MILLS SECTION

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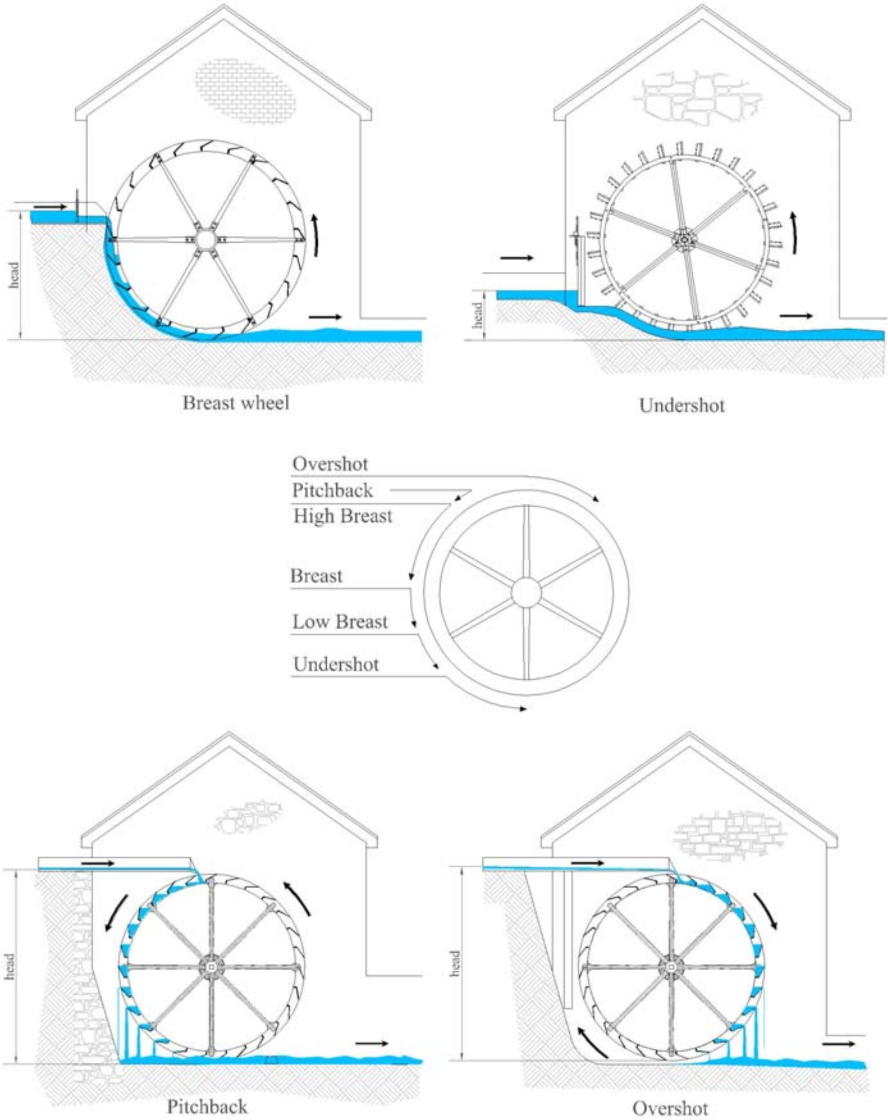
REPAIR OF WATERWHEELS

1 Introduction

Waterwheels come in all sizes, if not in all shapes and, when looking at methods of repair, the problems are basically the same for large wheels as for small ones. It is often simply a matter of scale, accessibility and the handling of parts.

When repairing or rebuilding waterwheels, a number of factors need to be taken into account. Traditional solutions are still often the most appropriate when dealing with the repair or replacement of components, the design of which has evolved over a considerable period of time, much of it due to empirical practice. To follow the Mill Section's *Philosophy of Repair*, it is important to observe closely the specific details of a wheel's design and construction and to repair or replicate them as accurately as possible, in order to maintain the historical, visual and structural integrity of the waterwheel. That being said, some materials and fastenings are no longer readily available and some practical compromises are therefore necessary.

