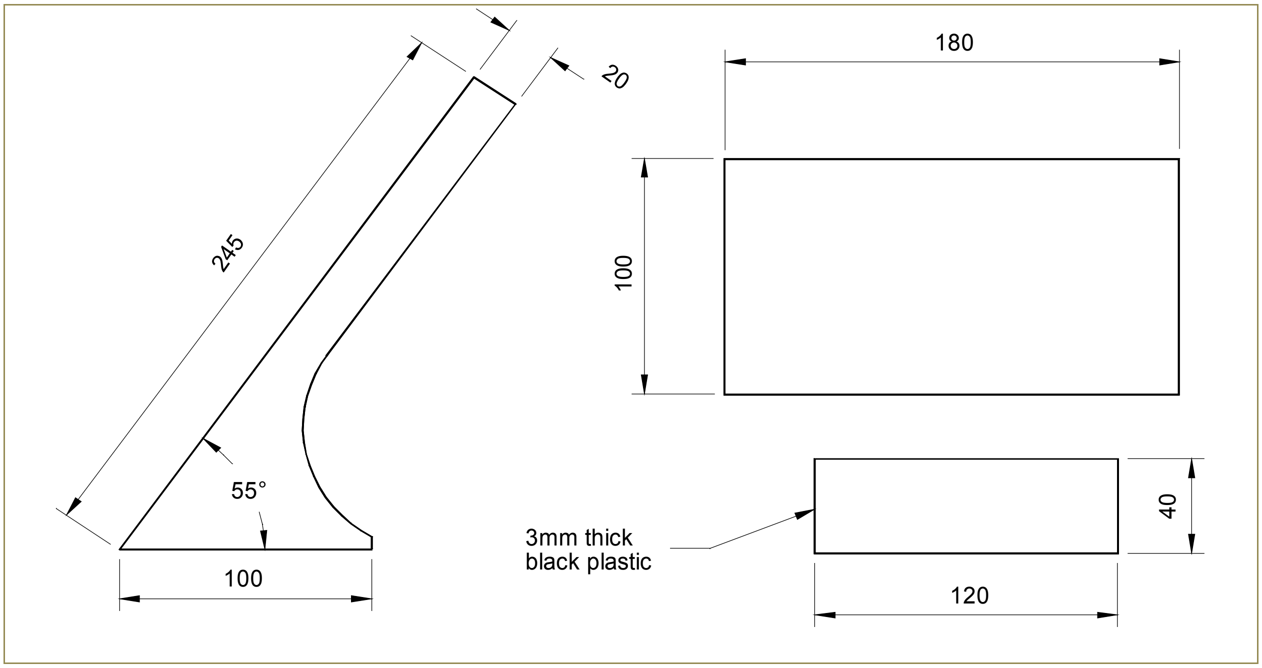
My advice is to make some 29'er specific jaws as shown on the right. Build your wheel using the jaws set to the normal position with jaws attached by the top holes, then at a later date if you need to true them (with a tyre installed) simply raise the jaws by using the lower holes. The jaws shown here will give 80mm clearance, if that's not enough then increase the 120mm and 40mm dimensions.



