

Building An Acoustic Steel-String Guitar

[Jon Sevy](#)

Dedicated to the memory of Irving Sloane, whose beautiful book
Steel String Guitar Construction inspired and guided my
explorations in the craft of lutherie.

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Introduction

The following illustrates the approach I use to build acoustic steel-string guitars. It's intended to be a sort of pictorial journey through the construction of a guitar. It's currently a work-in-progress; I'll add sections as I reach those points in building this season's instruments.

In general, I use the approach described by Irving Sloane in his wonderful book "Steel-String Guitar Construction" (E.P. Dutton and Co., NY, 1975). I've varied from his method in a number of areas (arched top, neck joint, truss rod, etc.), but I still use his wonderful rubber-band gluing jig for joining the top and back to the sides.

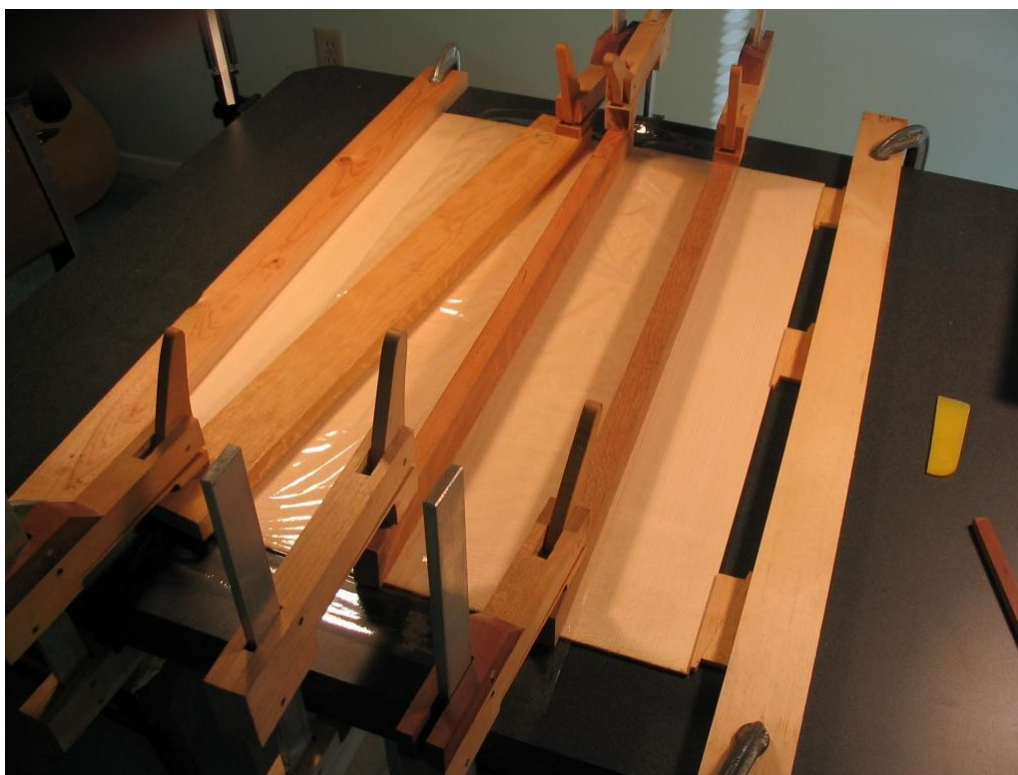
I'm currently in a "native American" phase, using native North American woods whenever possible, so many of the woods used in the photographs are non-traditional. For example, the backs and sides illustrated use mulberry and quartersawn red oak, the binding is curly maple, the back braces are walnut and soft maple, and dogwood is used for the bridge plates. The tops are Sitka and Engelmann spruce. The only parts I haven't found good local substitutes for are the fingerboard and bridge, for which I still use East Indian rosewood. I've also been using rosette designs that are inspired by Native American pottery and textiles.

The photographs show a number of tools and jigs used to build the guitars, but you can often get by with less elaborate equipment - using a hand-held jigsaw instead of a bandsaw, a handplane instead of a jointer and planer, etc.

Chapter 1 - Top and Back Plate Gluing

Top plate

The top plate halves are first thickened in the thickness sander. I generally thickness them to between .110" and .115". After the halves are thickened, the edges are run over a jointer and/or planed with a handplane to form a perfect joint. Glue is applied to the joining edge, and the halves are then glued together. Clamping is accomplished with pairs of wedges and two parallel boards clamped to a Formica tabletop. The halves are placed together, and the wedges are squeezed together by hand to bring the halves together. Plastic wrap is placed over the joint, and a caul is clamped lightly over the joint to keep the faces aligned - this is the middle caul seen in the photo below. The wedge pairs are then tapped together to tighten the joint. The wedges can exert a huge amount of force, so don't tap them too much or the joint may become glue-starved. A couple of additional cauls are seen below, to keep the halves from bowing.



After the halves have been glued together, the top is cut to the shape of the guitar body on the bandsaw.

Back plate

The back plate is fashioned in the same way as the top plate. The only difference is that a binding and purfling strip is glued between the halves.

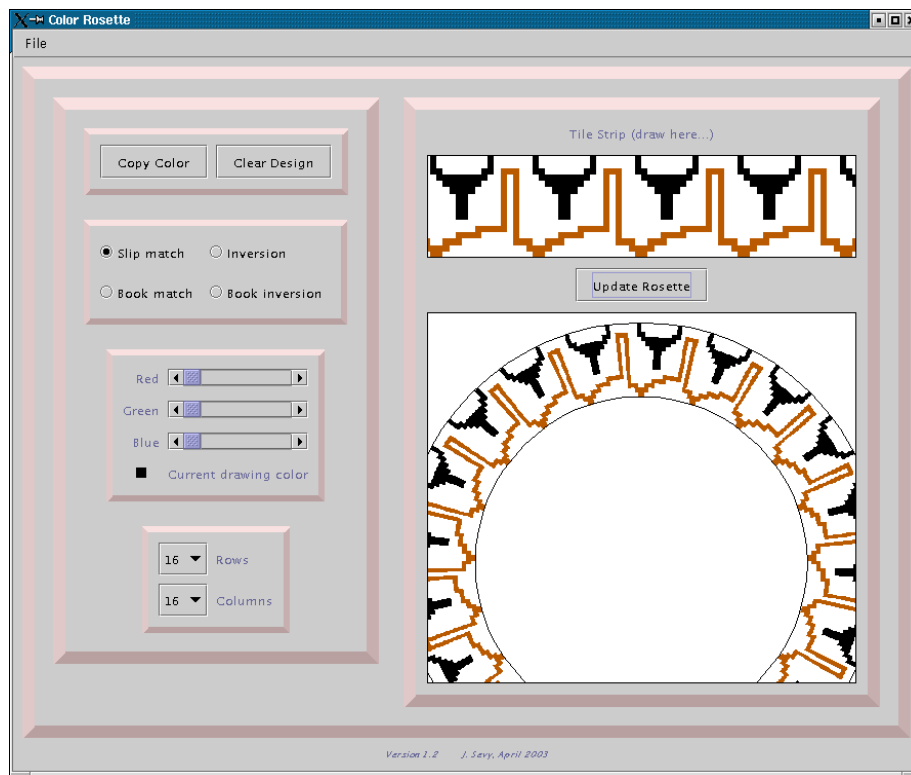
When the glue has dried, the back plate is also cut to the profile of the guitar body. However, it is cut about 1/8" larger all around to allow for the greater arching on the back. The expanded outline can be drawn by putting a small washer against the body profile template and putting the pencil inside it to trace the outline.

Chapter 2 - Mosaic Rosette Construction

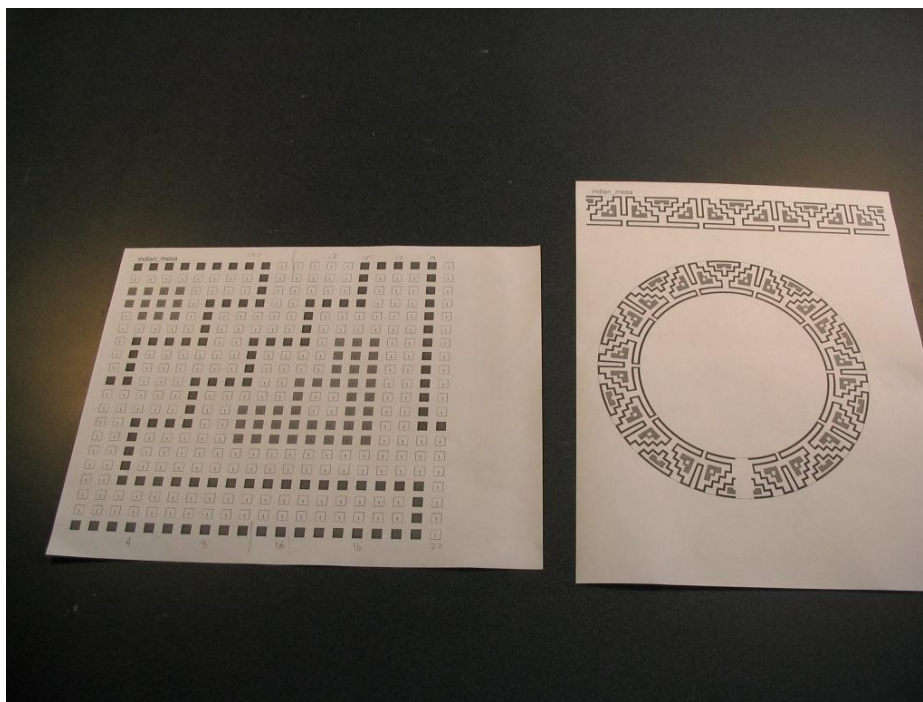
A mosaic rosette consists of tiny squares of wood that create a circular mosaic design around the soundhole of a guitar. The design usually has some form of symmetry, consisting of a single "tile" repeated (a slip match) or flipped as it's repeated (a book match). In either case, the mosaic can be made by creating a "log" whose cross-section is a single tile; tiles can then be sliced off the log, and glued side by side to form the circular rosette. Where each tile consists of small squares (really cubes) of wood, the log consists of long strips or "straws" of wood. The log will actually be built up as columns glued together. Construction of the tile log is covered in detail in the following sections, but the overall approach is as follows:

1. Design the rosette, determining the design of the fundamental tile
2. Construct column logs, for each of which a strip sliced off will form a column of the tile log
3. Slice columns from the column logs
4. Taper columns so the tile log will be tapered
5. Glue columns together to form the tile log
6. Slice tiles from tile log
7. Glue tiles together to form a circular rosette
8. Glue binding strips on the inner and radii of the rosette

To design a rosette, it's necessary to design the fundamental repeating tile that will generate the design. This can be done with graph paper, coloring in squares to get a design that's appealing, or can be done with software that acts like the graph paper and makes it easy to alter and experiment with rosette designs. One such program is [Color Rosette, a Java application](#). Squares are colored in a "tile strip", which automatically produces a repeating design. This design can then be transferred into a window that displays the design "in the round". Various symmetries can be used, including the slip match and book match. A screenshot of the application in use is below.