1.1 Types of Waterwheels



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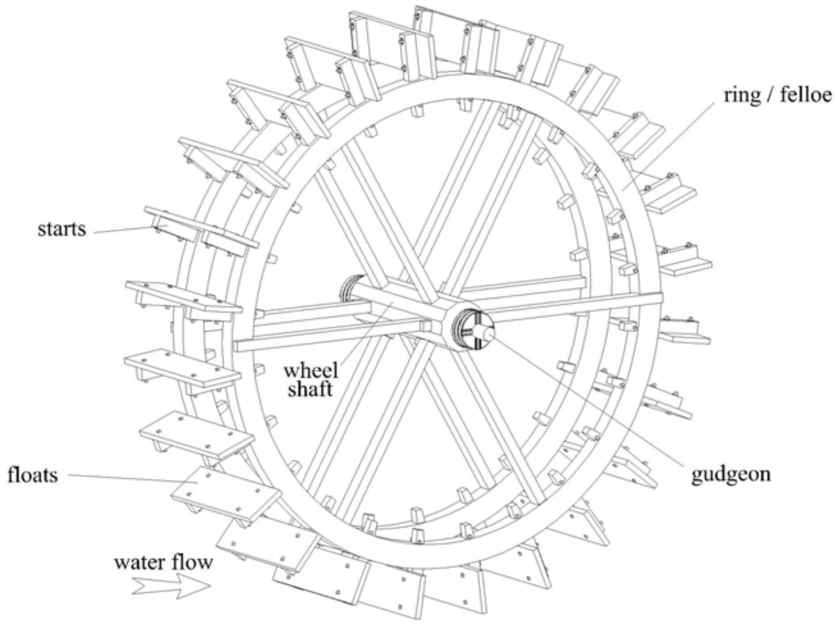
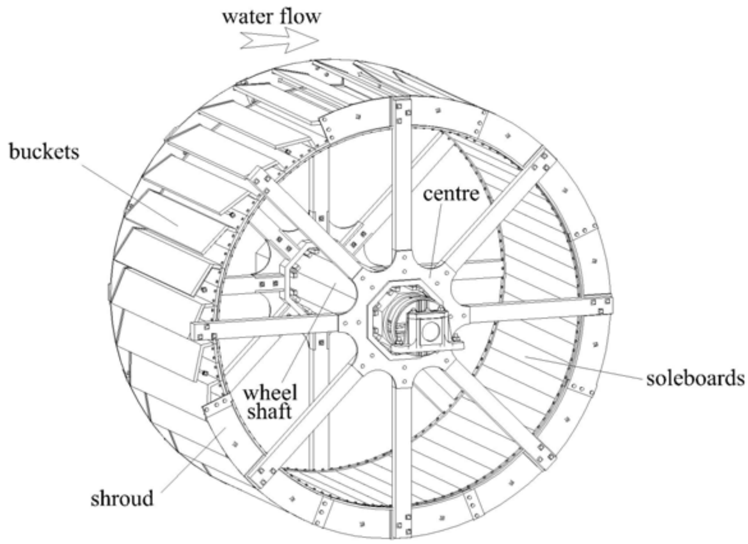
1.2 Nomenclature



Timber undershot wheel with named parts



Overshot wheel with iron shrouds and centres, timber shaft, arms and buckets

2 Dismantling

It may sometimes be easier to dismantle or remove a waterwheel from its working position to carry out repairs, but dismantling can cause problems, particularly if components are large and access for lifting and handling is restricted. If the shrouds or rings are of cast iron and structurally sound and the fastenings holding the sections together are in good condition, it can be more cost effective to work on them *in situ*. This also serves to retain the historical integrity of the waterwheel. If cast-iron sections are taken apart, they need to be clearly marked for correct reassembly, as the positions of fixings holes are unlikely to be consistent.

