The Cone Splice

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As furniture repair professionals, we come across component failures that have too little long grain gluing surface to effect a sound repair using just glue alone. Therefore a reinforcement of some kind is necessary to restore enough strength to withstand the stresses demanded of the component. Turned work, and legs in particular, are susceptible to breakage where the turning is smallest or weakest. Legs on Windsor chairs are prone to break at the seat as will backs and spindles. Historically, these repairs have ranged from inserting a screw or nail through the end of the component, to drilling through the damaged section and gluing in a dowel. I have even seen legs toe-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 at a different point. In the case of chair legs, they can be even more susceptible to breakage with damage extending elsewhere. The screw inserted down the leg will not have the same elastic properties as the wood and will break out the wood around it when it fails. A dowel may provide insufficient reinforcement and weaken the leg at both ends of its length because there is no continuity of grain at those points. The proper way to repair these breaks is to make long, tapered splices which accomplishes two things: First, the taper allows the splice to be as wide as possible at the break and second, it eliminates or minimizes end grain, really, spreading the transition the entire length of the splice.

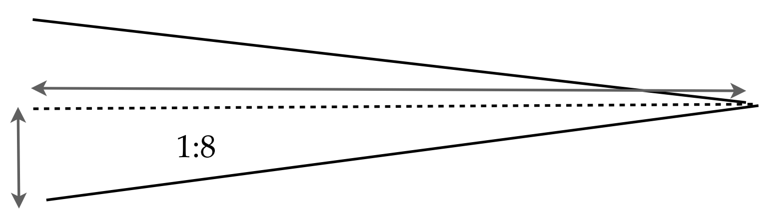
fig.1 A tenon being spliced into a leg

Reinforcing Using Splices

Not that many years ago, I sailed small boats with unstayed wooden masts. These masts were hollow and had no guy wires (stays or shrouds) to hold them up but rather, relied upon the compressive and tensile strength of wood to keep them upright. They were designed to bend but not break. However, the stress of sailing in extreme conditions would often damage them and required repairs in the form of splices. I quickly learned to engineer and execute proper splices. 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:

1. Maximize the number of fibers across the break, i.e. the splice should be as large as possible in cross-section
2. Maximize the surface area of the glue line
3. Orient the splice and the glue line so the widest part of the splice is parallel to the predominant stress, e.g., a splice on a chair back post would best be made on the sides of the post rather than on the front and back. In this article, splicing turned work, this principle is moot as the splice is equally wide, but on scarf joins, this orientation is important.

1. Taper the splice to eliminate or reduce end grain. 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] I have pushed that limit to 1:6 without failures.



Sometimes, some of the principles conflict with each other, e.g. where you are not able to orient the splice *and* maximize the width of the splice. You will have to weigh whether the splice is wide enough or change the orientation. Fortunately, good design usually dictates that a wide structural member is oriented to resist the stresses on it, so splicing simply follows the original design. Unfortunately, not all objects have been *well* designed!

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[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

fig.2 A double-wedge splice on one stanchion for a cheval mirror and a splice to a Windsor chair leg.

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 tapered wedge and gluing in a perfectly mating piece. I further developed this idea to repair breaks in the *middle* of legs and structural members using a double-ended version (tapered on both ends). (See *fig. 2*.)

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 with matching grain and gradually shape the wedges to get a perfect fit and alignment. This takes a great deal of time, but by using a Japanese ryoba saw to cut out the wedges on the component, I found I could consistently 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.) By employing bulked epoxy (filler added to the resin/hardener), I could be less than perfect in mating my splices and my time to make this repair decreased. 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, I believe 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 always cuts through into the visible surface of the leg. By excavating out a cone shape from center of the leg on either side of the break, most if not all of the original surface can 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 is no easy feat when working freehand. Drilling was made much more accurate if the leg could be mounted on a lathe and end-bored. Once the pilot hole was made, the hole was reamed to the diameter needed. Using the reamer as a template, I cut a matching turning on the lathe. The plumber’s reamer only allowed for 1/2”d. cones. However, finding a chair maker’s reamer[2] allowed me to make splices with 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.

fig.3 reamers and a large “pencil sharpener”

[2] Highland Woodworking (highlandwoodworking.com) sells a “spoon-type tapered reamer” manufactured by Clico.

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 this tool makes quick work of excavating for the splice. I have used his procedure and found it very satisfactory. Now 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 that has snapped at a small diameter in the turning as in *fig. 4*. 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 either side of the break. If the double-cone splice can be mastered, the single cone splice will be easy by comparison. First, the break should be put into alignment and pushed together again so that a registration mark can 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.4 Measuring the angle for reference when gluing

While it is necessary to bore the pilot holes freehand on the parts still attached to the frame, the 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) to keep from marring the original leg. Center this on the tailstock. The drill bit is mounted in a chuck on the headstock which should be pushed into the center of the break *with the lathe off*. While holding the leg in place with one hand, the lathe is then turned on. Turn the hand crank on the tailstock to push the leg farther into the drill. You may have to turn off the lathe and reset the tailstock to drill to the correct depth. This tricky technique does keeps things remarkable centered!