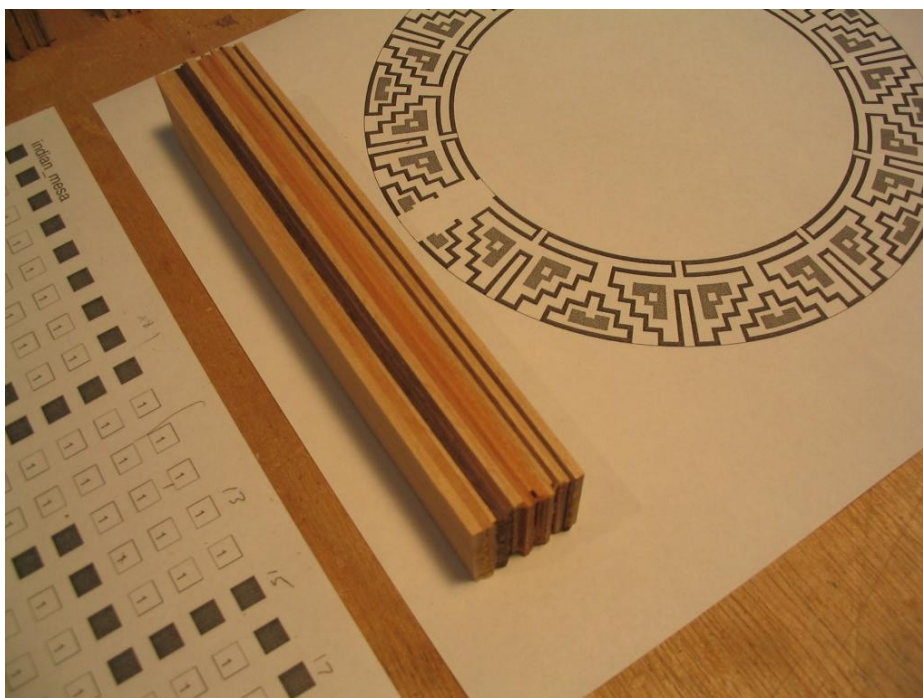


When the design is as desired, it can be printed, along with an expanded "tile map" that shows the elements in the tile as separate squares, to make it easier to build the rosette. These are shown below.



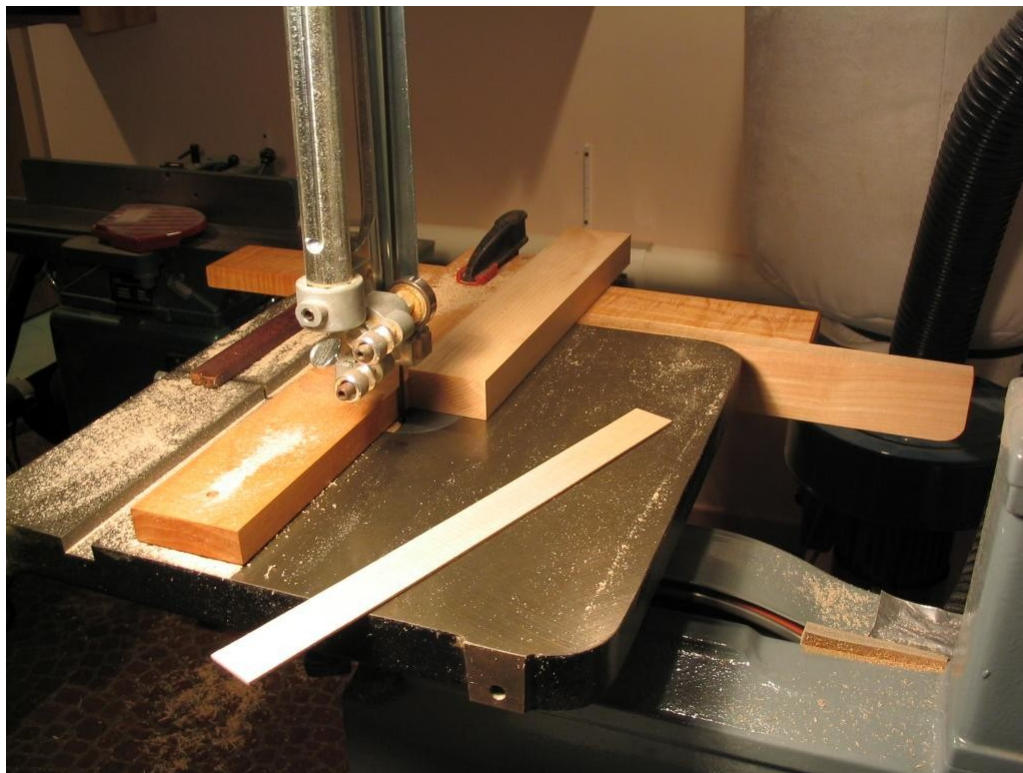
The tile map shows that the rosette design can be viewed as a set of columns of colored squares. If the columns are tapered from top to bottom, then the tile will be tapered, becoming a trapezoid rather than a rectangle, so that when the tiles are glued together they'll form a ring.

The column logs are used to produce the columns in the tile log. Each column log is a laminate of thin layers of wood of the colors needed to make up a single column in the rosette. Thus there will be one column log per column in the design.

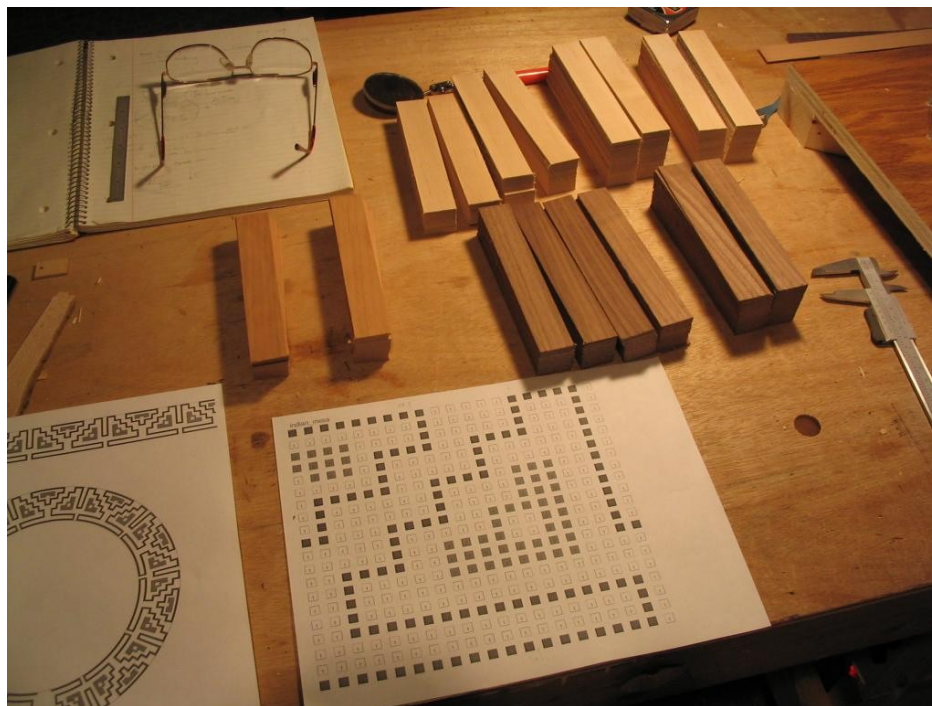


The first step in making the column logs involves creating the thin laminates of different woods. The thickness of the laminates is determined by the desired height of the tile, i.e., by the desired width of the mosaic rosette. If a design has 12 rows, i.e., each column has 12 squares, and the desired tile height is .600", then each laminate should be .050" thick. It's worth mentioning that accuracy in the thicknesses of the laminates is important to ensure that all of the column logs have the same height after the laminates are glued up, and that the adjacent columns' rows line up correctly. I generally shoot for an accuracy of approximately .002" in the thicknesses. This can be achieved by running all of the laminates through the thickness sander several times (and the same number of times) at the final thickness setting, so any differences will be minimized.

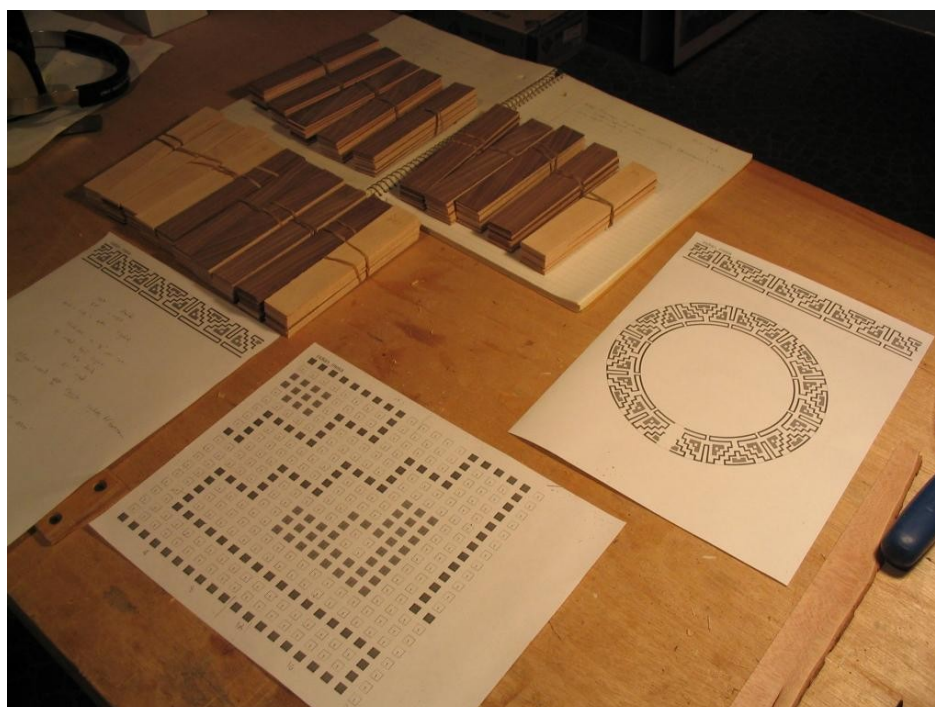
The laminates are made by slicing thin strips off of the edge of a plank, and then running them through a thickness sander to sand them to the desired thickness, as shown below. The lengths of the laminates determine the length of the final tile log; the width determines how many columns can be sliced off each log, i.e., how many tile logs can be made from the set of column logs. I generally use laminates that are 6" long and 3/4" to 1" wide. The planks from which the laminates are sliced should be of the correct size (e.g., 6" long by 1" thick) to produce the desired size laminate.