Broken castings can be repaired, unless too fragmented or the iron is too degraded. A traditional method of repairing a break or crack is by bolting a steel plate or straps over it. If there are several breaks or cracks in different places, however, such repairs may adversely affect the balance of the wheel. If castings can be removed to a workshop, then repairs by fusion welding may be feasible. This is specialist work and needs to be done at the provider's workshop, but metal stitching, which can also be used to repair cracks in cast-iron components, can be done on site and on large items. If castings are too badly damaged or degraded, then new sections can be cast from patterns and fitted.

The removal of seized and old fastenings can be achieved by cutting or grinding off nuts or bolt heads and drifting them out. It may sometimes be necessary to drill out fastenings that are particularly reluctant, but wrought iron or steel fastenings in cast iron will often drive out quite readily. Penetrating oil, such as 3-in-1, has been proved to be more effective than WD40 at easing seized items. Shafts and sleeves or bearings can often be separated with a suitable puller: if need be, by making a special fixture and using a bottle jack. Cutting and grinding using power tools and the use of heat to free fastenings is considered as hot work and suitable precautions should therefore be taken. Care should also be taken not to scar or otherwise damage castings or original components that are to be retained.

3 Materials

With wheels constructed predominantly of timber there is often a requirement for complete replacement of components, while what are sometimes described as 'composite' wheels may only need renewal of timber parts, such as arms and buckets, starts and floats, and sole boards. Wheels constructed entirely of iron, if they are structurally sound and have not distorted, may only require new buckets or floats and sole plates.

Oak, the traditional material of waterwheel construction, cannot be bettered as the timber to use for wheelshafts and arms. It is still feasible to obtain timber of suitable dimensions for the average waterwheel shaft, although it is important to choose an oak butt free from shakes and large knots and one that can be sawn to the octagonal, 12- or 16-sided cross section required, free from sapwood.

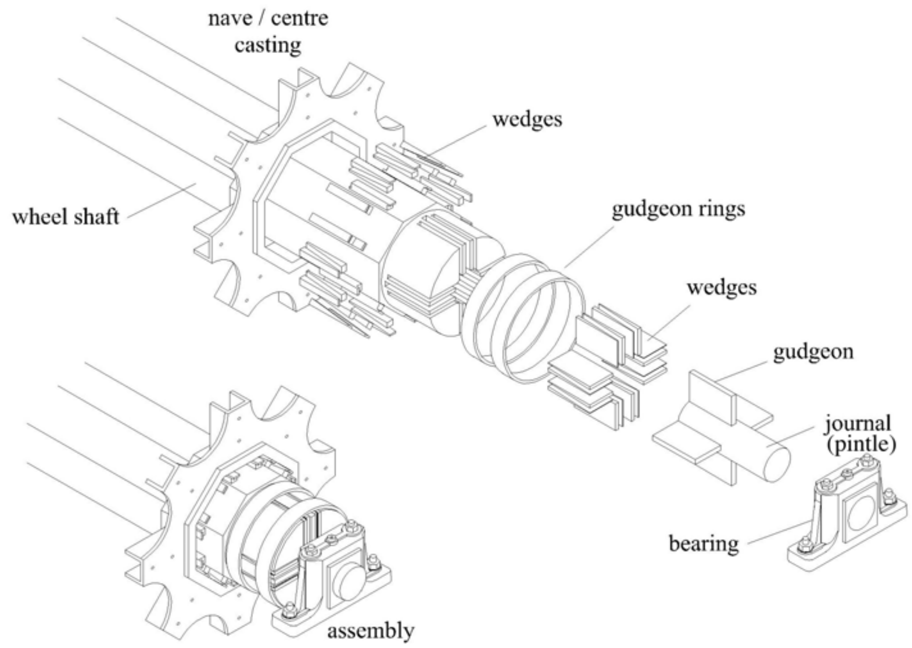
The selection of materials is important, particularly as some, such as elm and wrought iron which were traditionally used for buckets and floats, are now difficult and costly to source. Elm was formerly common because it was cheap and readily available in the wide boards needed to make buckets and floats. This is no longer so, but there are alternatives, such as larch or Douglas fir. Wide boards cut from these home-grown timbers can be sourced at many sawmills at a reasonable cost. Selection is important, the denser, more resinous boards being desirable. Look for growth ring spacing of 1-2 mm max – faster grown timbers are lighter and much more vulnerable both to rot and beetle. Often, slow grown timber is only available from abroad, particularly from slightly more northerly climates. Softwood can be pressure-treated with preservative after being cut to dimension, but such treatment may not penetrate very deeply unless the timber is dry. If boards are treated, then they should be allowed to dry out thoroughly before fixing, both for handling purposes and also to prevent any preservative leaching out when they are immersed in water.

