Geometry of the village wheelwright

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THE WHEEL, in all its varied forms-gears, sprockets, pulleys and road and track wheels-is an essential feature of all mechanical models and of general engineering. In the smaller sizes, metal blanks ***or*** bar stock are often employed for making wheels, and may be the easiest and most economical mode of production.

Larger wheels usually involve the need for castings or fabrication. The pattern for a simple wheel which can be machined all over, or which has no important detail work left unmachined, presents no problems, as it consists primarily of a disc with a boss on one or both sides, turned in one piece or built up, as may be convenient. Sometimes the web of the disc is relieved, pierced with holes, or ribbed. Unless balancing problems arise, the accuracy of these features is relatively tmimportant. But for fidelity in modelling, disc wheels sometimes need to have a special axial cross-section; an example is the Fowler traction engine flywheel which has a heavily dished and curved contour.

Spoked wheels call for special care in patternmaking, because both the appearance and the balance of the finished wheel are badly impaired if the spokes and the inner rim are mis-shaped or out of symmetry to any noticeable degree. Moreover, these parts of the pattern must always be given proper draught, and smoothly finished, to facilitate moulding. It is obviously inconvenient, if not impracticable, to carry out any machining or other work (except minor trimming) of the casting to correct inaccuracy of the spokes and inner rim. Faults here are often painfully conspicuous in wheels of working models, particularly locomotives and their rolling stock, and especially when they rotate at high speed.

Wheel patterns are often made from the solid, and may be fairly satisfactory if the wood chosen is stable, hard and close-grained and the work on them is skilful and painstaking. But I have seen too many horrible examples of solid spoked wheel patterns to be able to express any real confidence-whatever many conscientious patternmakers may feel-in this method of construction. Sometimes timber, even if seasoned for years, does not become completely stable. After being machined or carved it will warp or shrink to some extent, but never symmetrically to the centre of a wheel pattern. The most serious error which this may cause is to make the pattern more or less oval.

While it may be possible, in the essential machining operations, to set up a wheel casting to remedy an eccentric error of the inner rim nothing whatever can be done about ovality, which is all the worse because the deviation

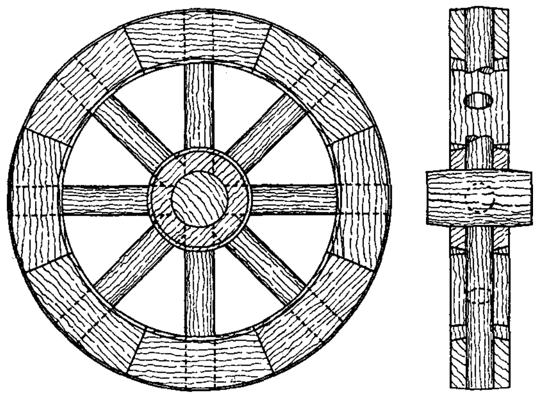


Fig. 35: ***Geometrical principle of the fabricated mu&spoked method***

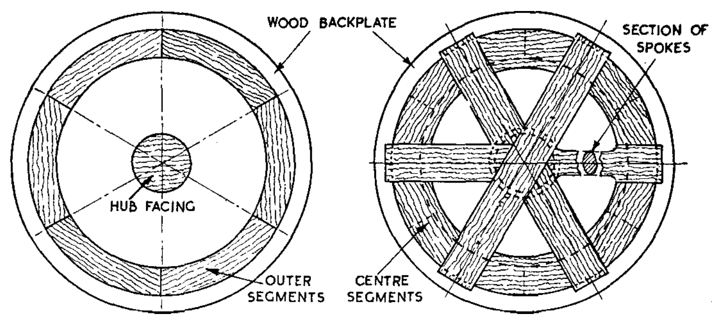
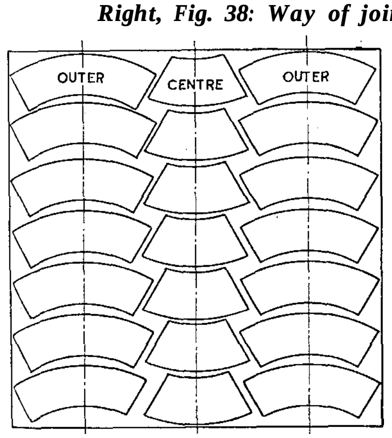
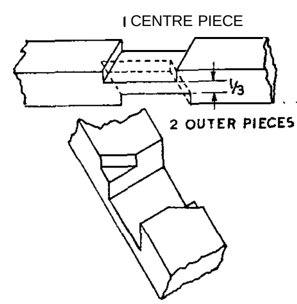