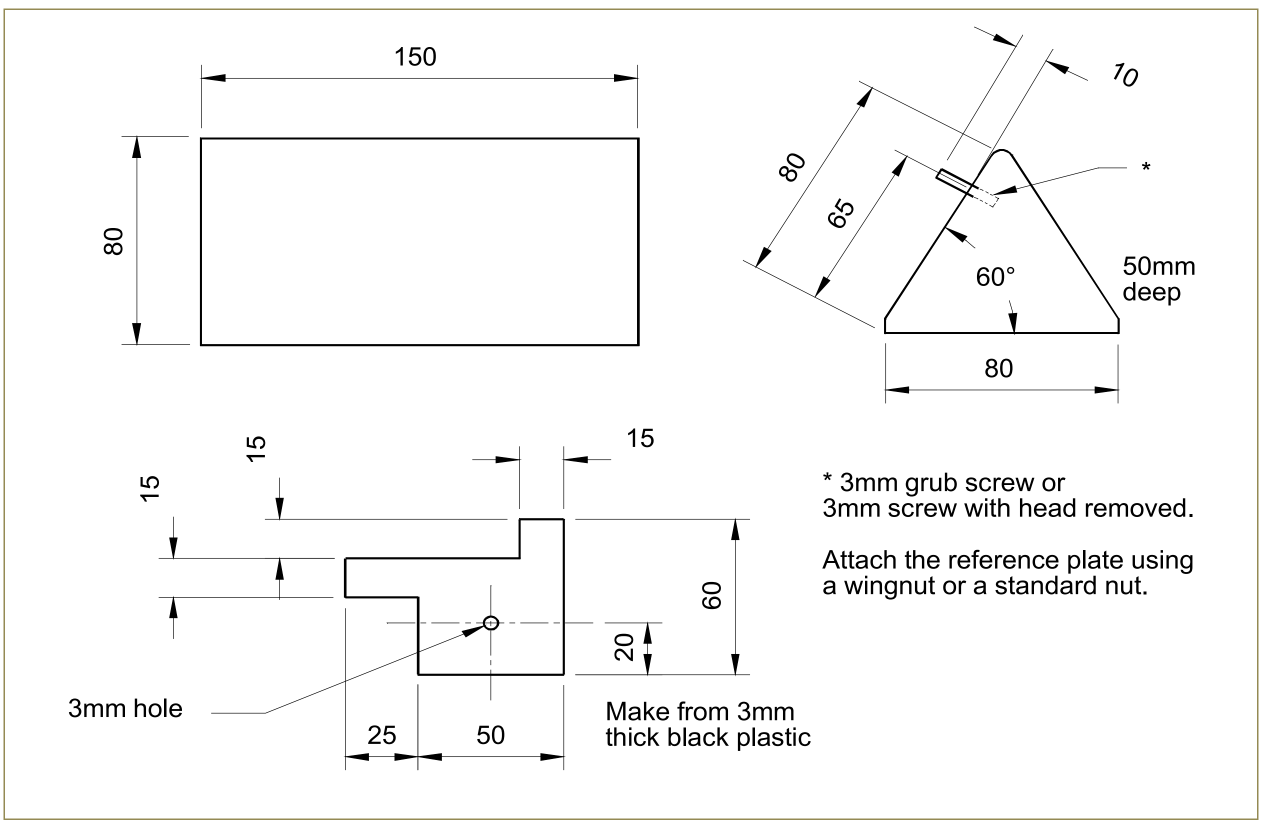
Fatbike wheels

The truing stand as drawn will hold a 170mm hub. If you haven't yet made your stand and intend to build 200mm hubs then increase the width of the baseboard from 320mm to 350mm and increase the length of the two slots from 80mm to 110mm. Increase the width of the guide block from 150mm to 180mm. All other dimensions remain the same.

Radial gauge (in these two diagrams each part is 20mm thick except where stated)

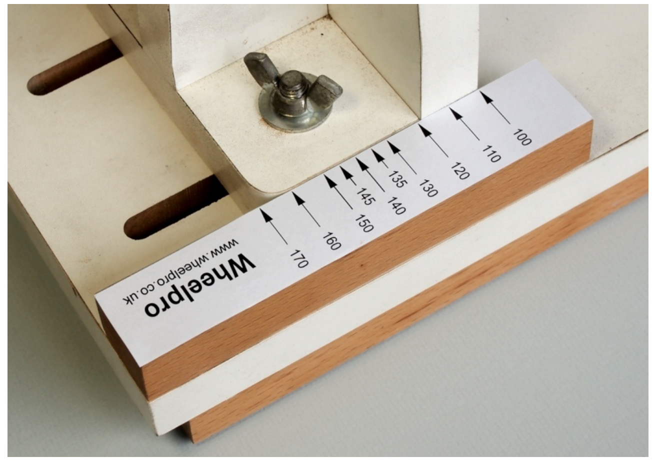


Lateral gauge



A template for these two gauges is provided at www.wheelpro.co.uk/support

Here you can see the adjustable side and how it accommodates different hub widths. The adjustable support slides against a guide block (the 150 x 25 piece in the plans) which is marked for different hub widths, in the photograph the stand is set for a 100mm front hub.



I've made a marker strip available for download at www.wheelpro.co.uk/support

Laminate the paper strip or cover it with clear tape before sticking it firmly in place using double sided tape. To install the strip, set the width of the truing stand so that there is a 100mm gap between the jaws that locate the hub i.e. set to hold a 100mm hub. Place the strip on the block so that the 100 mark is adjacent to the inner face of the support leg.

Checking radial and lateral trueness

I always use two separate gauges for checking lateral and radial trueness, I check and adjust in one direction then replace the gauge and check the other direction. For illustrative purposes two gauges are shown on the baseboard of my truing stand, but during building I use one at a time as required. When building a small diameter wheel, for example a BMX wheel, I raise the height of the two gauges by sitting them on a block of wood.

Lateral trueness gauge

This gauge is only used to check lateral trueness (the top surface is not used for checking radial trueness). It uses a single sided reference point and I always check the lateral trueness on the right hand side of the rim but it's easy to flip the plate over if you prefer the left side. It has two vertical reference edges, I use the one on the right most of the time and use the left side edge when checking the trueness of a wheel with a tyre installed (where the shape becomes obvious).

Radial trueness gauge

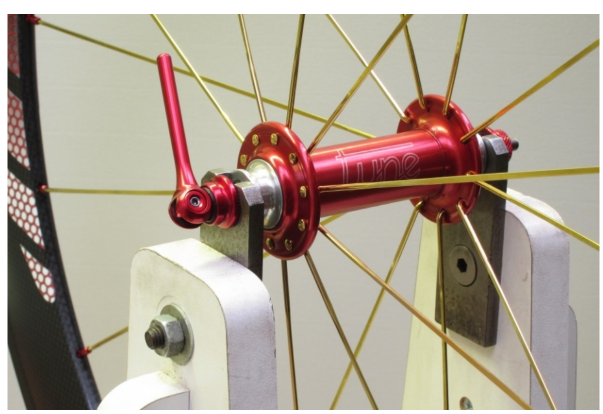
The conventional way for checking radial trueness is to use a flat surface underneath the rim but I find this technique difficult and slow to use and also not very precise, so I designed a unique method for checking radial trueness. The gauge is extremely accurate and easy to use and I couldn't imagine building a wheel without one.