Traditional wrought iron is available only in limited quantities and sizes, and the plate is of very variable quality. A good contemporary alternative is an alloy steel such as 'Cor-ten', which was developed for applications where painting and maintenance are difficult, although it should not be used near salt water. Cor-ten must not be painted – the paint destroys its self-limiting weathering property. If ordinary mild steel plate is used for waterwheel buckets, it should be galvanized and painted. Cutting galvanised sheet to the required size for buckets or floats and drilling for fastenings will expose un-galvanised edges. Such holes and cut edges should be flame sprayed with zinc (available from some sand blasters) to maintain the integrity of the galvanising before painting.

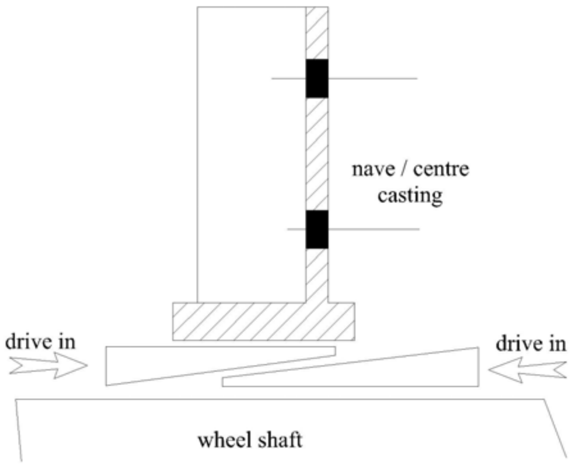
It is important to make new steel buckets or floats from plate of an appropriate thickness. If the plate used is too lightweight, as has sometimes been done from cost or weight considerations, it may flex whilst working and cause drumming or vibration, which can be very noisy.

The appearance of galvanized steel plate may be considered too bright or stark, particularly if only a few floats or buckets are to be renewed. It is feasible to apply paint after using an etching solution to provide a key, although in practice most paint finishes tend to deteriorate quite quickly due to the abrasive action of water and sediments in suspension. As the outer edges of buckets and floats are easily damaged by debris and some may require repair or individual replacement within a few years of renewal, they can be regarded as sacrificial to a certain extent, so a practical and economic working compromise may be considered a better choice than aiming for complete authenticity in terms of materials.

4 Gudgeons



Cross tail or wing gudgeon fitted to timber wheelshaft



Folding wedges holding nave/centre casting to tinber wheel shaft

Cutting the cross mortises or housings in both ends of a timber shaft and fitting the gudgeons and rings is skilled work, best undertaken or supervised by someone with experience. Primary cuts can be made at the sawmill when the shaft is being sawn to shape, or precisely marked out and cut using power or hand saws of adequate size and depth of cut. It is essential that the faces of the housings are cut squarely and finished flat so that the wings of the gudgeons can be located accurately and fitted securely using dry oak wedges and packing, to ensure that the pintles that form the bearing journals are truly aligned. The shaft needs to be set up on half bearings or vee-blocks fixed to a suitable base and which have themselves been aligned using a straight bar. The wedges can then be tightened in stages, continuously checking alignment of the pintles in the bearings and turning the shaft to check for wobble.