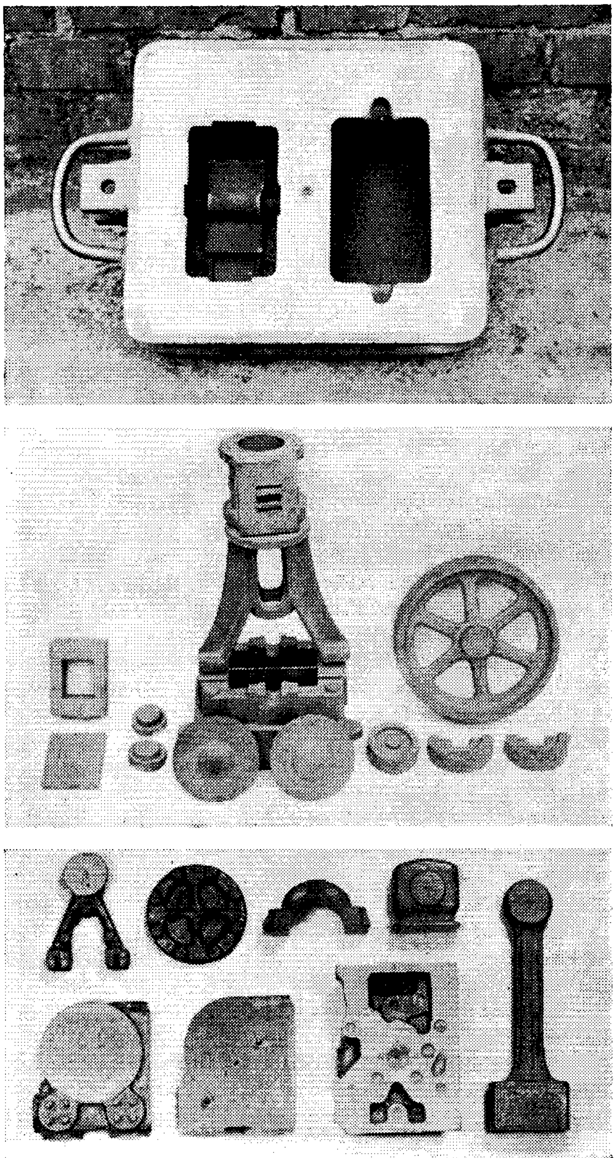
Fig. 36: Making a ***six-spoked wheel pattern on the lathe faceplate. Below, left: Fig. 37. Set of rim segments cut from single piece of wood Right, Fig. 38: Way of joining the six spokes***





occurs twice in one revolution, and can be seen even at a low running speed of the wheel. For this reason, I strongly urge that in any important pattern for a spoked wheel every effort should be made to ensure that it is not only true in the first place, but that it remains true for as long a period as the pattern is in service. A properly fabricated wheel is more likely to fulfil this condition than one made from the solid, besides being stronger and more durable.

A fabricated pattern is inherently true only if we use proper methods in its construction, besides observing the accurate shape and dimensions of its individual parts. Having encountered the task of making wheel patterns many times, I have successfully employed, and can fully recommend, basic methods applicable to all kinds. In my early youth-before I had any training or experience I took a great interest in the methods adopted by country craftsmen, and particularly wheelwrights, in tackling the geometrical problems associated with their work. Some of their methods were traditional, they may never have heard of Euclid, but they could construct a true-running wheel without having recourse to elaborate mechanical aids.