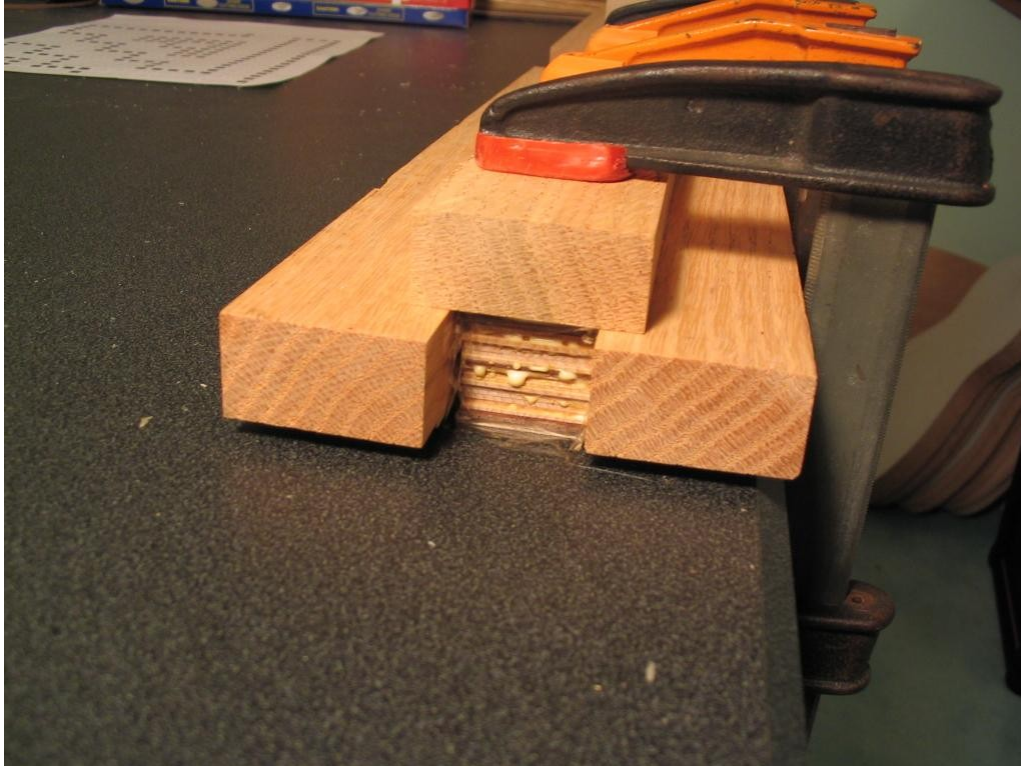
You'll need one laminate for each square in the design, of the appropriate color, of course. So if a design has 12 rows and 20 columns, you'll need a total of 240 laminates, which might be 24 cherry, 80 walnut, and 136 maple strips. When sawing and thickness sanding is finished, you'll have piles of thin laminates in the different colors needed to form the column logs.



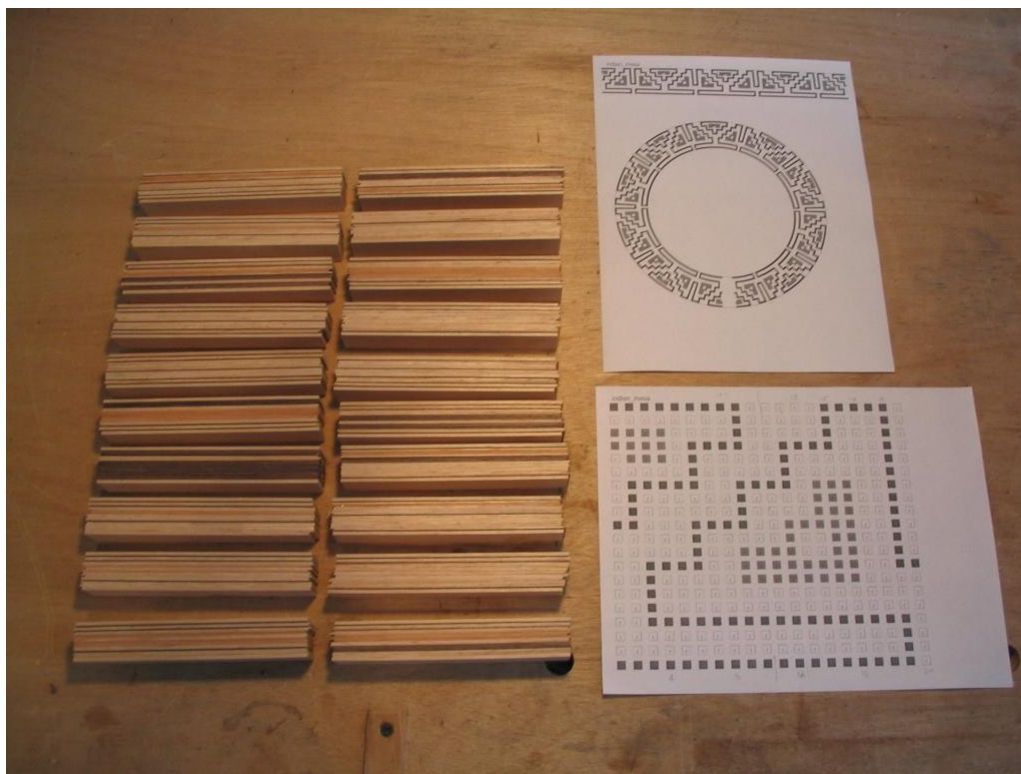
The column logs are now assembled, picking the correct sequence of colors for the laminates in each column. The logs are shown here prior to glue-up, one log per column, with each having the appropriate color sequence to match the color squares in the corresponding column. It's worth double-checking that the laminates in each log are in the correct order, as it's frustrating to find that a log has its colors out of place after gluing, requiring a new log to be made.



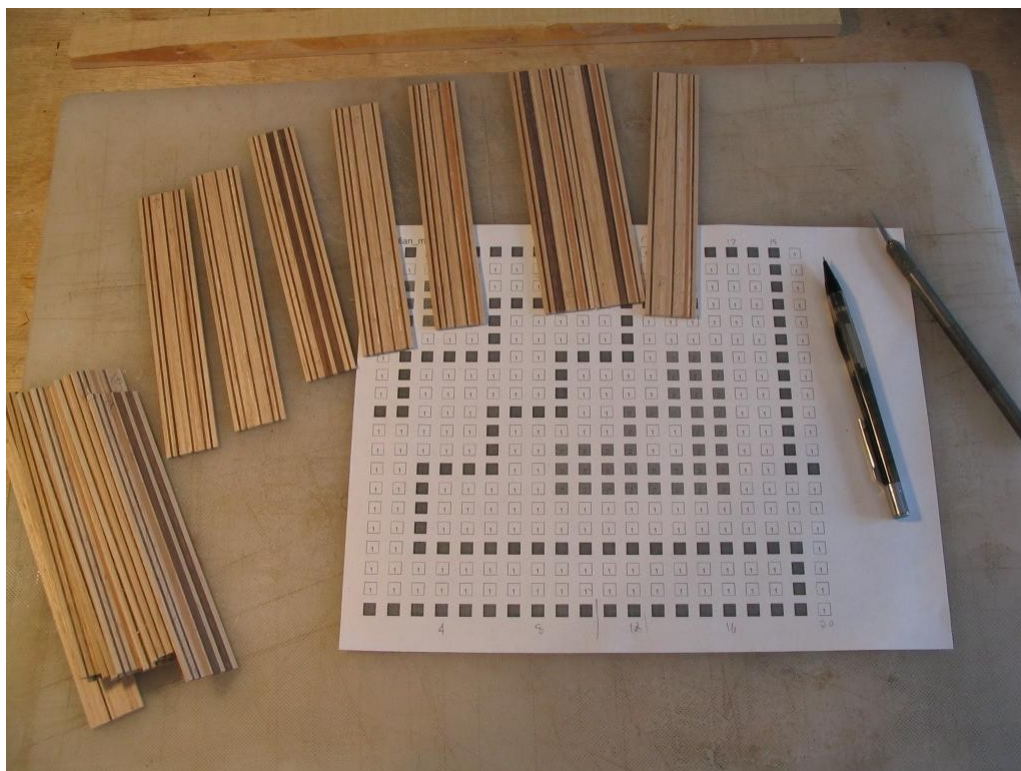
The column logs can now be glued up. One of the most important things is for the glued-up column logs to have exactly the same thickness. If the thickness of the logs varies, then the columns will be of different heights, and the rows in adjacent columns won't match up, leading to discontinuities in the design. To make sure the column logs have the same glued-up thickness, cauls are made in the final thickness of the logs, and used on either side when clamping to keep the thicknesses uniform. The thickness of the cauls should allow approximately .002" for each glue layer. Thus if a column log has 12 laminates of thickness .050", then the caul thickness should be $12 * .050" + 11 * .002" = .622"$. Note that in the image below, the cauls on either side have shims on the bottom that aren't visible to bring them to the correct height. Also note that the column log has been wrapped in plastic wrap to keep the glue off the cauls.



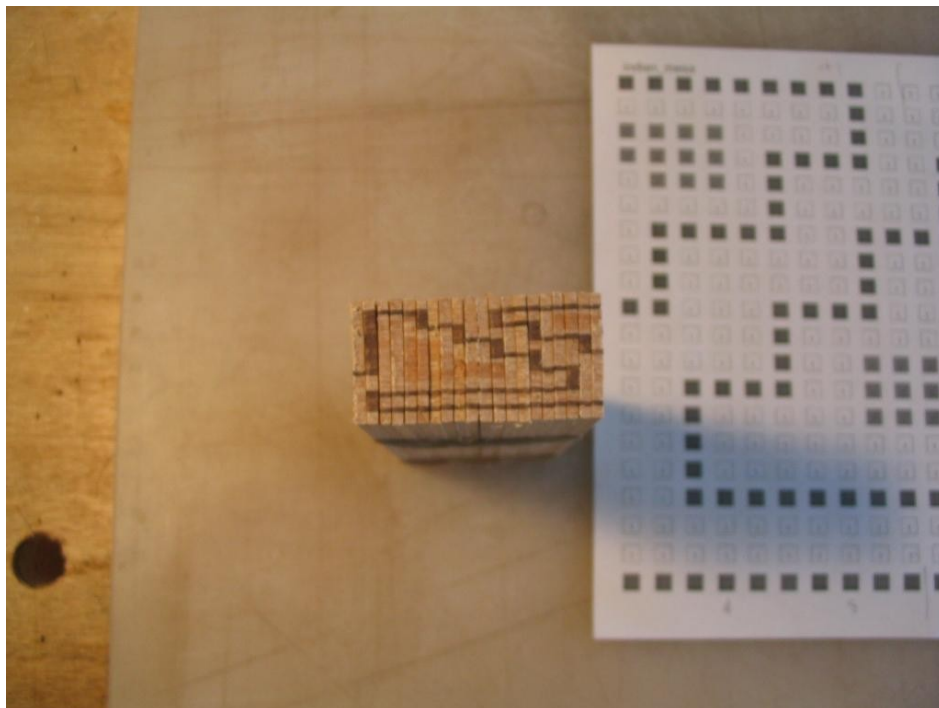
When the column logs have been glued up, their edges are squared up. The edge of each log should show the sequence of colors in the corresponding column.



