The Cone Splice

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As repair-people we come across breaks that have too little long grain gluing surface to effect an adequate repair with just glue. A reinforcement of some kind will be necessary to restore enough strength to withstand the stresses demanded of it. Turned work, legs in particular, are susceptible to breakage where the turning is smallest or weakest. Legs on Windsors will break at the seat as will backs and spindles. Historically, these repairs have ranged from inserting a screw or nail through the end to drilling and gluing in a dowel. I have even seen legs tow-nailed into the seat! The problem with all of the above repairs is that they usually don't provide *enough* strength and often, weaken the structural member somewhere else. Typically, the leg is even more susceptible to breakage with damage extending elsewhere. The screw down the leg will not have the same elastic properties as the wood and will break out the wood around it. The dowel weakens the leg at the end of the dowel because there is no continuity of grain at that point. The proper way to repair these breaks is to make long, tapered splices that does two things. First, the taper allows the splice to be as wide as possible at the break and second, it eliminates or minimizes endgrain.

Reinforcing Using Splices

Not that many years ago, I sailed small boats with unstayed wooden masts. These masts were hollow and had no wires to hold them up but rather, relied upon the compressive and tensile strength of wood to keep them up. They were designed to bend but not break. However, extreme conditions would often damage them and required repair in the form of splices. The sailor quickly learned to engineer proper splices as the failure of these repairs often resulted in a swim and a tow back to the dock! Whether we are talking about repairing masts or repairing chairs and wooden furniture, the same engineering principles apply and can be summarized as follows: Maximize the number of fibers across the break, maximize the width of the splice, maximize the surface area of the glue line, and, taper the splice to eliminate or reduce endgrain. While the optimal ratio for this taper is 1:12, (across -the-grain:with-the-grain), a ratio of 1:8 has been demonstrated to be adequate for most joinery .[1]

Evolution of the Cone Splice

Before arriving at the idea of using a cone shape to splice, I began making repairs to tenons, both round and rectangular, by cutting out a long wedge and gluing in a mating piece. I began using this idea to repair breaks in

[1] Forest Products Laboratory. *The Encyclopedia of Wood*. Forest Service, U.S. Dept. of Agriculture. 1974. pp. 185-186, 194. Reprinted by Sterling Publishing Co., New York, 1980

the *middle* of legs and structural members using a double-ended version. I could cut out the wedges on the damaged part, taking care to keep the break in alignment, transfer the shape onto a piece of oversized wood and gradually shape the wedges to get a perfect fit and alignment. This takes a great deal of time, but by using a Ryoba Japanese saw, I found I could at least get accurate, straight cuts that required little touch up with a chisel. (The long patternmaker's chisel is superb for this work but it must be perfectly sharp without any wear on the flat side of the cutting edge. You will be cutting wood "uphill" or against the grain.) The use of bulked epoxy meant I could be less than perfect in mating my splices and my time to make this repair improved. This splice is still the strongest repair but it removes more wood than a cone splice and it does not preserve the outside surface. For repairs which require the greatest strength, this is the proper repair. Where there is a need to preserve the outside surface or minimize the amount of wood removed, the cone splice is the next best way to repair a break on a turned object.

Turned Work

Turning the long tapered splice was a natural extension of this idea and posed fewer alignment difficulties. On turned legs and rungs, splicing with wedges would cut through into the visible surface of the leg. By cutting out a cone shape into the leg most if not all of the original surface would remain unmarked. The tool I initially used for these splices was a plumber's reamer. The center of the turning was marked and a long, 1/8"d. pilot hole was made to the proper depth, trying to keep it centered and parallel to the turning – no easy feat freehand. Drilling was much more accurate if the leg could be chucked into a lathe and bored. Once the pilot hole was made, the hole could be reamed to the diameter needed. Using the reamer as a template, a matching turning was made. The plumber's reamer only allowed for 1/2"d. cones. Finding a chair maker's reamer allowed this splice to have a maximum diameter of 1 1/4". A larger pilot hole is required (1/4") and the reamer can be worked to one side or other to straighten up the excavation.