	
This is the side-on view with the radial gauge in place. You **do not** check radial trueness from this view.	You are now stood upright at the front of the truing stand 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. Place the gauge on the left or right side of the rim, whichever you find best.

Holding the wheel in the stand

For quick release hubs use a quick release skewer to clamp the hub using a very light pressure because excessive force achieves nothing.

For solid axle hubs use the axle nuts supplied with the hub and use light finger pressure to tighten them.



Through axle hubs

For through axle front hubs use a standard 100mm front quick release skewer. The skewer does not need to be central through the hub, let the skewer rest in the bottom of the jaws and let the hub rest on the skewer and lightly clamp. A 20mm front hub is shown in the photograph. The hub should spin freely and all the hubs I've used can be located this way.

For 135mm through axle rear hubs use a standard 135mm rear quick release skewer using the same technique described above. For 142mm-150mm let the hub to rest on an M8 x 180mm hexagon headed bolt and secure with a wingnut, finger tight is all you need, these bolts are low cost and easily available from online engineering suppliers.

Designing the tools, writing the book and keeping everything up to date requires a lot of work. The book is not expensive, yet some people will still try and obtain a free copy by whatever means. If you are using a free copy of this book and you are benefitting from my work then please go to www.wheelpro.co.uk and make a purchase. Making a purchase also means you get a free upgrade whenever a new edition is released.

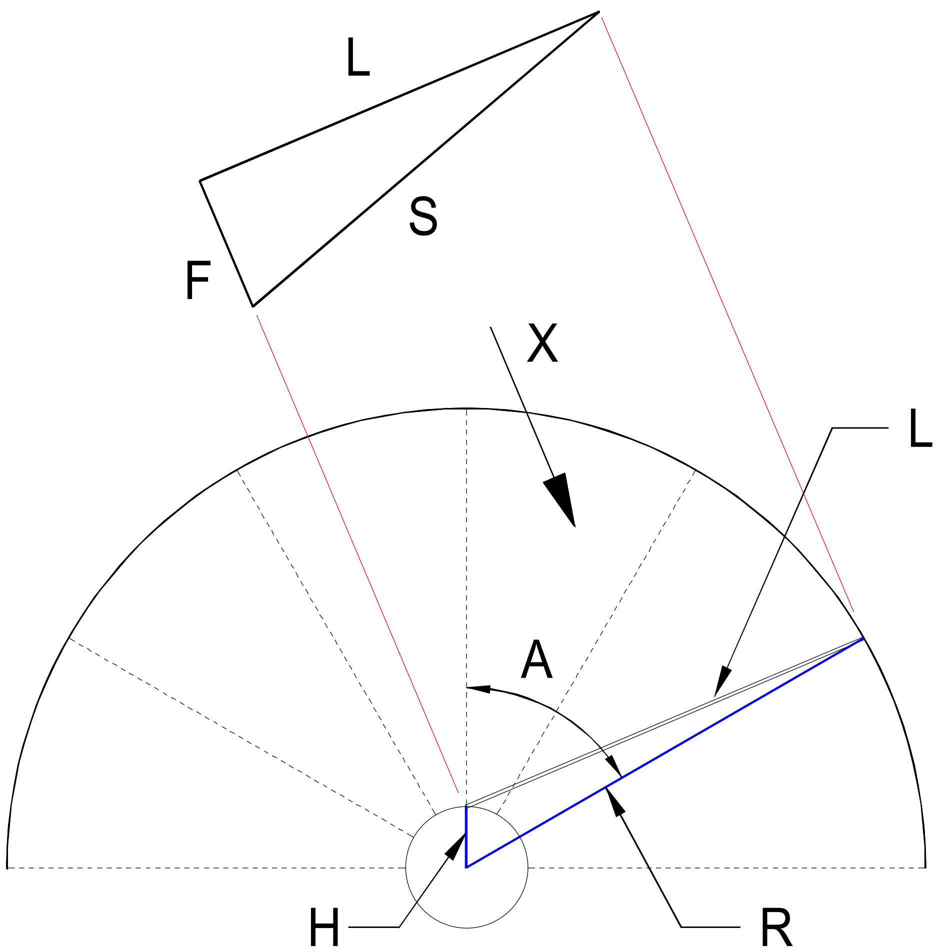
Thanks,

Roger.

Appendix 3

Spoke length formula proof

The diagram shows a single spoke in a 24 hole 2 cross wheel. It is the same proof regardless of spoke count and cross pattern. The dotted lines are radial guidelines that align with the hub and rim spoke holes. The spoke in a 2 cross wheel crosses 2 sectors which is explained in *The Geometry of a Wheel* on page 123.



Look at the triangle with sides H L R with included angle A where :

L = *Intermediate spoke length*

R = *Rim radius (half the ERD)*

H = *Hub flange radius to spoke holes*

Using the *Cosine* rule (en.wikipedia.org/wiki/Law_of_cosines)

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

Now look at the 3 dimensional construction with the spoke connected between the rim and hub flange making the triangle F L S (looking in direction X in the diagram of the wheel).

Using the Pythagoras rule (en.wikipedia.org/wiki/Pythagorean_theorem)

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

where:

S = Spoke length

F = Flange offset (dimensions C and D on page 55)

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 inside bend of the spoke which rests on the edge of the hub spoke hole so half the spoke hole diameter in the hub must be subtracted.