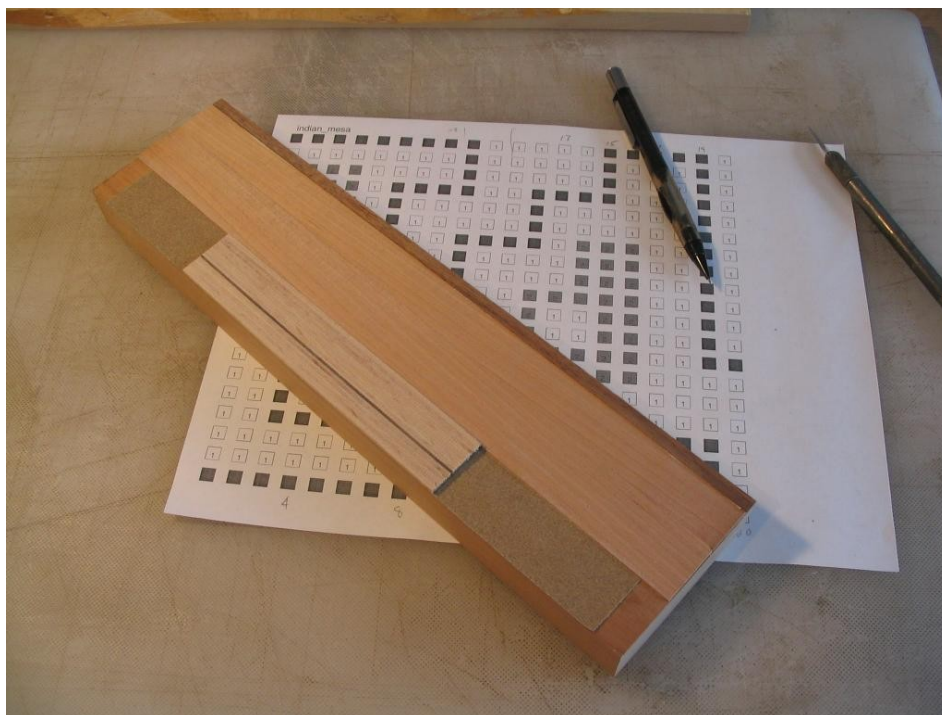
A column is now sliced off of the edge of each column log. The thickness of the slices determines the resulting width of the tile log.



After sawing, the columns can be placed together to see the tile pattern in the end view.



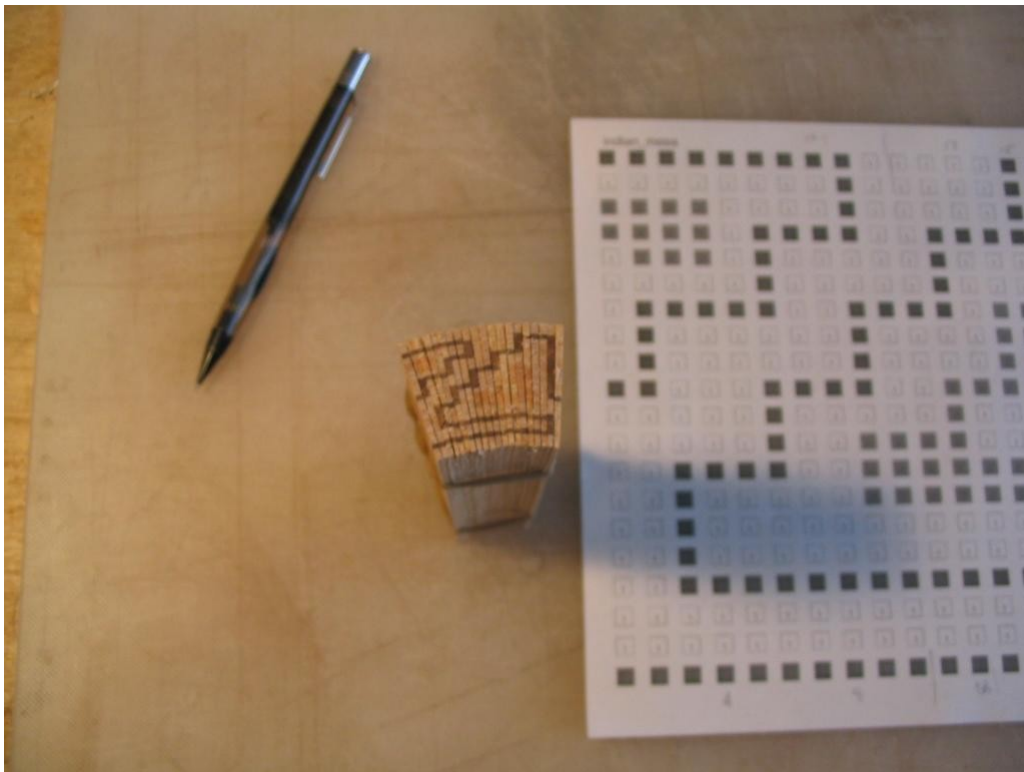
Before being glued together, however, the column slabs have to be tapered, so the resulting tile log and tiles will be tapered and will form a circle when glued together to form the rosette. The columns are tapered by placing them in a carriage tapered side-to-side and run through the thickness sander. The columns must be tapered at exactly the right angle so that the tiles sliced from the tile log will have the correct angle to form a circle of the desired radius. However, the angle that must be used depends on the final thickness of the columns. (More on this later.) In the photograph, the carriage has a side-to-side taper of .020" per inch; this isn't detectable in the photo.



The carriage with the column slab on top is then run through the thickness sander.



After tapering, the column slabs should form a tapered column log.



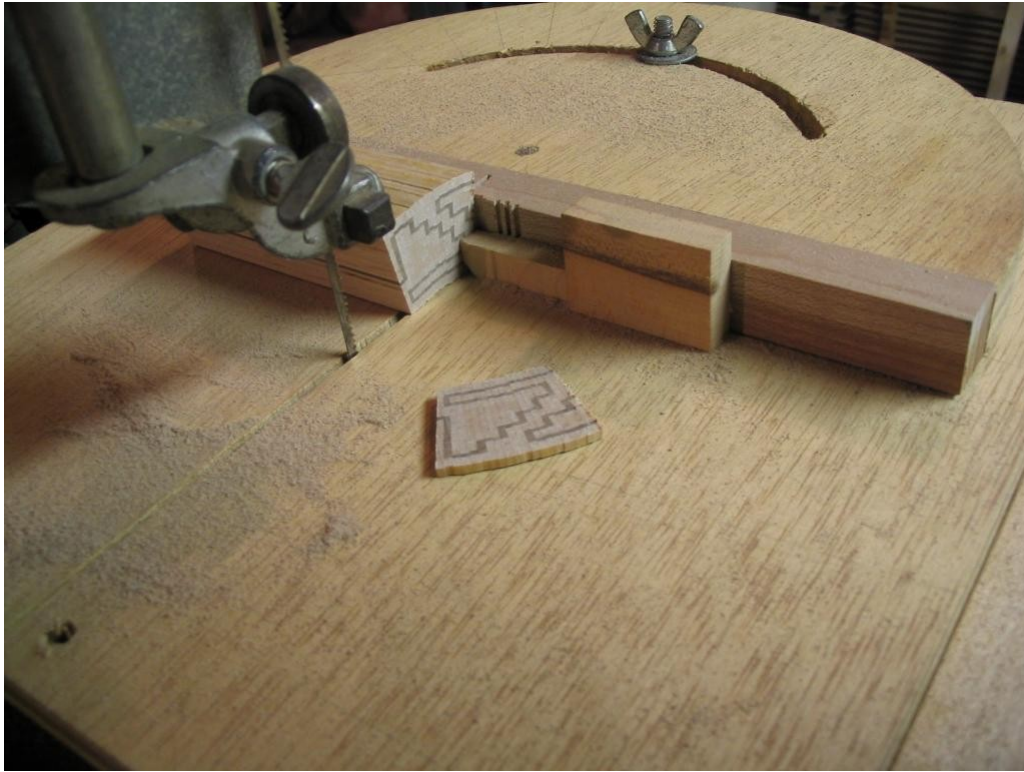
The column slabs can now be glued up to form the tile log. To make sure they stay aligned, the column slabs should be glued together one at a time. One complication is that since the column slabs are tapered, they're difficult to clamp. A handy jig consists of two clamping cauls attached at one end to a hinge. These will apply clamping pressure evenly to the tapered tile log as successive column slabs are added. To keep the slabs from being squeezed out of the caul, plywood "stops" are attached that hold them at the correct radius in the jig.