A colleague, James Schooley, independently came up with a similar repair using a different tool. He ground a taper onto a flat-bit, typically called Speed-Bore®, and makes quick work of excavating for the splice. I have used his procedure and found it very satisfactory. If only I could find a bigger bit for large legs!

Step-by-Step

Let's start with the worst-case scenario, a turned leg snapped at a small diameter in the turning as in Fig. 1. This will require a double-cone splice where the splice will be shaped with a cone on each end. This will be let into excavations on both sides of the break. If this can be mastered, the single cone splice will be easy by comparison. The break should be put into alignment and pushed together again and a registration mark should be made on the outside spanning the break. While a grease pencil will work adequately, there is a risk of losing the mark. I usually make a small knife mark on all but the most important objects. On this particular restoration the back legs were angled back so I recorded what I thought was the original set based on a tight fit of the part.

fig. 1 measuring the angle for reference when gluing

While it is often necessary to bore the pilot holes freehand, any detached portion of the leg can be bored using a drill bit chucked into the headstock of a lathe with the end of the leg centered on the tailstock. Using hot melt glue or double-stick tape, attach a small block to the end of leg (not the broken end) and center this on the tailstock. The drill should be pushed into the center of the break with the lathe off. The lathe is turned on, holding the leg in place with one hand while turning the handwheel on the tailstock to push the leg farther into the drill. This technique keeps things remarkable centered.

Once the pilot holes are made the leg may be excavated with a reamer (see *fig. 2*). How far should you go? Optimally, if all of the broken wood is replaced by the splice then all of the strength should be restored. If the diameter of the leg at the break is, say, 1” then the maximum diameter of the splice would be 1”. This would mean that there would be a feather edge on each side of the break. While in actual repairs this would be difficult, make the diameter as large as you dare! Remember, the strength you get is directly proportional to the **square** of the radius of the splice and the resistance to deflection is proportional to the **cube** of the radius![2] Often during the reaming process I will wrap the ends with a bit of leather and hose clamp to keep that edge from breaking out. During the reaming process, try to keep the excavation as centered and true as possible. When you feel you have excavated as much as you dare, mark the reamer and check to see if you’ve excavated the same amount on the other side of the break. If you’ve chipped out some of the wood near the edge, put it back with hide or CA glue. Check that your excavations are in-line with the leg. You can check this by turning a single cone on a long piece of scrap, inserting it in the reamed leg and rotating the leg on its axis. This should give you a ballpark idea how off your reamed hole is. For overly out-of-line excavations we can turn out-of-line cones. More on that later.

fig.2 This blurry image shows the reamer in action. Once the leg has been reamed as wide as you dare, mark the depth of the excavation with tape. The reamer can now be used as a model for turning your cones.

fig. 3 This is a view of the break after reaming each side.

[2] As an example : a 1”d turning has a surface area across the grain of πr^2 or .31416 x $.5^2$ or .7864 sq. in. A 1/2”d. splice will have a surface area of .1963 or only 25% of the original. A 7/8” d. splice will have only 76% of the original strength. The effect on deflection is even more pronounced. For a more comprehensive explanation I suggest reading R. Bruce Hoadley’s “Understanding Wood”, Taunton Press, Newtown, CT. 1980., especially Chapter 6, “Strength of Wood”.

Now it's time to turn the splice itself. Pick out a piece of suitable stock that has similar characteristics as the original. Using wood for the splice that is substantially stronger risks further damage to the original in any subsequent failure. It is best to go with a wood the same or weaker than the original so that any failure is one of the splice rather than the surrounding wood. Gentle use and conservative treatment would call for a weak link here while regular use would necessitate matching strength characteristics. The blank should be oversized enough to allow for working room, otherwise it is a fairly straightforward turning. If you turn the splice slightly undersized you will have a little "wiggle room" to put the leg in perfect alignment. The epoxy will fill the gap. If your excavations are too out-of-line for an undersized splice to make up, the blank can be offset. Turn the first cone near the headstock and then reestablish the center on the tailstock in a new location on the stock. The second cone is then cut. When you insert the splice into the leg it can then be rotated to where it matches the offset of the excavations. Knowing that most freehand drilling and reaming are not going to be perfect, offsetting your cones might be the norm. Splicing a set of legs offers the possibility of trying out each splice on a different leg to see which works best and being able to modify the offset on your splices with the knowledge you've just acquired fitting the first splice.