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

where ϕ = the diameter of the spoke hole in the hub.

The angle "A" depends on the cross pattern and the number of holes on the hub flange. Study the diagram of the wheel on page 123 and note how the angle changes with cross pattern. Each cross takes up one sector.

If h = total holes in the rim, then the number of sectors on a single hub flange = $h/2$

$\therefore$ the angle in one sector (degrees) = $\dfrac{360}{h/2} = \dfrac{720}{h}$

and for any cross pattern X

$$A = \frac{720}{h}.X \qquad (4)$$

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

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

where :

R = Rim radius (half the ERD)
H = Hub radius to holes
F = Flange offset
h = Holes in rim
X = Cross pattern
ϕ = Spoke hole diameter in hub

A worked example is shown on page 61 together with some additional notes.

The straight pull spoke length formula

$$Spoke\ Length\ (straight\ pull) = \sqrt{R^2 + H^2 + F^2 - 2RH\cos\left(\frac{720}{h}.(X + 0.5)\right)} + Spoke\ Offset$$

- There is no spoke hole diameter.
- $(X + 0.5)$ only applies to **cross laced** wheels. For radial wheels this value is zero.
- There is an additional dimension on straight pull hubs called the *spoke hole offset* which is shown on page 63. This dimension is either added or subtracted from the calculation depending whether your hub has a positive or negative offset.

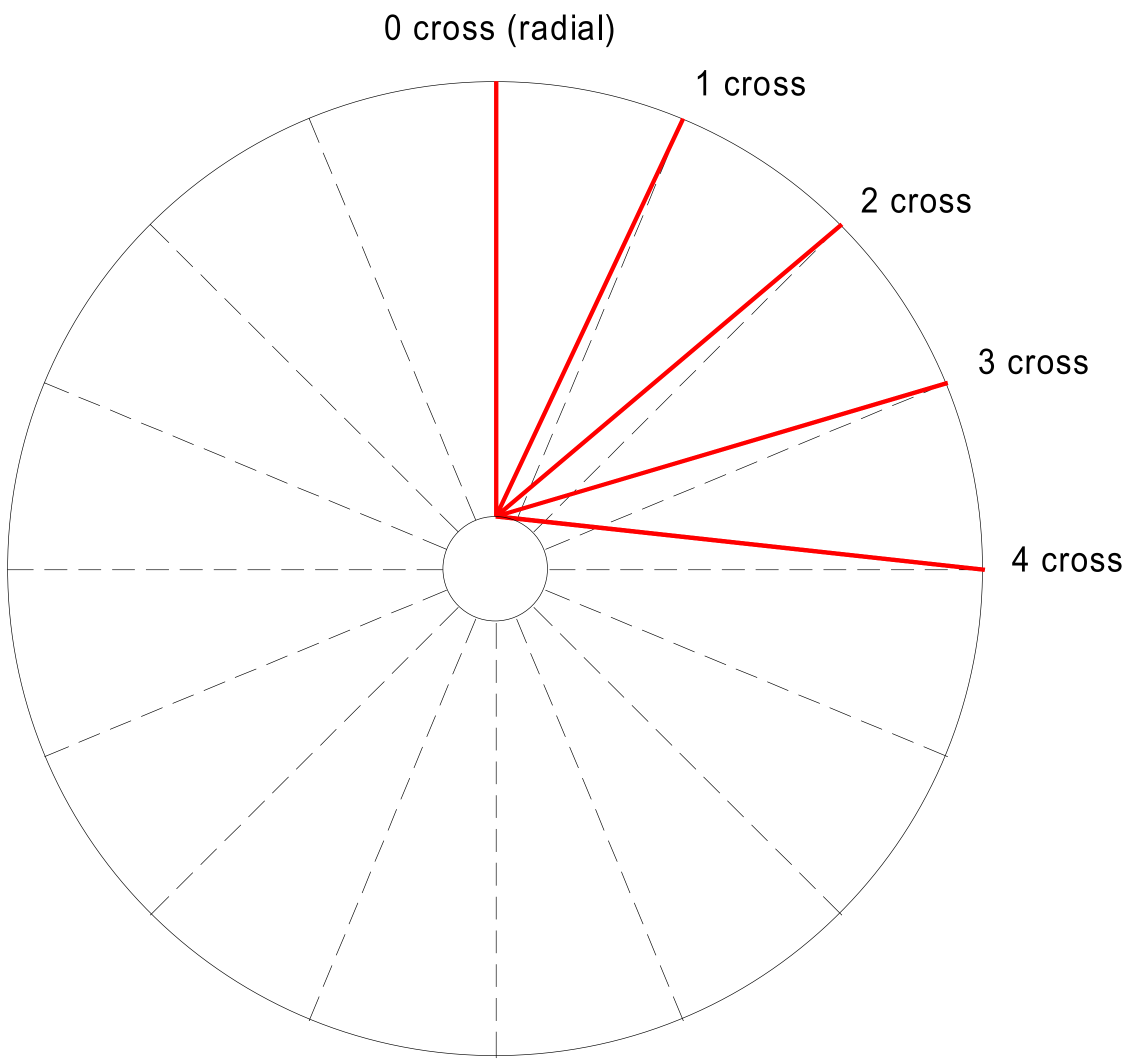
This is explained in more detail on page 126 which describes the geometry of a straight pull hub.