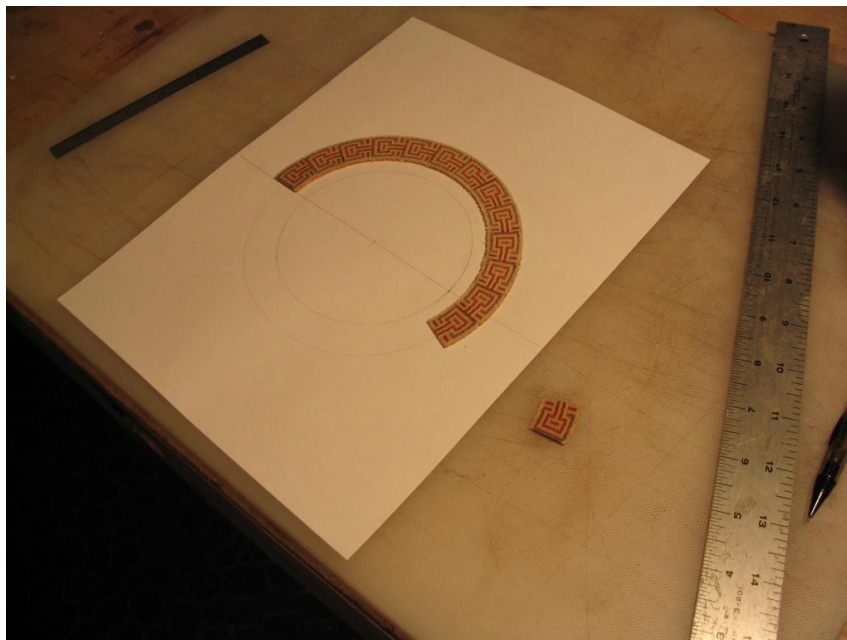
You can see in the photograph below that I didn't do a very good job of lining up the columns; in fact, this log was scrapped as a result... :-)



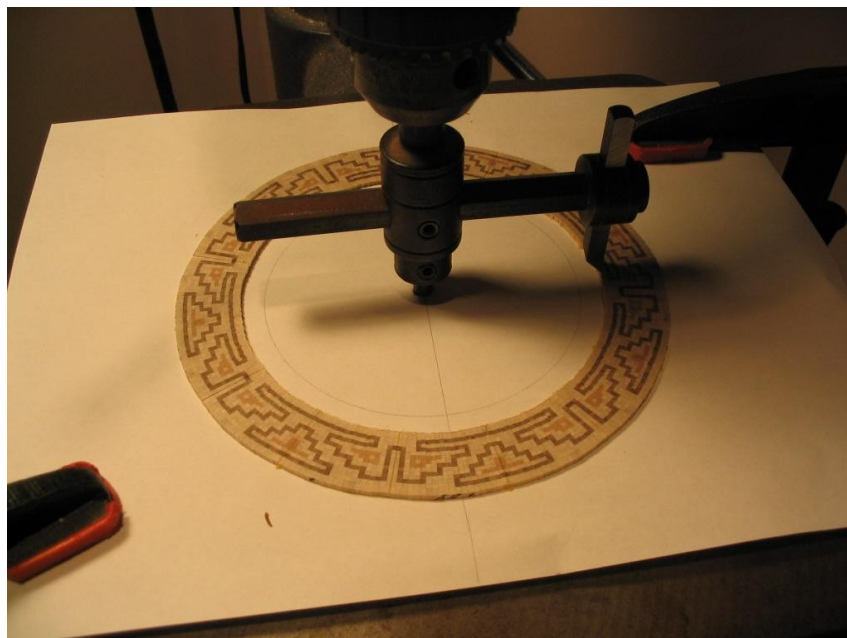
When all of the column slabs have been glued on, tiles can be sliced off the end of the tile log. I use a carriage on the bandsaw with a very thin blade.



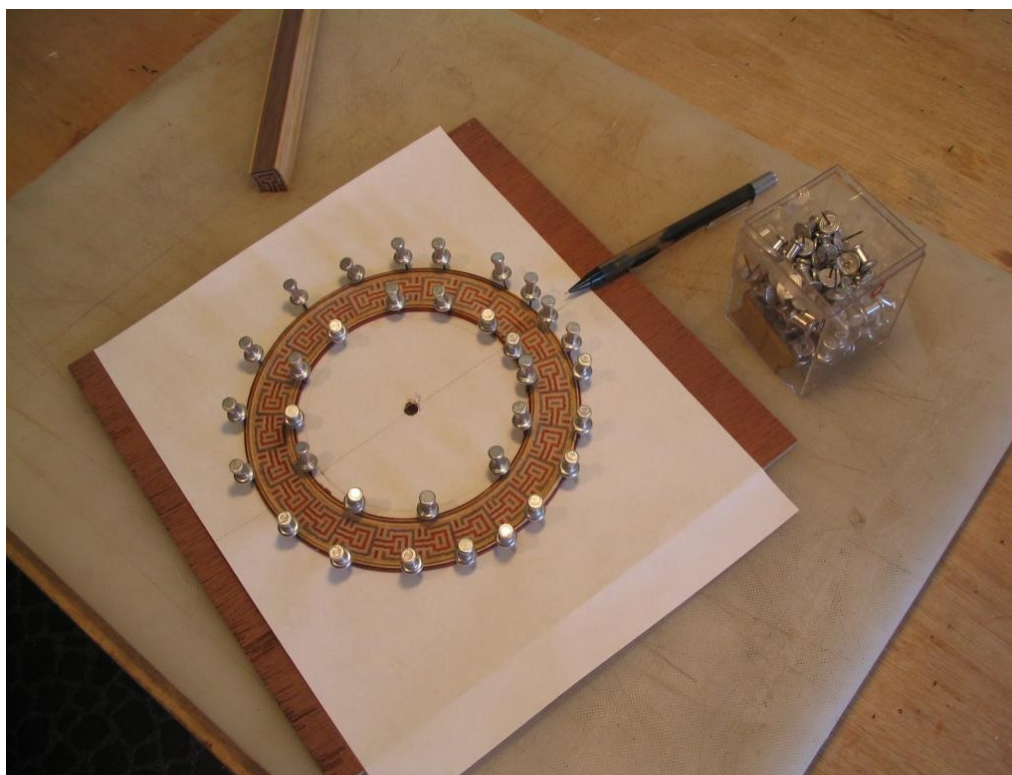
The cut tiles can now be glued into a circular rosette. A circle is traced onto a piece of paper that is used to assure that the tiles form a circle of the correct radius as they are glued together, rather than a spiral. I generally shoot for the inner radius of the rosette being 1/8" to 1/4" greater than the radius of the soundhole, after all the banding is glued onto the mosaic rosette. The rosette tiles are glued edge-to-edge with Titebond, and when they're pressed together the glue secures the tiles to the paper. (Note that the photograph below is from a different rosette than the one the tiles above are for.) There will likely be a need to use a partial tile to fill the last gap to close the circle. Since this part of the rosette will be covered by the fingerboard, the lack of pattern match where the partial tile joins the first tile won't be visible.



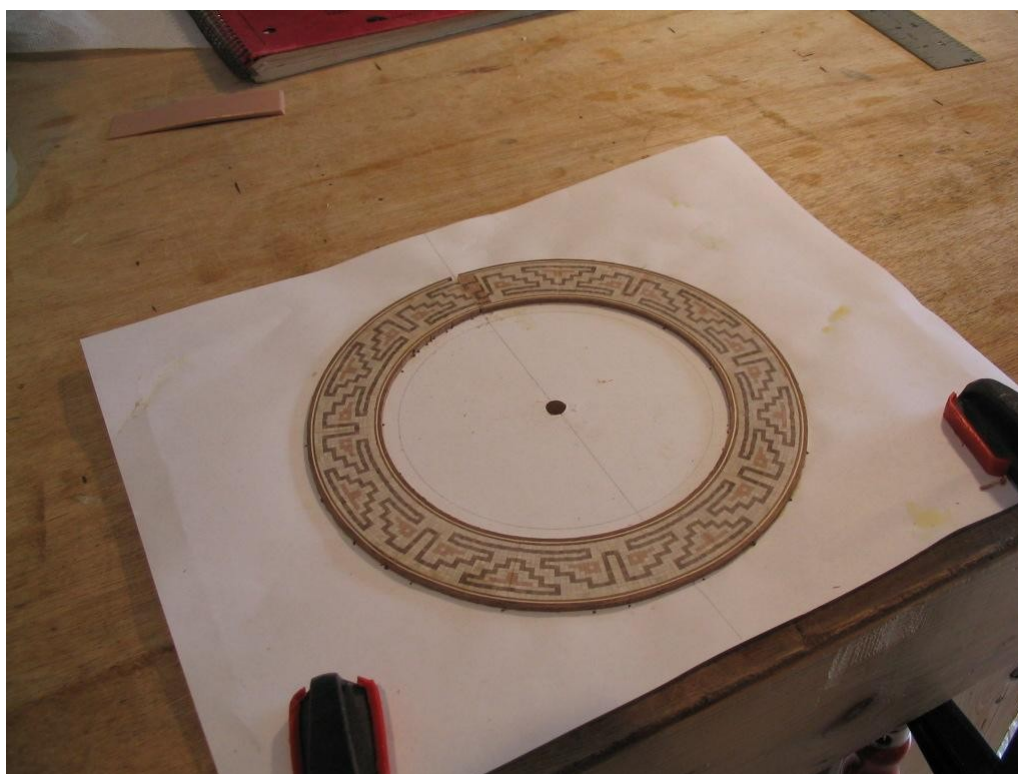
When the rosette is completed, the paper that the rosette is attached to is glued to a workboard of 1/4" plywood. A 1/4" hole is drilled at the position of the center of the rosette circle, to be used to guide a flycutter to trim the inner and outer radii of the rosette. The photo below shows the rosette workboard clamped to the drill press table, with the flycutter set to trim the inner radius.



Banding is now glued to the inner and outer radii of the mosaic rosette. I generally use several alternating dark and light veneer strips, with a final thicker strip on the inside and outside. Push pins are used to secure the banding strips. The ends of the banding strips are positioned at the partial tile that closed the rosette; since this will be under the fingerboard, the ends of the banding strips don't need to meet exactly.



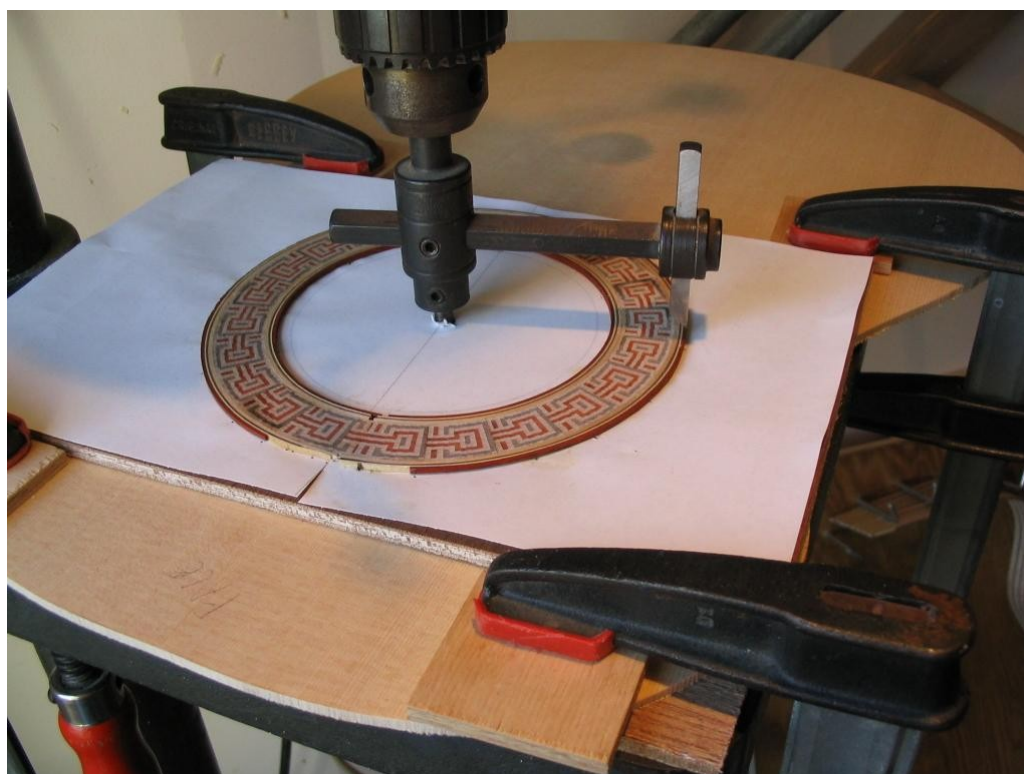
When the banding glue has dried, the banding can be planed so it is flush with the top surface of the rosette.