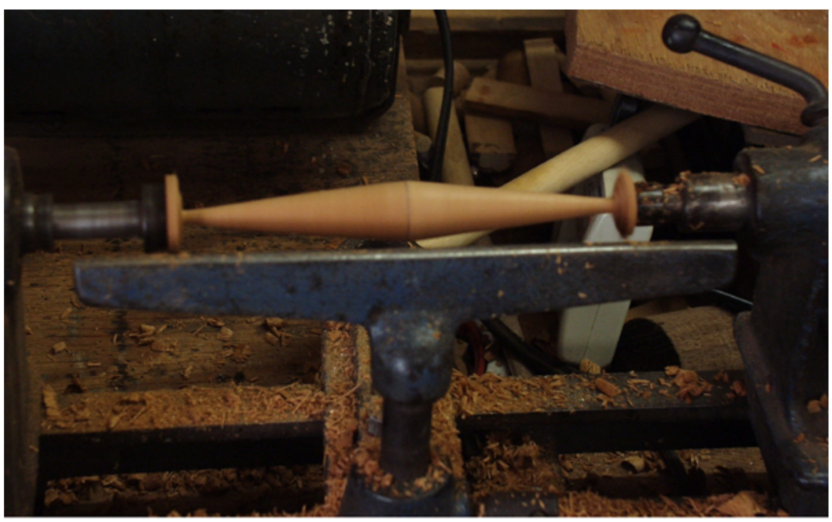


fig. 4 Turning on a lathe is not very difficult.

There are many ways of turning on a lathe so work in the way that you are most comfortable. I eyeball the turning, using the reamer as a model and try to make it slightly undersized. The tendency is to turn the splice too big. If you leave a 1/4" end on one end you might be able to re-turn the work should it not fit exactly. Offset cones will be much more troublesome so try to get it right before taking it off the lathe. Should things not fit perfectly the first time (likely) you can open up the excavation and/or trim up the cones with files, rasps, and chisels. By rocking the cones in their mortises you can tell whether they are tight at their widest or at their ends and trim accordingly. Try to maximize the width of the splice at its widest while getting the leg in perfect alignment. The last thing to do before gluing is to round off the end of each cone. As explained to me by Don Williams, the point forces on the end of the splice are eliminated.

Happy that the cones fit and the two halves come together well, mix up the adhesive of choice. Perfectly fitted cones would allow for hide glue or a PVA glue but, more likely, you'll need a gap filling adhesive. I routinely use epoxy, West System 105/205 with 403 Microfiber filler. Should you wish future conservators the ability to remove the splice, the interior of the excavations should be coated with a barrier coating. Two coats of B-72 with a 28 hour drying time has been shown to be an effective, strong barrier[3]. Add metal filings to the B72 or the epoxy to make the repair x-ray opaque so future conservators can determine that the leg has in fact been spliced.

Glue up the assembly and clamp. Most importantly, have some sort of jig to keep the turning in alignment while clamped. Allow the epoxy to become a firm plastic before unclamping. Let the epoxy cure fully before applying a load to the repair. Since all of the splice is inside, very little touch up will be needed, another added benefit of this method.

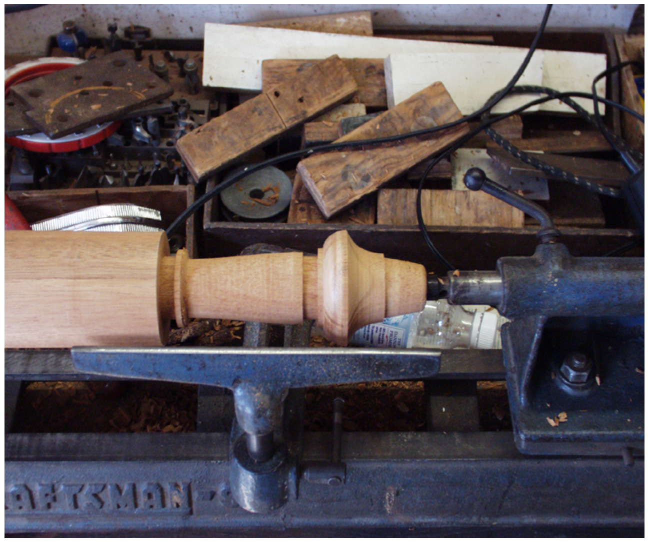
fig. 5 Devising ways to keep everything in alignment can become involved indeed! Here, I'm trying to clamp two legs at the same time.