Cross-tail or wing gudgeons are traditionally made of cast iron and can still be made and supplied by iron foundries. Any machining required to ensure that the pintle is a true cylindrical shape should be carried out before fitting. The bearing surfaces should then be protected from damage whilst fitting is being undertaken. Fabricated steel gudgeons are an alternative, but the small saving in cost will not compensate for the loss of traditional appearance or the durability of an iron casting.

Cast-iron gudgeons are usually fixed into the ends of timber shafts using dry oak packing and wedges. Iron or steel hoops or rings, usually two or three in number, are driven or heat-shrunk on to the ends of the shaft, to bind it and hold the gudgeons and packing firmly in place. Wedges, both timber and metal, can be driven into the end grain of the shaft, to secure gudgeons firmly, and can also be driven in subsequently, if any movement of the casting is detected.

5 Bearings

As a general rule, bearings should always be renewed or replaced in their traditional form, with cast-iron pedestals or plummer blocks (plain bearings) fitted with bronze shells which have been machined to suit the diameter of gudgeon pins. Worn bronze shells can be re-cast, or they can be re-machined to enlarge the hole, which is then fitted with a sleeve using soft solder. After soldering the sleeve, it is cut to separate the halves. In the long term, this repair can be repeated by un-soldering the old sleeve and replacing it again. Roller and self-aligning bearings have been used on some waterwheels with mixed results and are not recommended. Generally, plain bearings are considered both appropriate and adequate for waterwheel shaft bearings.

Some existing gudgeons and the journals of iron shafts may have become pitted or uneven through wear and decay. It is sometimes possible to turn the journals to achieve a new clean working surface. This can be done *in situ*, by setting up a cutting tool and turning the wheel, or by removing the shaft or gudgeon and turning the journals in a workshop. It is also possible to work on worn journals *in situ*, by carefully filing or grinding the surface to remove ridges. An alternative *in situ* repair for a badly worn journal is to fit a sleeve, a steel cylinder, over the worn pintle. This is specialist work which needs to be done with precision.

6 Fastenings

Many wheels were put together using forged square-headed bolts and square nuts, which are no longer readily available. If only a small quantity of large bolts need replacing, then new ones can be forged or machined to match those existing, although this may be costly. If all the fastenings require renewal, then new ones can be selected from available stock, for example, coach bolts with domed heads (cup square) or hexagonal-headed bolts. The size – both length and diameter – of the fastenings is important. Bolts should always be of the appropriate diameter to fit the existing holes in the castings, as under-size shanks will be sure to 'work' if not. The use of threaded bar or studding should always be avoided in waterwheel work, as the continuous thread will act like a file and holes in both timber and metal will be enlarged and become oval if the fastenings become even slightly loose, which they are likely to do, given the stresses in working waterwheels. Some timber arms are bolted in place with forged square or rectangular plate washers under the nuts, which should be re-used if possible, or good-sized square plate or full washers should be used. These should be thick enough to resist bending or cupping when nuts are tightened. Although traditional fixings may sometimes appear over-sized for the work they have to do, it is important that their size and form is retained, for both historical and aesthetic reasons

Some wheels were built with iron buckets and sole plates riveted *in situ*. This is still an option (obviously hot work), but a rather elaborate and costly solution if all the buckets and sole plates are being replaced in mild steel. Small flat round or dome-headed bolts can be used to reproduce the appearance of rivets. All mild steel bolts should be galvanised and threads greased before assembly – they will then outlast the timber.

7 Naves

It is important to fit the naves or centres accurately to the shaft, to ensure that the wheel is circular and will turn as truly as possible. Old castings may be uneven or may have distorted a little, but a slight side to side movement is generally more acceptable than the visual effect of the circumference of a wheel which runs unevenly. True circularity of motion is more important with an undershot or breast wheel running against a curved cill or masonry breastwork than with an overshot wheel. Circularity is also critical if the drive is taken from the wheel by an annular or ring gear fixed to the shrouds, rather than from the wheelshaft.