Appendix 4

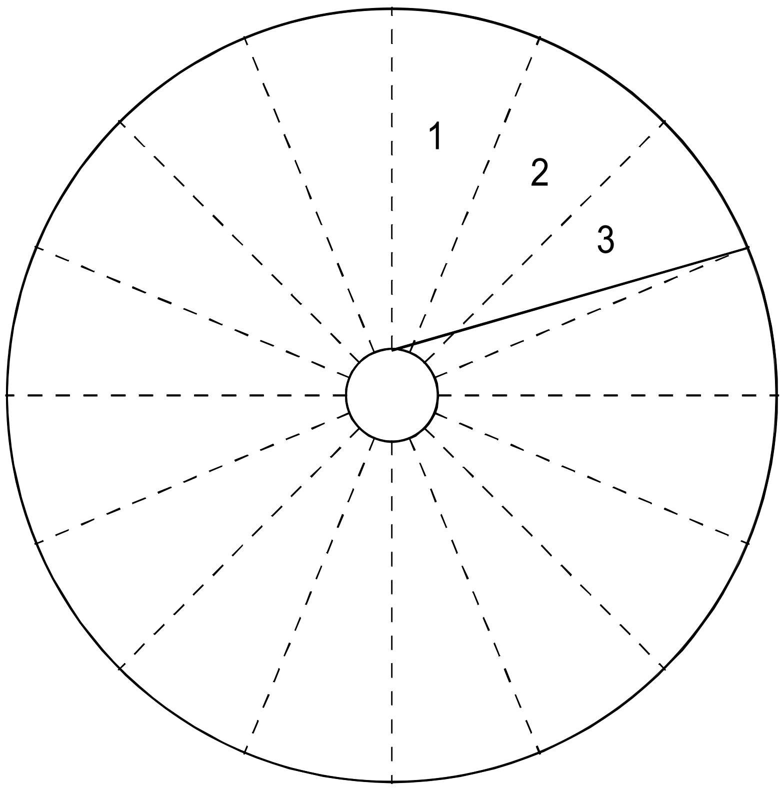
The geometry of a wheel

The construction of a wheel may appear complex but with the aid of simplified diagrams a regular geometric pattern can be seen.

The radial guidelines in the diagram align with the hub and rim spoke holes. Only one side of the wheel is shown. The same hub hole is used and lines are drawn to different positions on the rim to show the different cross patterns. 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.



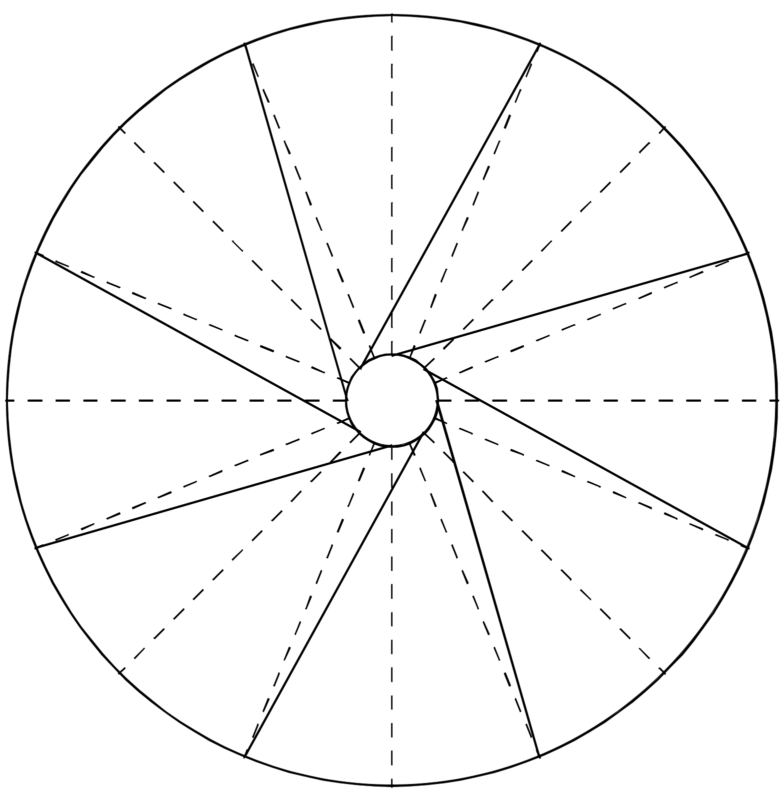
The following diagrams show you how to draw a 32 spoke, 3 cross wheel. It is only necessary to draw one side because the opposite side is identical but rotated half of one hub hole pitch. The same technique is used for all other spoke counts and cross patterns.