Top: Half-mould for main bedplate and sub-base of Stuart Turner 5A steam engine. Centre: Castings for the 5A Above: Patterns for the display model of a large marine diesel engine. (Technivision Limited)

While I do not suggest that the methods applied in building a cartwheel are those necessarily most appropriate in making small patterns, I maintain that the principles involved are worthy of careful study. These wheels usually comprise a solid central hub, with radial mortices to fit tenons on the inner ends of the spokes. Similar tenons on the outer ends of the spokes are fitted to mortices in curved segments known as felloes. The assembly is bound together and pressed inwards by shrinking on steel tyres; usually the hub, nave or stock also has steel bands shrunk on to resist any tendency to splitting. These details are not, of course, required in patternmaking. Often there are at least twice as many spokes as felloes, and for such wheels to be assembled the outer sides. of the spoke tenons must be tapered, and must be sprung inwards by a Spanish windlass of twisted rope to get them into the mortices of the felloes.

I concede that the method of making a pattern may be much less elaborate, but the point that I am making is that by adopting the same ***geometrical*** principle both the strength and accuracy of construction are assured. If the indexing of the hub mortices is correct, the spokes all the same radial length between tenons, and the felloes all identical in shape and dimensions, including the mortices, it is a geometrical impossibility for any wheel with three or more spokes to be out of truth when assembled. This is shown in Fig. 35, which represents a wheel pattern with round spokes, to avoid the need for cutting tenons and mortices. Not many wheels have spokes of this shape; oftener they are more or less rectangular, or elliptical, with the major axis in the circumferential plane, but they could be pre-shaped as required before assembly.

To simplify construction, while still retaining correct principles, I have adopted the method of building up the rim, and in many instances the hub as well, from three, or possibly more, layers of segments, all with the grain running the right way for maximum strength (Fig. 36). The complete set of segments for a six-spoked wheel may be cut from a single piece of suitable wood of appropriate thickness; Fig. 37 shows how the set for a wheel of 7 in. diameter, with trimming allowance, may be economically cut from a piece IO in. square, by a fretsaw, or better still, by the Duplex jigsaw or the ME sawing and filing attachment for the lathe. There are 21 segments, though only 18 are required; it is always prudent to have one or two spares-just in case ! The end faces of the segments should be trued up to an included angle of 60 degrees, for which purpose a sheet metal template, or two strips of metal clamped to a board at this angle, will be found very useful.

In building up the pattern, I have found that a wooden backing plate, screwed to the lathe faceplate and trued up in position, will greatly assist accuracy. It is covered with a sheet of white paper, glued in place, and marked with concentric circles to outline the position of the hub and rim, while the work is running in the lathe. A set of outer segments may be fitted in place and glued down to the paper, together with the outer facing of the hub, as shown in Fig. 36. The edges of these parts can then be turned true while in position.

We must now consider how best to make the spokes. In a wheel of four or six spokes, it is convenient to joint together strips of wood in the manner shown in Fig. 38. If a greater number of spokes is required, individual strips accurately cut to the required included angle (45 deg. for 8 spokes, or 36 deg. for 10 spokes) to fit at the hub centre, can be used. The width of the strips is largely dictated by the size of the hub, unless small sectors are fitted between, to fill up and cover the hub area. The central part of the spoke can be pre-shaped as shown by the section. This, I consider, is better than making the strips to finished spoke width, because it helps in producing a liberal fillet where the strips join the hub and rim.

A central pin may be used to locate the spoke assembly on the hub. We then fit the centre segments in position,