[3] Ellis, Lisa & Arlen Heginbotham. 2002. "An Evaluation of Four Barrier Coating and Epoxy Combinations in the Structural Repair of Wooden Objects"; WAG PostPrints, Miami

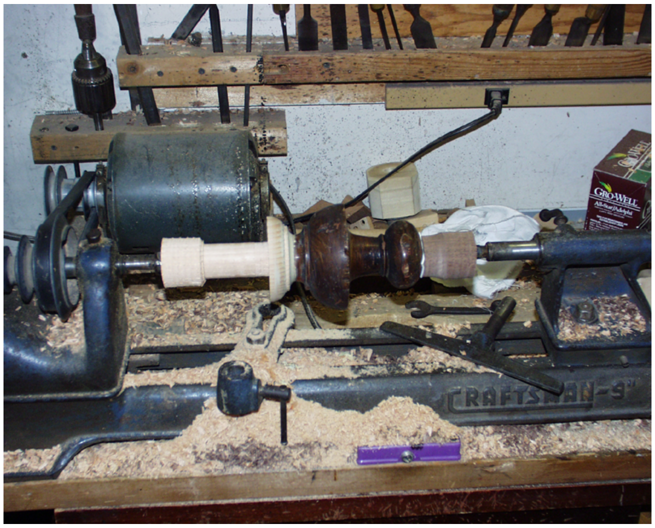
Other examples of turned splices:

Below are examples of some single cone splices used to extend the legs of a desk and to repair a broken bun foot. In the first series a desk was deemed too short. There was insufficient clearance for the average person to get his or her knees under the desk. This is a common problem dealers face as it makes the desk unsellable. In this case the solution was to cut off the turning where the caster fit and turn and glue an extension to the leg that would give 24” clearance, the minimum needed. A conservative approach would be to turn a mortise in the extension that fits over the cup tenon, a difficult but not impossible job.

The first series of photos shows the preliminary drilling and reaming. The second series are of the turning and finishing off. Note that tailstock center is directly against the bottom of what will be the cup tenon. This allows you to remove the turning and check the fit of the caster. This must be an exact mate as the torque applied to the leg by the caster is substantial. The screws holding a poorly fitted cup in place will loosen in short order. Sorry for not having a photo of the finished turning. That would have been nice!



The next series of photos shows better some of the steps outlined in this article. The foot shown had been broken off below the tenon and raised with blocks and toe nailed in place on a decoratively painted hutch. My solution was to splice on where the foot had been cut and re-turn the remaining portion using the other legs as models. I turned the last little bit of the transition area between original and restoration by turning the lathe by hand and holding the gouge in place, cutting only the restoration wood. Note the scrap attached to the foot near the tailpiece. This keeps the lathe center from marring the original. It is only held in place by double-stick tape, which was sufficient. Hot melt glue would have worked just as well if not better.



Conservative Treatment?

Splicing requires removal of original material. This is not exactly conservative, yet, objects lose their original function when structural members are no longer strong enough to meet the demands of use. Furniture that will remain in use will need more intrusive repairs. What we *can* do is make them the least intrusive. And we can make them retreatable. The cone splice removes the least amount of wood with greater reinforcement than many other repairs. It doesn't generally disturb the surface of the turning and, if a barrier coating is used to isolate original material from the epoxy, a vapor trap can facilitate removal of the splice without further destruction of the object.

In determining the size of the splice, the restorer must balance size against the extent of the intrusion. For objects in use, the loss of strength using small diameter splices may actually hasten the demise of the object as subsequent failures are often accompanied by failures elsewhere. By making cone splices we can maximize the diameter of the splice and, consequently, the strength of the repair without appreciably weakening the structure elsewhere.