Once the pilot holes are made, the leg may be excavated with a reamer (see *fig. 5,6*). 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, I recommend making 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![3] Often during the reaming process I will wrap the ends with a bit of protective leather and hose clamp to keep that edge from breaking out. During the reaming process, it is critical 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, glue the chips back with hide or CA glue. Check that your excavations are in-line with the leg. You can do 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... but more on that later.

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[3] As an example : a 1"d turning has a surface area across the grain of πr^2 or 3.1416 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".

fig.5 This is the view of the break after reaming each side.

fig.6 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.

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 then being able to modify the offset on your remaining splices with the knowledge you've just acquired fitting the first splice.

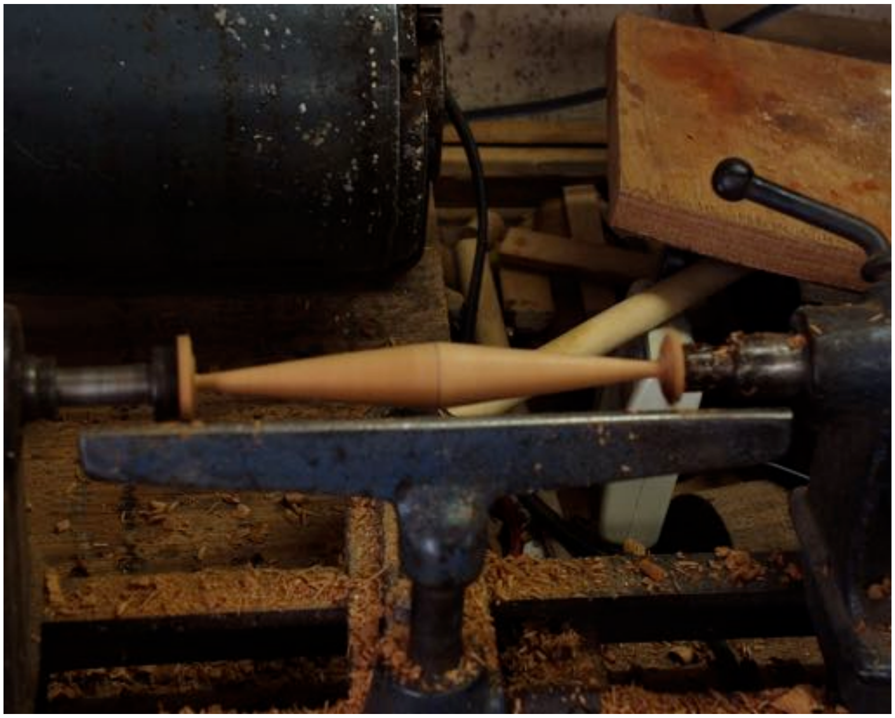

fig.7 Turning on a lathe is not very difficult

There are many ways to turn using 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. I have found there is a tendency to turn the splice too big. If you leave a 1/4” diameter tip 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 them right before removing them from the lathe. Should things not fit perfectly the first time (which is likely), you can open up the excavation with the reamer 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 while still maintaining the leg in perfect alignment. As explained to me by Don Williams[4] , both the end of the mortise for the splice and the splice itself should be rounded to eliminate “point forces” there. Fortunately the chair reamer *is* rounded on the end and rounding the end of the splice is an easy matter.

When you are happy that the cones fit and the two surfaces come together well, mix up the adhesive of choice. Perfectly fitted cones will allow for hide glue or a PVA glue but, more likely, you’ll need a gap filling adhesive.

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[4] Don Williams, Senior Conservator at the Smithsonian, teaching a class on “Techniques for Veneer & Structural Restoration”, given at Dakota County Technical College, Rosemount, MN, August, 2007.

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 pre-coated with a barrier coating. Two coats of Acryloid B-72 with a 28 hour drying time has been shown to be an effective, strong barrier[5]. If you add metal filings to the B72 or the epoxy, the repair will be x-ray opaque and future conservators can determine that the leg has in fact been spliced.

The final step is to glue up the assembly and clamp it. In this case, a jig was important to keep the turning in alignment while clamped. Allow the epoxy to become a firm plastic before unclamping and trimming. 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.8 Devising ways to keep everything in alignment can become involved indeed! Here, I'm trying to clamp two legs at the same time.