Step 1

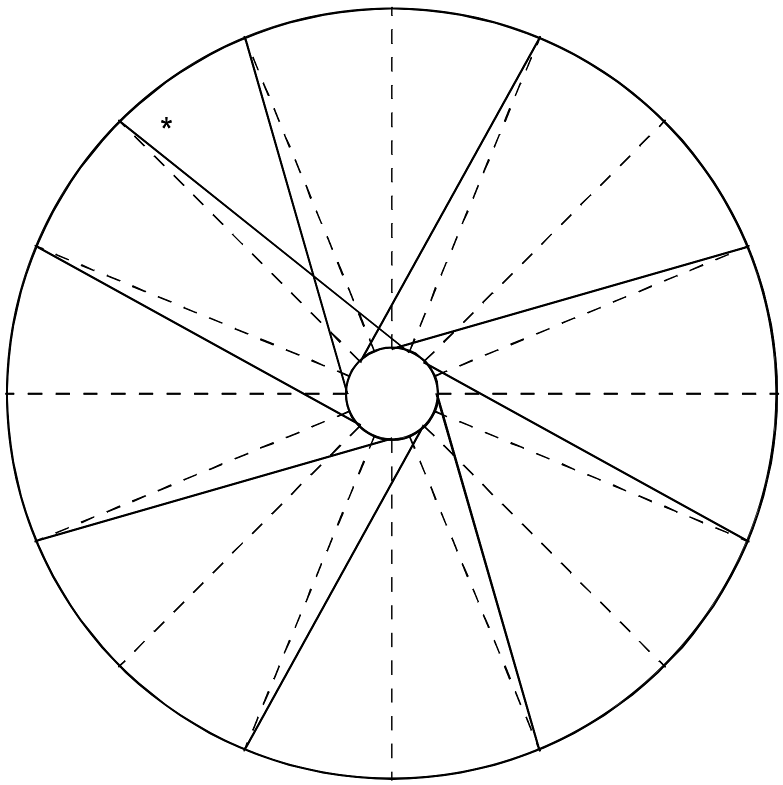
The first spoke is shown in position.

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.

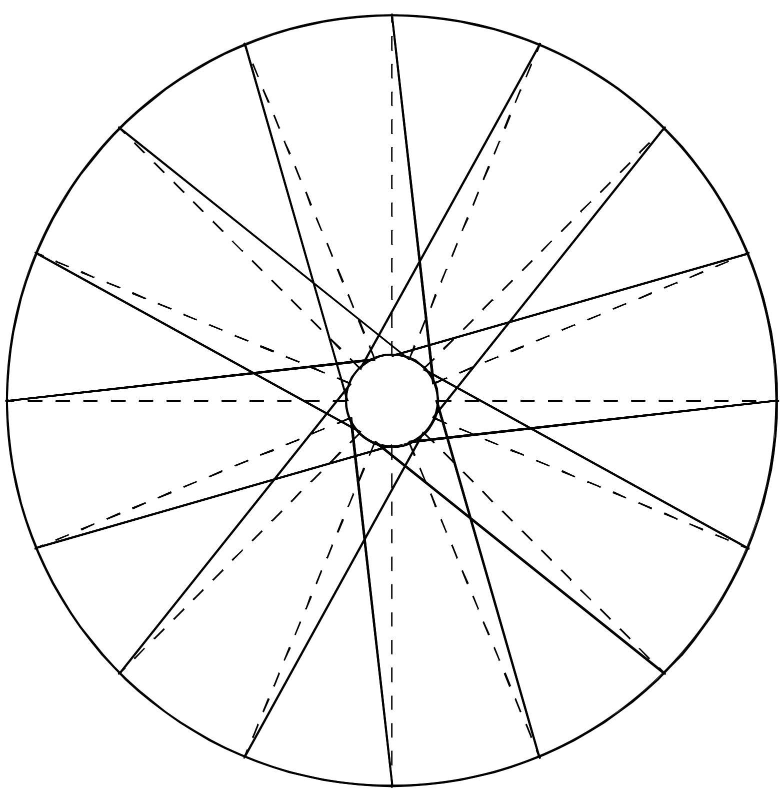


Step 3

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 a *cross pattern*. The first spoke it crosses is very close to the hub and is often missed when counting crosses on a wheel.