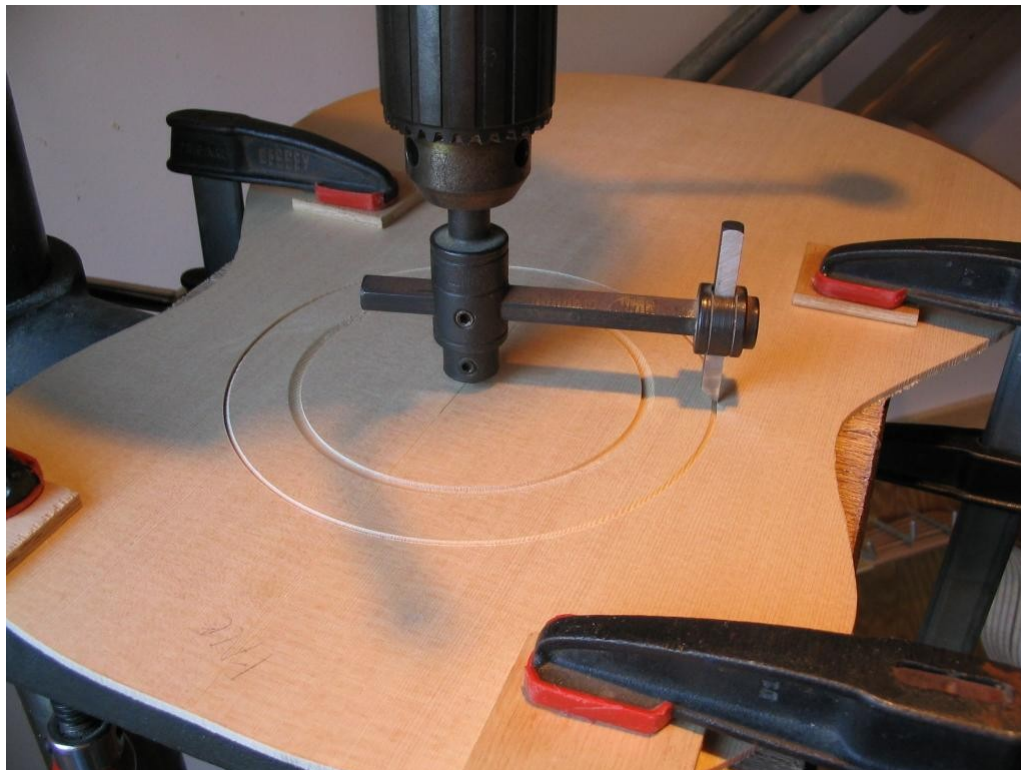
Chapter 3 - Inlaying the Rosette

The rosette is inlaid by cutting a groove in the guitar top that exactly fits the assembled rosette, and then gluing the rosette into the groove with epoxy. The outer and inner edges of the groove are cut with a flycutter on the drill press. The principal trick is in getting the size of the groove so that the rosette fits perfectly. This is done by setting the flycutter directly from the rosette. The rosette, still glued to its building board, is placed on the drill press. Since the flycutter was used to cut the inner and outer edges of the rosette (before the rosette banding was glued on), the 1/4" guide hole for the flycutter is used to center the building board on the drill press. The flycutter diameter can then be set from the rosette, as illustrated.

Note that a flycutter is an inherently dangerous tool - it's a fairly heavy, unbalanced mass of rotating steel. Be sure to protect yourself when using it. I wear a complete facemask protector; I've even heard of someone putting a phone book into his shirt as a chest protector. Always use the flycutter at the slowest speed available on the drill press, to minimize the centrifugal forces. And because it's so unbalanced, don't even think about using one in a hand drill!

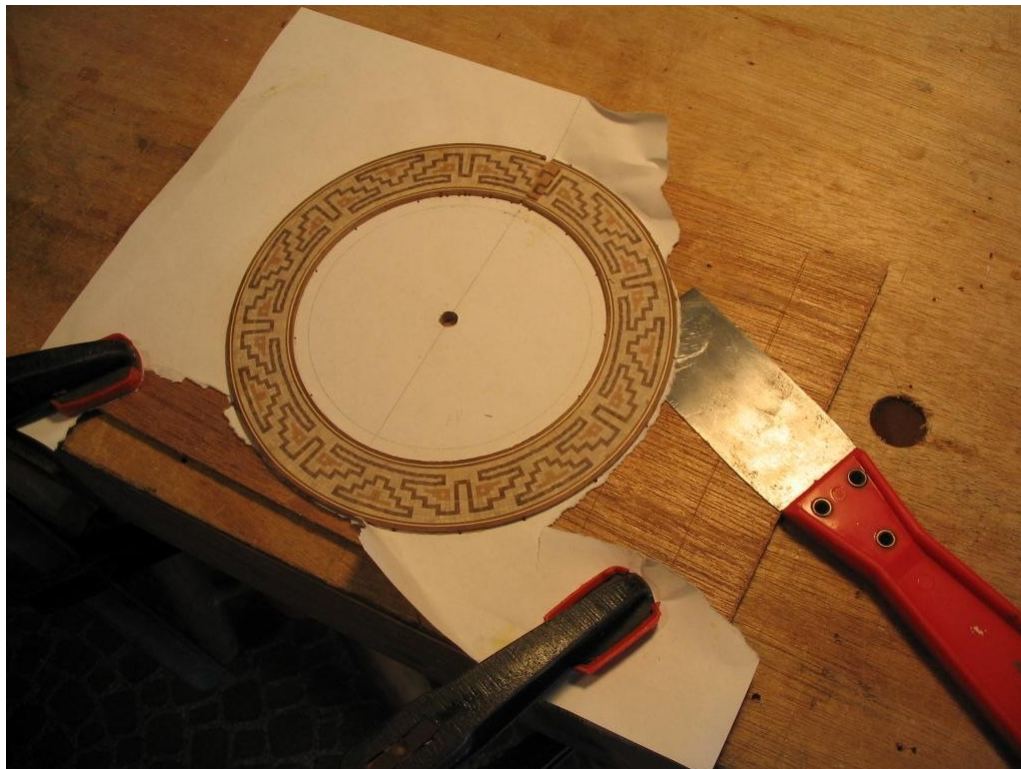


Note that in the photograph, the rosette building board is placed directly on the guitar top into which the groove will be cut, for convenience. The cutter diameter is set, and the rosette building board is removed. The depth of cut of the flycutter is set to be a little less than the thickness of the rosette, so that the rosette will sit a little proud when glued. The excess can then be scraped off, leaving the rosette flush with the top. The next photo shows the grooves cut in the guitar top. Note that the soundhole is not cut until after the rosette has been glued and scraped.



After the inner and outer radii have been cut with the flycutter, the remainder of the material in the groove can be removed with a router, with the depth set appropriately. The groove can then be cleaned up with a chisel.

The rosette should now be removed from the building board. Since it was glued onto the board with a sheet of paper in between, the rosette can be relatively easily removed by sliding a thin blade between the rosette and board - the paper will split fairly easily.



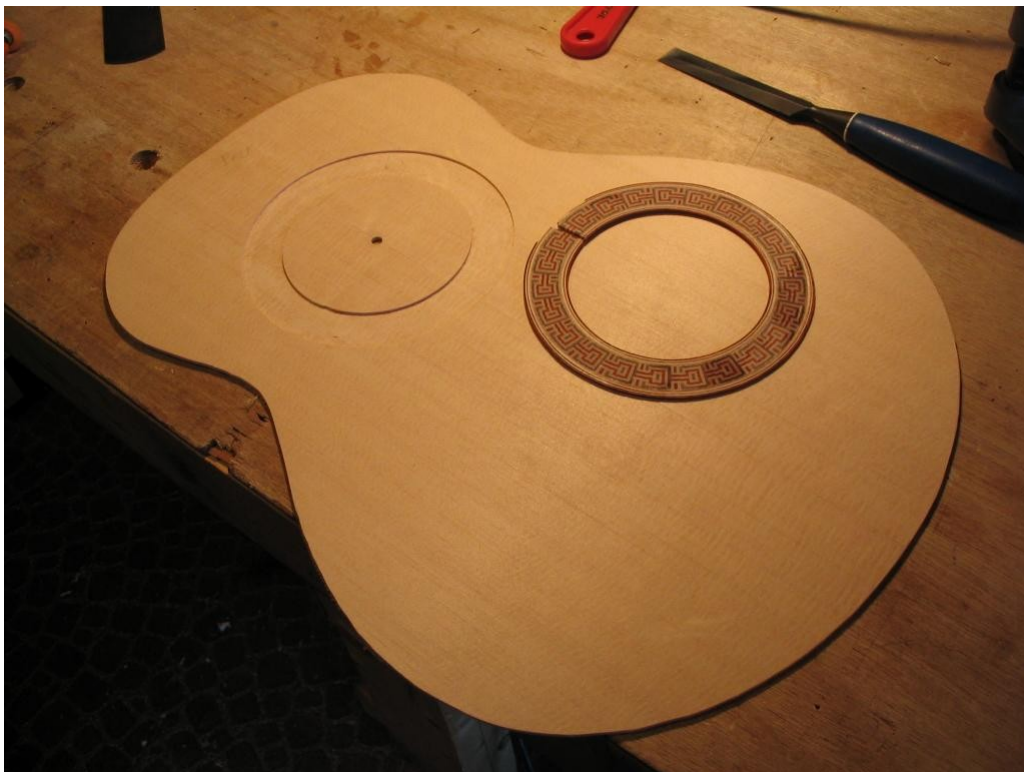
The paper that remains on the rosette can be removed with a scraper.



The inner and outer edge of the rosette banding should have their edges chamfered (beveled) slightly so the rosette can be pressed into the groove. The rosette ring should now be cut to permit easier gluing into the groove in the top.



The groove in the guitar top and rosette are shown in the next photo.



In preparation for gluing, the groove is next sprayed with a couple coats of shellac. The purpose of the shellac is to seal the end-grain on the edges of the groove near the centerline of the top. If this isn't done, the epoxy used to glue the rosette will wick into the endgrain, discoloring the spruce near the soundhole. You don't have to be careful when spraying the shellac, as the overspray on the top will disappear during finishing. (However, if you don't use the shellac, the epoxy staining doesn't disappear even under the finish - discovered this the hard way...)