The traditional method of fitting cast-iron naves or centres to a timber shaft is with the use of pairs of folding wedges, cut from clean, straight-grained dry oak heartwood. A nave can be centred using four pairs of wedges, on quarters, and the remaining faces/gaps filled with shaped packing pieces. The wedges should be made the full width of the shaft flat faces. It is good practice to drive the wedges in as tightly as possible and check them each time the wheel is run at first. After running the wheel for a few weeks, the wedges can be given a final test to ensure their tightness and their ends trimmed off. To secure the wedges and finish off neatly, shaped cleats can be fixed around the shaft to cover the trimmed ends of the wedges.

Cast-iron naves on iron or steel shafts are usually secured with keys or steel wedges, sometimes in a keyway or ways, or sometimes staked onto flats or ribs or splines on the shaft. If such fixings are sound and tight, then it is preferable not to disturb them.

It may sometimes be necessary to replace a nave, due to damage or breakage of the original. If the wheel can be dismantled and the shaft removed, then the fitting of a new replica casting is relatively straightforward. If, however, access is difficult or limited, it may be preferable to replace a nave with a new split-cast version, made in two (or more if necessary) parts which can be bolted together around the shaft.

8 Arms

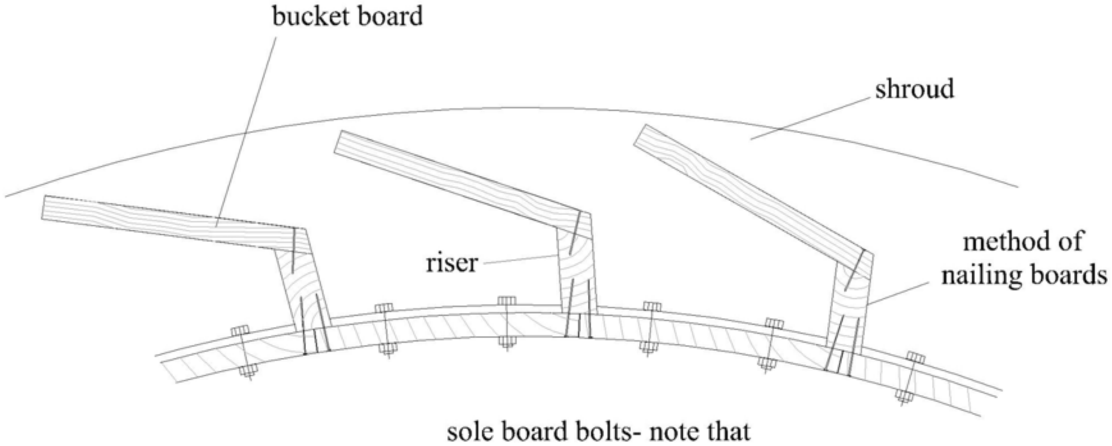
New or replacement timber arms should be cut accurately so that both ends fit snugly into the pockets in the nave and shroud castings. It is unlikely that, if a wheel has two sets of six arms, for example, they will all be identical. Careful measurement and individual fitting is therefore needed, particularly if all the arms have to be renewed because the existing ones have gone. If the rings or shrouds are complete and circular, then it is a good idea to set up false or temporary arms using softwood of a suitable section to fit easily into the pockets and take the weight of the rings or shrouds. By setting up say every other one on both sides, the wheel can be rotated and its turning circle checked for trueness against a gauge or marker fixed to make contact at a suitable point on the circumference. The precise length of each arm can then be measured and the intermediate arms fitted. It is useful to make thin plywood or hardboard templates of the nave and ring or shroud pockets, so that the arm ends can be cut accurately to fit. Bolt holes should then be marked and drilled individually, as the holes in the castings are invariably different from arm to arm and end to end.