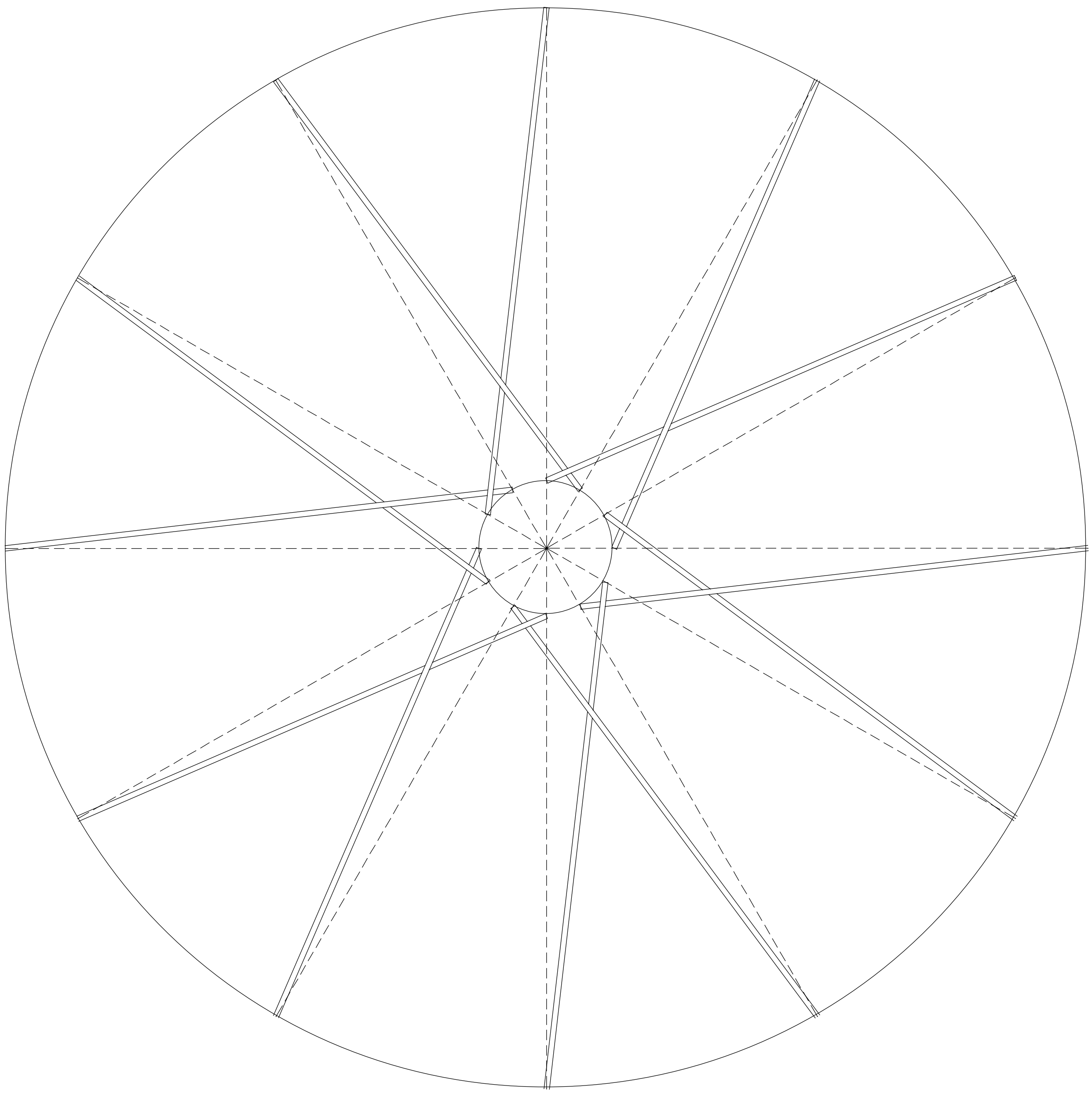
Step 4

The wheel with one side drawn.

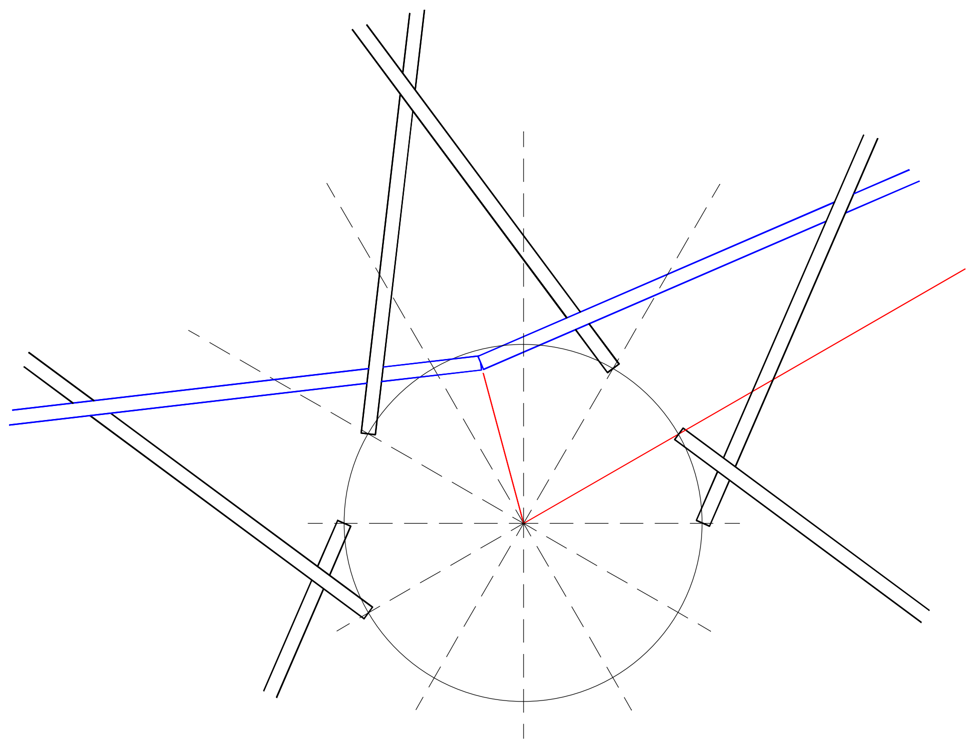
What appears to be a complex arrangement is in fact quite a simple repeating pattern.

Geometry of a straight pull hub

Here is a 24 spoke 2 cross wheel built with a **normal hub** and drawn using the same technique as described on the previous page. Only one side of the wheel is shown.



To convert a normal hub into a straight pull hub each pair of opposing spokes are extended until they meet each other. The diagram below is an enlarged section taken from the previous wheel and shows one pair of extended spokes (the blue spokes). These spokes now locate sideways into the hub and the end result is a hub similar to the one shown on page 63.