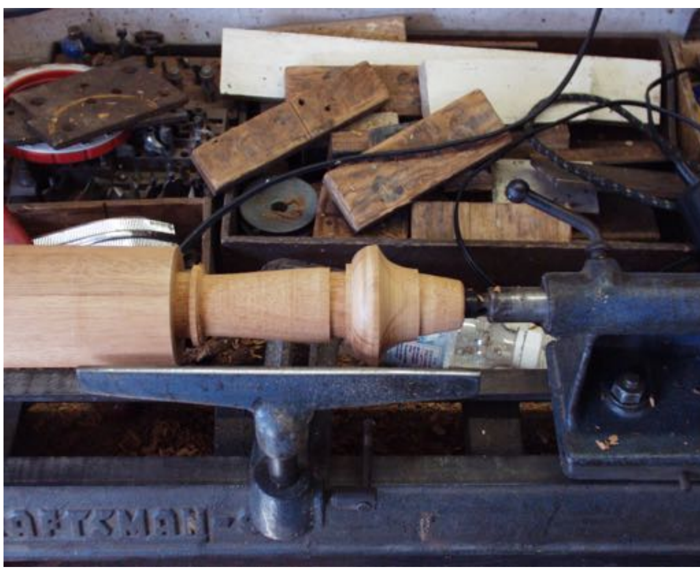
[5] Ellis, Lisa & Arlen Heginbotham. 2002. "An Evaluation of Four Barrier Coating and Epoxy Combinations in the Structural Repair of Wooden Objects"; WAG PostPrints, Miami

Other examples of turned splices:

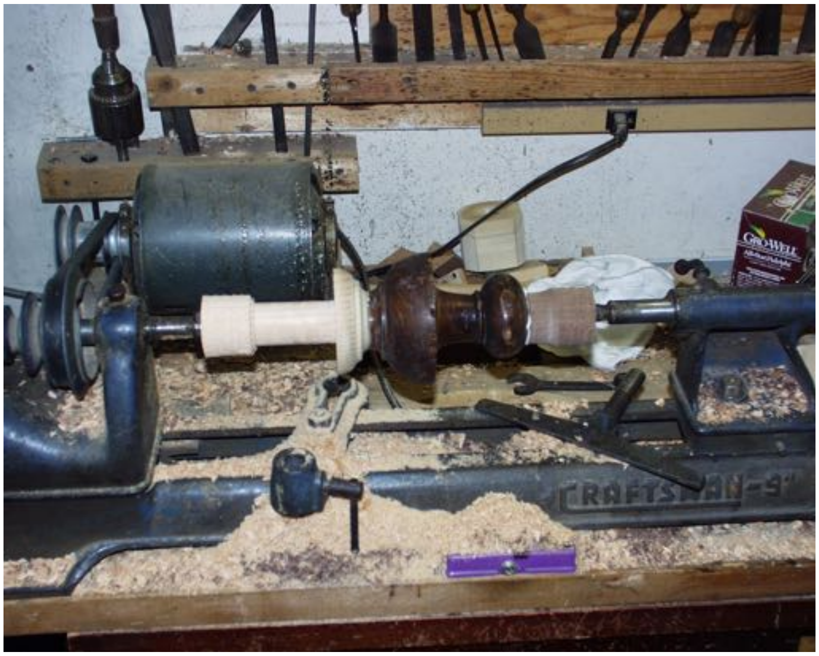
Below are examples of some single cone splices used to extend the legs of a desk and to repair a broken bun foot. In the first series, a desk was deemed too short as there was insufficient clearance for the average person to get his or her knees under the desk. This is a common problem dealers face as it makes the desk unsalable. 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 the required 24” clearance. A conservative approach would have been to turn a mortise in the extension that fits *over* the existing cup tenon, a difficult but not impossible job.

The first two photos show the preliminary drilling and reaming. The next three are of the turning and finishing off. Note that the tailstock center is directly against the bottom of what will be the cup tenon. This allowed me to remove the turning and check the fit of the caster. By turning the cup tenon in the cup, rubbing marks will show the highs and lows of the turning. 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. A photo of the final turning (before clamping and touch-up) would have been nice!


PARIS



The next series of photos illustrates better some of the steps outlined in this article. The foot shown had been broken off below the tenon and then raised with blocks and toe nailed in place on a decoratively painted hutch. My solution was to splice on new material 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 the original and the restoration by turning the lathe by hand and holding the gouge in place, gently cutting only the restoration wood. Note the scrap attached to the foot near the tailstock. This keeps the lathe center from marring the original. It is held in place only by double-stick tape, which was sufficient. Hot melt glue would have worked just as well if not better.



Conservative Treatment?

Splicing usually requires the removal of original material. This is not a strictly conservative approach, yet, objects are unable to fulfill their original function when structural members are no longer strong enough to meet the demands of use. Furniture that will remain in use will therefore need more intrusive repairs. What we *can* do is strive to make them less intrusive and re-treatable. The cone splice removes the least amount of wood with the greatest reinforcement than do other repair strategies. 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 simple vapor trap can facilitate removal of the splice without further destruction of the object. While we can make smaller, less intrusive splices, the exponential loss of strength in those repairs may actually hasten the demise of the object as future failures will often be accompanied by significant, even catastrophic, failures elsewhere on the object. By employing well executed cone splices we can create stronger, less intrusive repairs which should serve their owners for generations to come.

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