9 Cross tie rods

Wheels with timber buckets usually have cross tie rods spanning between the shrouds, which are used to pinch the shrouds together and hold the bucket boards in place once all have been fitted. Old cross tie rods were often made as long bolts, forged with a square section under the head and a short threaded length at the other end, to accept a nut. If existing tie rods are too badly corroded for re-use or the nuts cannot be freed, they will need to be renewed. They should be reproduced in square or round galvanised steel or wrought iron bar, not in standard threaded bar or studding which has poor appearance and does not last. They could be forged, or more simply reproduced by tapping a short length of thread at both ends of a length of steel bar, to accept specially made square nuts or standard full hexagonal nuts. The tie rods should not be tightened up until all of the bucket boards are in place and the lateral trueness of the wheel has been checked. For wheels with captive sole boards, where the ends of the boards are fitted between two flanges, it is essential to have cross tie rods that can be slackened off, to allow the boards to be fitted on sections before the tie rods are tightened up.

10 Buckets

Waterwheels with timber shrouds are now relatively rare survivals. The ends of the bucket boards - the short bevelled riser and the wide outer or float board - were usually housed into the shrouds or supported on timber cleats. With cast-iron shrouds there are usually integrally cast pockets in which the ends of the riser and float boards are located, and a return flange around the inner circumference to which the sole boards are bolted. Iron or steel buckets are usually bolted to single flanges.



When replacing all of the buckets, it is usual to work around the wheel, setting up a working platform in a convenient position and using suitable restraints and props to control the rotation of the wheel. It is possible to construct each bucket in turn, but more practical to fit first all of the bucket risers, followed by the sole boards and finally the outer or float boards. The outer boards and sole boards are either nailed to the risers, or sometimes both boards are held by bolts passing through the riser. Galvanised cut nails, such as those used by boat builders, are still available and can be used to spike the boards together at about 250-300mm centres. Holes for the nails should be pre-drilled using a small pilot, to prevent splitting. The leading edges of the outer boards should be chamfered to reflect the circumference of the shrouds and not present a square, bluff edge to the water entering the buckets.

The long sides of sole boards need to be bevelled or rebated to make them a good fit and as water-tight as possible. The joints between the sole boards should be positioned under the bucket risers, to minimise leakage. When sole boards are bolted to a return flange on the inner circumference of the shrouds, they should be prepared slightly over-length so that they can be trimmed and finished neatly, with the arrises planed off. (In general, sharp corners should always be chamfered or rounded – they form vulnerable points at which rot can take hold.). The bolts holding the sole boards to the flanges should be fitted with their heads inside the buckets and the shanks/nuts facing into the centre of the wheel. This is the traditional method and allows for easier replacement. Bolts through timber sole boards should have good sized washers under the nuts. Cutting and fitting the sole boards around the arm ends, on wheels where the arms are bolted to the inside faces of the shrouds, should be done with care, to make them as water-tight as possible.

Traditionally such materials as wool and tar or lead putty were used to caulk joints in both timber and rolled iron plate buckets, including those between the arm ends and the sole boards and between the sole boards and the risers. Modern mastics, particularly those used in boat building, provide a good alternative. It is important to restrict leakage to a minimum, both to slow down decay and for aesthetic reasons, and to make the best use of the available water

11 Painting

Painting timber parts of waterwheels is generally not practical, although some parts were treated with bitumen in the past. Cast-iron components were usually painted and if in good condition can be cleaned down and finished with black bituminous paint. Bare metal can be painted with a suitable metal primer and finished either with bituminous paint or micaceous iron oxide. If there is any evidence of a colour having been used on castings, this could be replicated, using an appropriate paint system. Applying a paint finish to new galvanised sheet metal buckets or floats has already been mentioned.

MILLS SECTION

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12 Key Points

12.1 Must Do's

- use traditional methods of repair as far as is practically possible
- select appropriate materials
- select appropriate fixings and fastenings
- mark all dismantled parts for correct re-assembly
- allow treated timber to dry thoroughly before fitting
- grease mild steel threads and fixings before assembly

12.2 Must Avoid

- poor quality timber
- threaded bar/studding (for fixings)

For help with finding millwrights and suppliers of materials or for further advice see the SPAB website http://www.spab.org.uk/advice/ or ring 020 7456 0916 / 020 7456 0909

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