Why not use Titebond instead of epoxy? Wouldn't this eliminate the problem of the glue staining the top through the endgrain? Well, yes, but the problem is that the rosette is itself mostly endgrain. If yellow glue is used, the tiles in the rosette tend to expand due to the moisture in the glue, warping the rosette and even the top.

The groove can now be coated with epoxy - either 5 minute or longer cure time will work fine - and the rosette pressed into the groove. The top is placed on a flat workboard, a piece of plastic wrap is placed over the rosette, and a piece of 3/8" or 1/2" thick Plexiglas is placed on this as a clamping caul. The rosette is then clamped and left for the glue to cure, as in the next photo. The plastic wrap keeps the epoxy from sticking to the Plexiglas caul.



When the glue has cured, the clamps and caul can be removed. You can see in the photo below the shellac overspray and the epoxy squeeze-out.



The rosette rises a little above the surface of the top; this is next scraped flush (along with the epoxy squeeze-out).



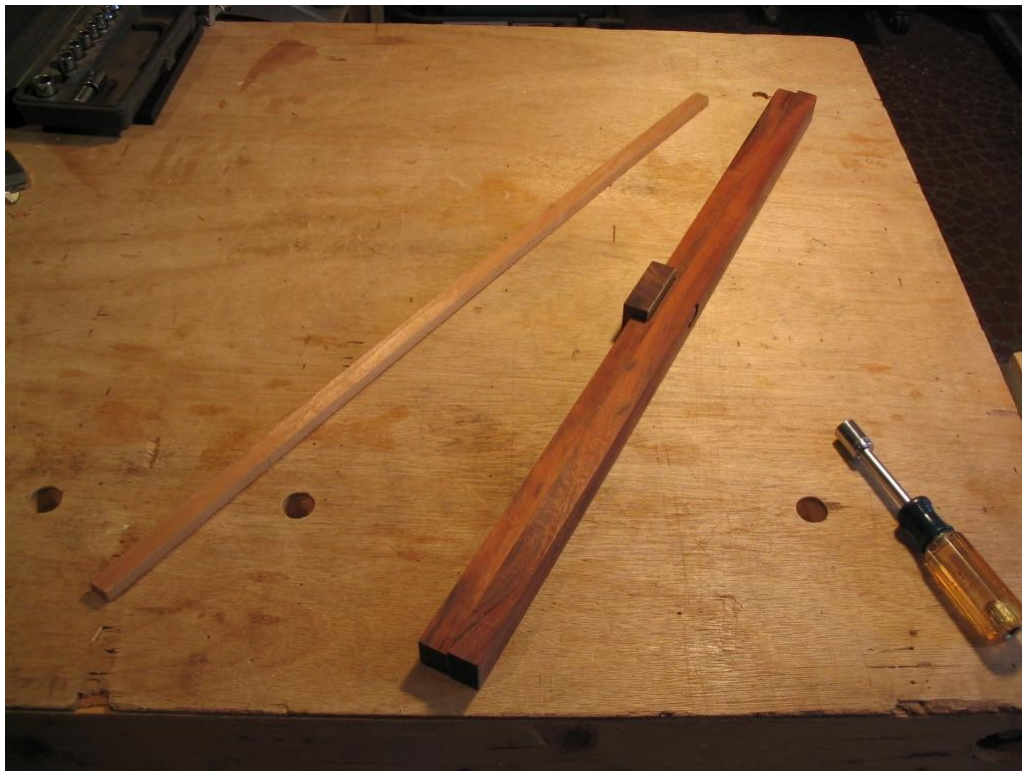
After the rosette has been scraped flush, the soundhole can be cut with the flycutter on the drill press.



Chapter 4 - Arching the Braces

The tops of most high-quality "flat-top" steel-string acoustic guitars built today are not really flat. The top is arched slightly, bulging outward. This arching serves a number of purposes; an article about it can be found at http://edge.cs.drexel.edu/GICL/people/sevy/luthierie/workboards/Arched_Workboards.html.

In order to build a guitar with a slightly arched top, we need to arch the braces that will be glued to the underside of the top. This is easily done with the nifty jig pictured below. The jig clamps a brace into a desired arch, but in reverse - it clamps the brace into a concave arch, with the ends higher than the middle. The concave top surface of the brace is then planed flat; when the brace is released from the jig, the brace springs back so the bottom surface becomes flat again, and the top surface, which was planed flat while the brace was bent, becomes a smooth convex arch.



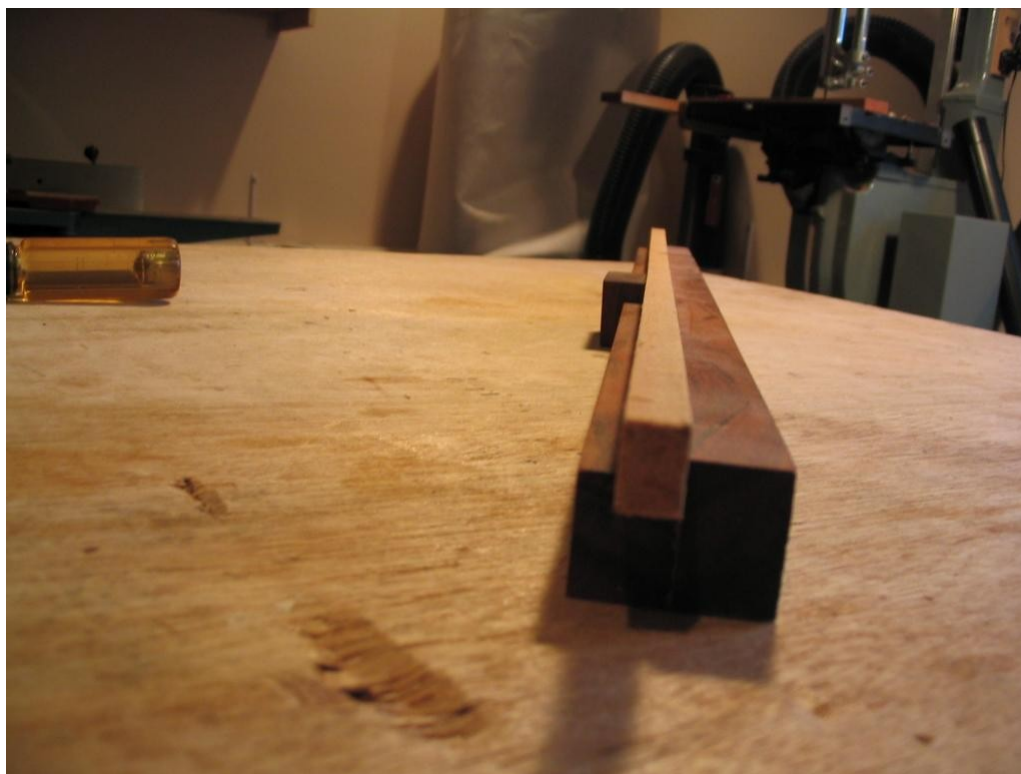
The jig consists of a movable jaw that clamps the brace in position by squeezing its sides - this way the top surface is open for planing. The jaw has sandpaper glued to the face to provide extra gripping power.



In the photo below, a spruce brace is shown clamped in the jig. The brace is pressed down so it contacts the curved bottom surface of the jig, and then the jaw is tightened to hold it down.



The photo below shows an end view with the brace clamped in position. This shows the concave top surface of the brace.



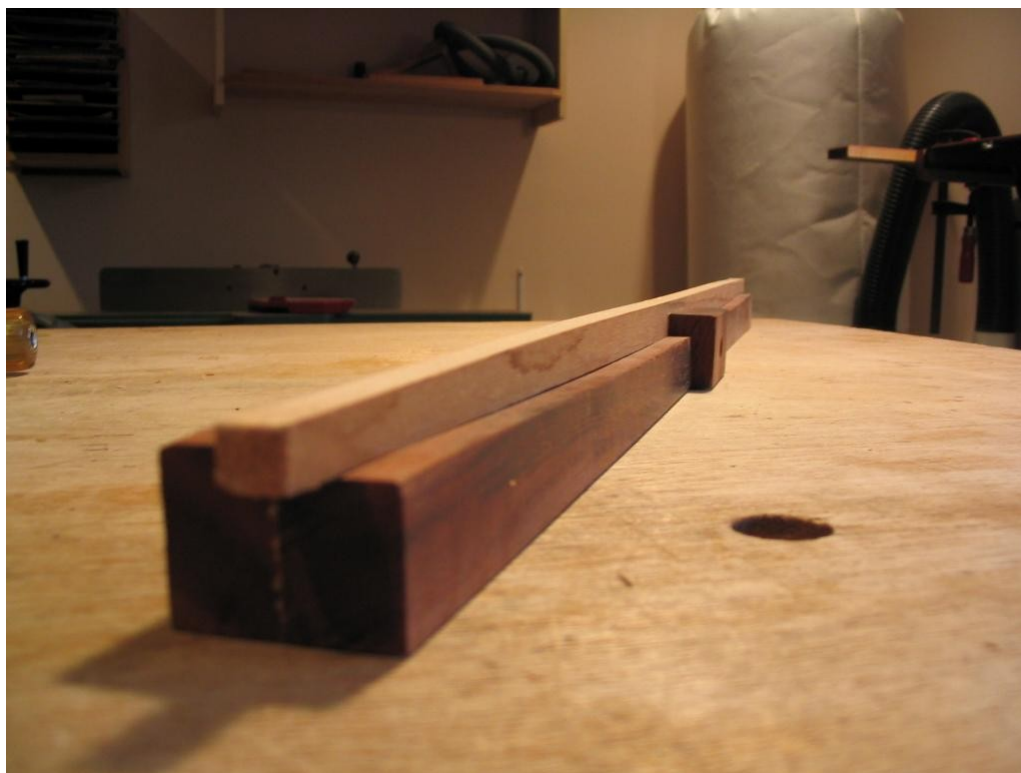
The top surface of the brace is now flattened. The brace clamped to the jig is first run through the bandsaw, to saw the top of the brace flat...



... and the jig is then run through the planer to smooth the top surface of the brace.



The photo below shows the jig after planing with the brace still clamped in position. Notice that the top surface of the brace is flat.



When the brace is removed from the jig, it springs back, and the top surface becomes the desired convex arch.