The spoke length formula requires the following changes when using a straight pull hub:

Diameter

The circle in the above diagram represents the pitch circle diameter of the original **normal hub**. For a straight pull hub the diameter is measured at the crossing point of the two spokes (also shown in Figure 54 on page 63).

Spoke hole diameter

The spoke hole diameter is not required because the diameter of the hole where the straight pull spoke passes into the hub does not influence the spoke length.

Cross value

The angle bounded by the red lines is angle A in the spoke length proof on page 119, but the angle increases by half a sector (or half a cross) on a straight pull hub. This means that for all cross patterns (with the exception of radial) you must add half a cross. For radial straight pull hubs the angle is always zero.

Spoke hole offset

The formula will calculate the length of the blue spoke, but depending on the design of the hub the spokes my extend further or less. This value is called the spoke hole offset and is added to or subtracted from the spoke length. Positive and negative offsets are shown in Figure 55 on page 63. The blue spokes in the above wheel meet each other and the offset is zero.

Appendix 5

Straight pull hub wheelbuild example

Here is an actual example of a straight pull wheel build using a WTB i35 ASYM 27.5” (650b) rim and a Hope Pro4 straight pull hub, 32 spokes.

Rim and hub measurements

I measured the rim erd and it came to 563mm. I checked the rim specification on the WTB website and it listed the ASYM offset as 4.5mm

The Hope website provides the hub dimensions required for spoke length calculations. Shown below is the data for the Pro4 straight pull hub.

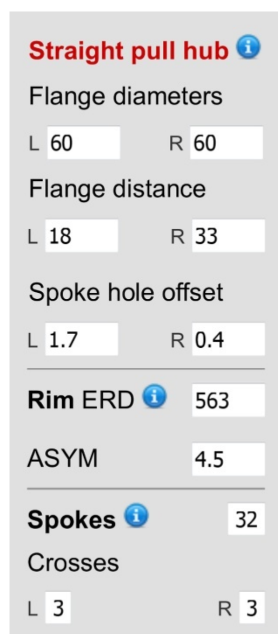
2016 STRAIGHT PULL PRO4/SP24 HUBS SPOKE OFFSET AND PCD							
HUB TYPE	PCD LEFT	PCD RIGHT	FLANGE OFFSET LEFT	FLANGE OFFSET RIGHT	CROSS PATTERN	SPOKE OFFSET LEFT	SPOKE OFFSET RIGHT
Pro4 Front 32 SP	60mm	60mm	18mm	33mm	3x	1.7mm	0.4mm
Pro4 Rear 32 SP	60mm	60mm	32mm	19mm	3x	0.4mm	1.7mm

www.hopetech.com/product-documents/hubs

Instructions for measuring a straight pull hub yourself are shown on page 63.

Spoke lengths

The image on the right shows the values entered into the Wheelpro spoke length calculator.



The calculated lengths are:

Left 279.6

Right 278.9

I can only purchase straight pull spokes in 2mm increments and I select 280mm for both sides. In the spoke rounding discussion on page 55 I said you can go 1mm either side of the theoretical length, but my chosen spoke for the right side is 1.1mm long and slightly out of this range, let’s see what happens.

Lacing the wheel

The design of the straight pull hub dictates the lacing pattern (3 cross in this example) and it also dictates where the pulling and pushing spokes are located (the discussion on page 29 does not apply to straight pull hubs). The hub can only be laced one way and it's impossible to lace it any other way, although when lacing you need to check that:

- The valve hole lies between two parallel spokes.
- Left orientated rim holes are connected to the left side of the hub and vice-versa.
- And for ASYM rims the offset is positioned correctly. In this example of a front disc brake wheel the offset is positioned away from the disc side.

The design of the hub also dictates the type of stagger the rim must have, for example the Pro4 (and I guess all other straight pull hubs) should be laced to a rim with a type 1 stagger or centrally drilled (see rim stagger on page 12). If you try to lace it to a type 2 rim then the spokes will cross over at the valve hole, the wheel will still be okay, it's just that it will be cosmetically poor and the crossed spokes may interfere when attaching the tyre pump. However, type 2 rims are rare and often found on low cost city bikes in Europe. The WTB i35 appeared to be centrally drilled with no observable stagger.

Oil the rim and spokes. I start the lacing on the inner row of spoke holes and place a spoke into the hub (left or right side, it doesn't matter), it can only go through the hub one way and it's not possible to get this wrong. Locate the valve hole in the rim and offer the spoke up to the rim so that it slopes away from the valve hole. There are two rim holes available and in my rim it must go through the second right rim hole, and if you want further confirmation that it's correct then place the opposite side spoke into the rim and you'll see that there are now two spokes to the right of the valve hole sloping away from it.

Once the first spoke is attached you can lace all the inner row of spokes, with the spokes going into every 4th hole, then the outer row to complete one side of the wheel. Remember to weave the spokes. Then lace the other side. Complete the tensioning as described on page 81 doing everything apart from aligning the spokes because in a straight pull wheel the spokes are already straight and perfectly aligned.

Spoke length check

The left side spokes finished flush with the top surface of the nipple so 280mm was the preferred length, with 279 as the alternative. The right side spokes protruded through the nipple 3 spoke threads and whilst it was okay the preferred length would be 279 and I'd choose 278 as the alternative.