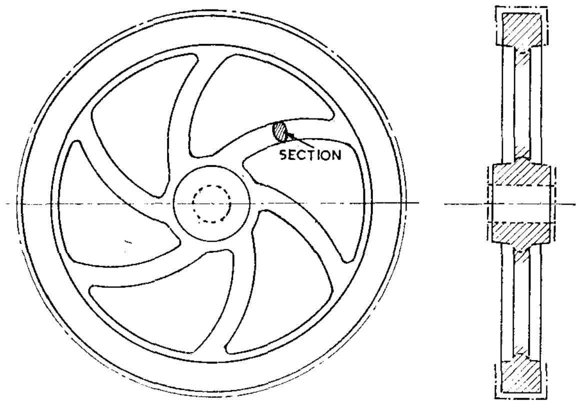


Fig. 39: Pattern for wheel with curved spokes

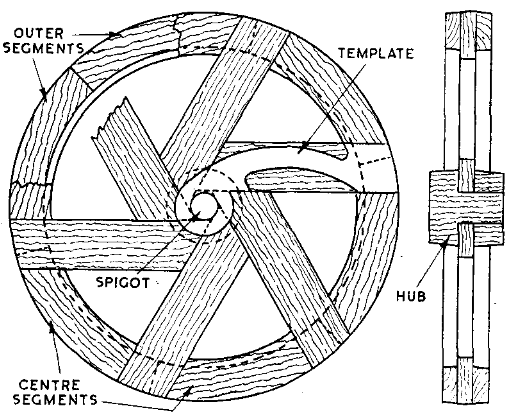


Fig. 40: ***Construction of pattern for curved-spoke wheel***

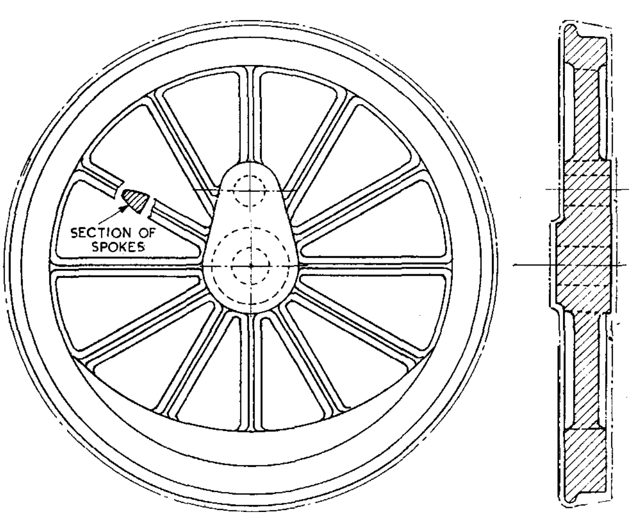


Fig. 41: ***Locomotive wheel pattern with crank boss and balance weight***

bridging the joints of the outer segments so that maximum strength is assured. After gluing these parts down, we can fit the other outer segments in line with the first layer, and machine them true when the glue has set.

The centre segments are deeper than those on the outside, to provide a central rib; this is common practice to stiffen the junction of the rim and spokes, but a similar purpose can be served by a pronounced taper from the centre to the outside of the rim. When finished, the wheel can be stripped from the backplate by the insertion of a sharp chisel under it, to split the paper layer. Do not neglect the paper, or, if the glue is really doing its job, you may have to machine away the backplate to get it off. This pattern will never alter its shape, and will resist any abuse in the foundry, short of deliberate brute force.

Flywheels for some full-size steam and i.c. engines are often made with curved spokes. Besides improving their appearance, this relieves stresses in the casting which may tend to cause cracking of the spokes if made straight. By the curving of the spokes, compression or tension stresses between the hub and rim can be accommodated within certain limits. Sometimes the spokes have a reverse curve or S-bend, but more usually the curve is an arc starting more or less tangentially from the hub. In modelling, the reasons for making the spokes curved may not be so important, except to preserve fidelity to the full-size thing.

Methods somewhat similar to these may be used for wheels with curved spokes, but radially disposed strips will not give maximum strength, as the curve will cross the grain of the wood to some extent. It is therefore ***better*** to fit the strips at a tangent to the hub, as shown in Fig. 4. A dowel or spigot let into the exact centre of the backing plate will ensure that they are centrally located.

After the strips have been cut to the required angle, and fitted to make a snug joint at the hub centre, they may be stacked together and the curved part cut to shape with a fretsaw. You can then check their uniformity after assembly by making a metal template which is laid over each spoke in turn, as shown in the drawing of the partly-built pattern.

This method is applicable to any number of spokes

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THESE ARE THE CAMS

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complete their working cycle in 720 degrees, or two complete revolutions of the crank. To show the sequence of operations in one circular diagram, the opening periods of the two valves are indicated by arcs, or incomplete circles, which must necessarily be of different radii 'so that they are distinct and do not clash with each other. It has been suggested that the diagram should consist of separate circles for the two revolutions but on careful consideration, I do not think that this would simplify the explanation at all.

In the left-hand diagram the arrow indicates that the engine is turning in a clockwise direction-which, in the instance of the Whippet, is correct for normal rotation, viewed from the timing end, though it is subject to modification in certain circumstances. The crank angles are generally checked from the top and bottom dead centres, when the piston is stationary, as these are the easiest positions to verify by removing the cylinder head or inserting a probe or feeler through the sparking plug hole. This is not the most precise method of checking, but it is sufficiently accurate for assembly or servicing.

Starting from t.d.c. on the firing stroke, both valves remain closed until the crank approaches b.d.c., when the effective effort of the burning charge becomes so small that it is not worth while to confine it in the cylinder any longer. A more important matter is to give as much time as possible for getting rid of the exhaust gases, and to clear or " scavenge " the cylinder and so the exhaust valve begins to open well before t.d.c. (60 degrees in the Whippet) as indicated by the outer heavy-line arc. This valve remains open throughout the entire return stroke of the crank, and for 20 degrees after t.d.c., to take advantage of the momentum of the escaping gases.

As shown by the inner arc the inlet valve opens at 10 degrees *before* t.d.c. so that it is well open by the time that any effective suction takes place on the next stroke. It remains open as long as the combined effect of suction and momentum can be used-till 50 degrees after b.d.c., in fact. For the rest of the stroke, both valves are closed, and the fresh mixture is compressed, before ignition at or near t.d.c., when the cycle of events is repeated. The period of 30 degrees during which both the valves are open together at " half time " is known as overlap. It can be used in high-speed engines to increase effective charging, but this benefit is limited in side valve engines, and its usefulness here consists mainly in preventing restriction or " wiredrawing " of the gases at the time when the valve opening is very small. There is some latitude in the actual opening period, and points of opening and closure of both valves; generally speaking, the best results for a particular engine are obtained by experiment.

The left-hand timing diagram, useful as it is for its designed purpose, is not much use to the constructor, unless it is translated into terms of camshaft angle, as shown in the right-hand diagram, with the cams superimposed on it in their correct relative position. As the camshaft rotates at half engine speed, the equivalent crank positions, t.d.c. and b.d.c. are each shown twice, at 90 degrees to each other. It is not so convenient to indicate events from all four positions; start from t.d.c. and work round the complete circle, with the angles counted in rotation. At first sight it might be thought that the sequence of events has been reversed, though in the Whippet the camshaft rotates in the same direction as the crank, owing to the interposition of an idler pinion. It depends, however, on whether the engine in the diagram is assumed to be stationary. A pointer mounted on the shaft is convenient to indicate rotation.

Details of the cam contours are shown separately in the next drawing, where it will be seen that the major part of the contour is a circular arc, concentric with the shaft axis, and known as the base circle. The flank curve which joins this arc at a tangent, has a radius of 1 in., and the angular distance embraced by the roots of

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ELEMENTS OF PATTERNMAKING

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likely to be used in such a wheel. An old handbook on engineering design which I once read specified that the wheels should have seven spokes; there may have been some logical reason for this rule but it seems to have been more honoured in the breach than the observance.

One of the commonest spoked wheels which model engineers encounter is the driving wheel of a locomotive; it generally has a large number of spokes, and may also incorporate a crank boss and a balance weight. The section of the spokes may vary. Usually they are oval or almond-shaped. To cast them properly, it would be necessary to form impressions in both halves of the mould, and in a small wheel this would not only be difficult, but would tend to leave unsightly flashes on the centre line. It is more usual to cast the spokes of model locomotive wheels with a taper from front to back, so that moulding is simplified. As the inside surfaces of the wheels are scarcely visible when the engine is assembled, this departure from scale accuracy is generally tolerated.

The section of spoke shown in the drawing illustrated looks better than a plain truncated cone, and in relation to the width on the front edge is rather stronger. Most wheels have a larger number of spokes than the twelve shown, and it is also usual to taper them slightly from the hub to the rim. A liberal fillet should always be given at their inner and outer junctions. Where it is necessary to vary the position or mass of the balance weights in a given set of wheels, it is possible to make the weights in the form of plates which can be temporarily attached on both sides of the wheel, the space between the spokes being filled with wax or another mouldable material. This avoids the need for the making of separate patterns for each type of wheel.

A pattern of *this* kind may be built up on the faceplate like earlier examples, beginning from the front layer of segments and finishing with those of the back. It would be quite in order to use pre-formed strip for the spokes; and to cut indexed grooves to fit this section, in both the rim and the hub, with a suitably shaped D-bit or router. But I fear that my friend who objects to "machine tool" methods in patternmaking might not approve !

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* *To be continued*