Chapter 5 - Bracing the Top

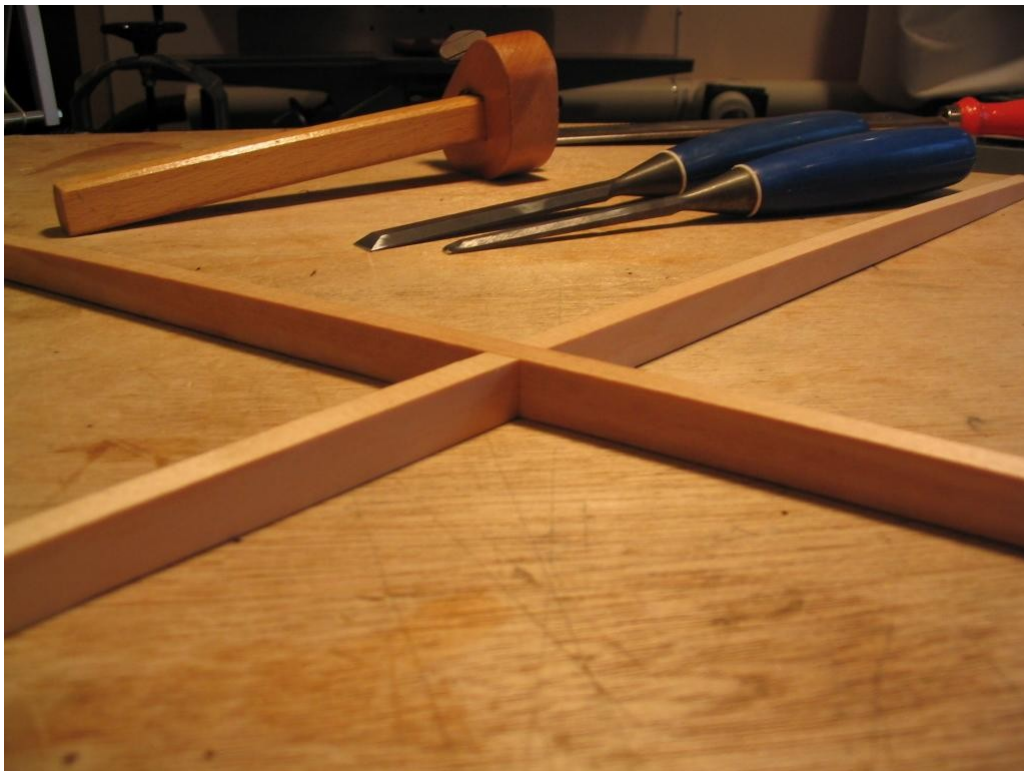
The top has braces glued on the underside, both to give the top extra strength - the "X" brace and upper-bout struts - and to improve the tone of the resulting instrument. The photo below shows the underside of the top with the position of the X brace and upper bout cross brace lightly marked in pencil.



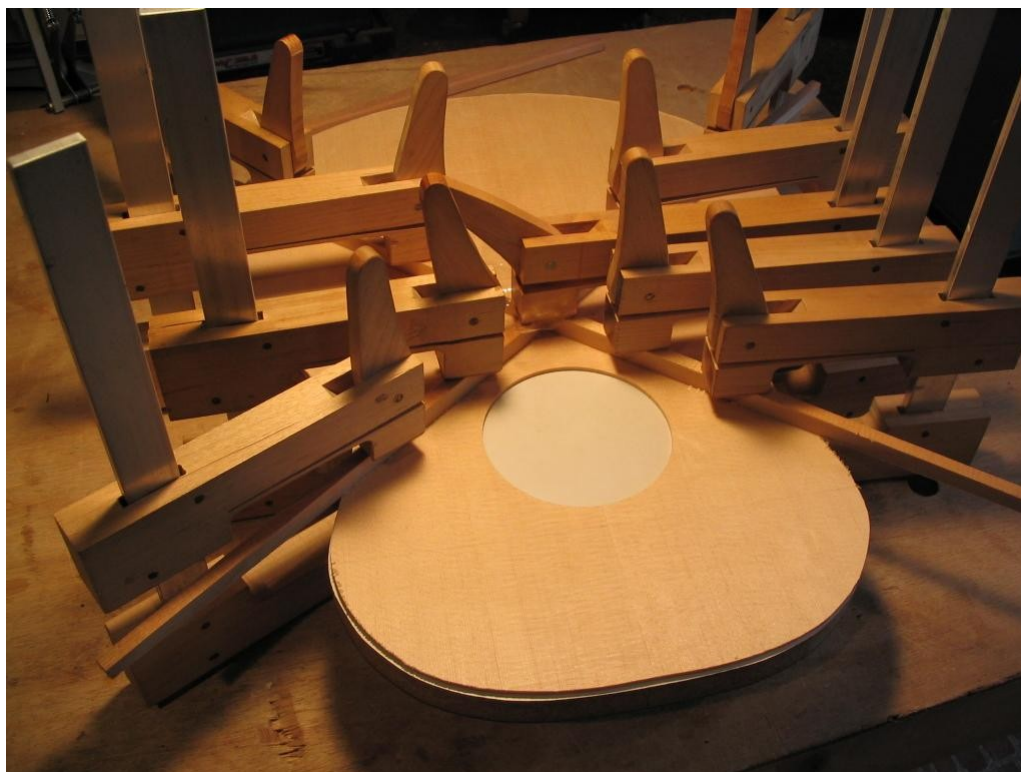
The X brace legs must have the lap joint cut before gluing; the joint is marked using an angle gauge since the braces don't meet at a right angle. The joint is then cut in each leg with a dovetail saw, and then pared with a chisel to get a tight fit. (If you're good with the saw, paring may be unnecessary, but make sure to get a tight joint.)



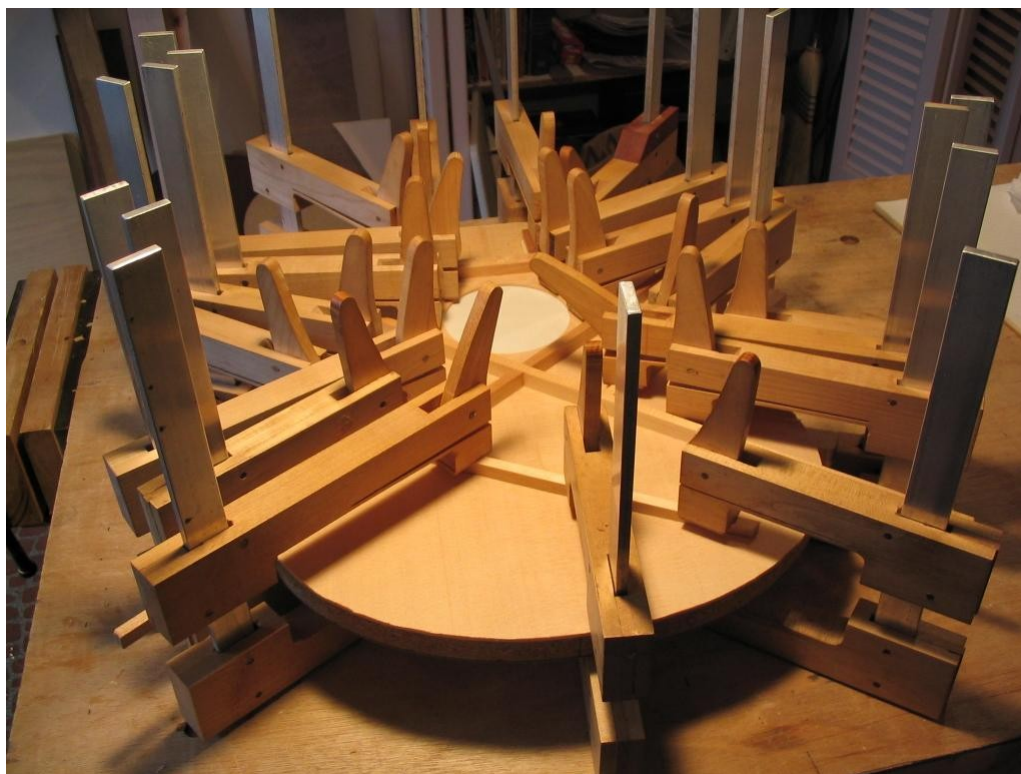
The photo below shows the completed X brace, with joints cut. The legs are glued together when the brace is glued to the top. Notice how the top surface (which will be glued down to the top) is arched.



The X brace is being glued to the top, below. Glue has been applied to the joint faces as well as the brace surfaces. The top is placed on an arched workboard whose arching matches that of the braces. [Here's an article on how to make such an arched workboard.](#)



The photo below shows additional braces being glued to the top.



Below, the bridge plate is being glued (this one is .100", made of dogwood).

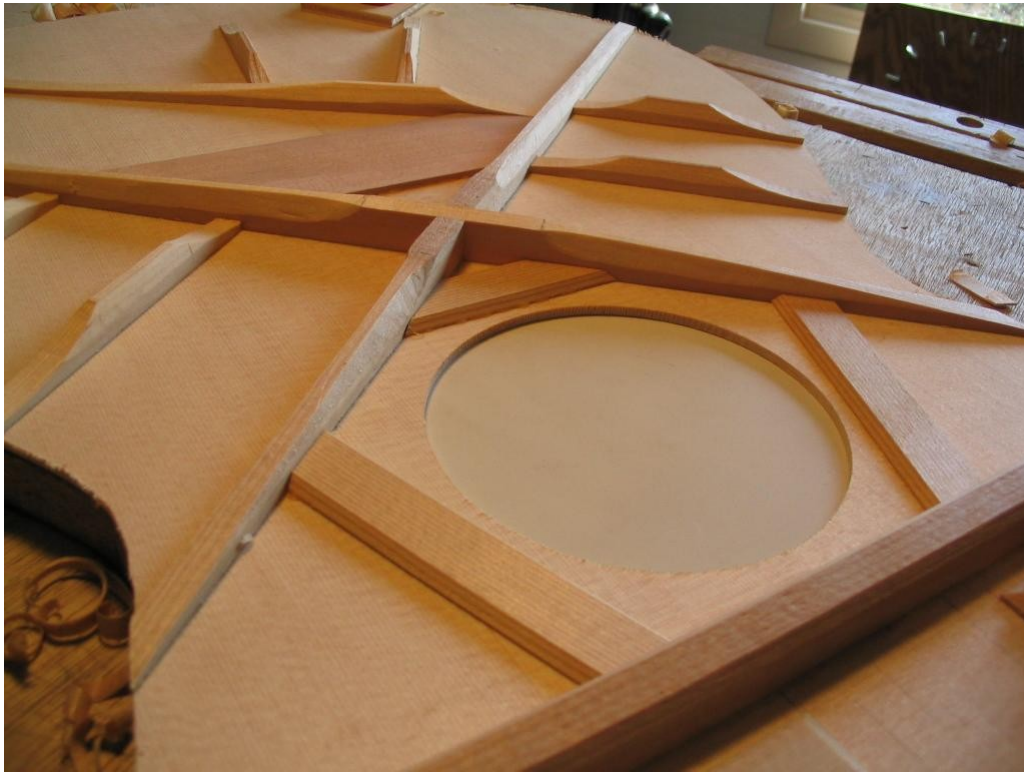


The top with all braces glued, but unshaped, is shown below.



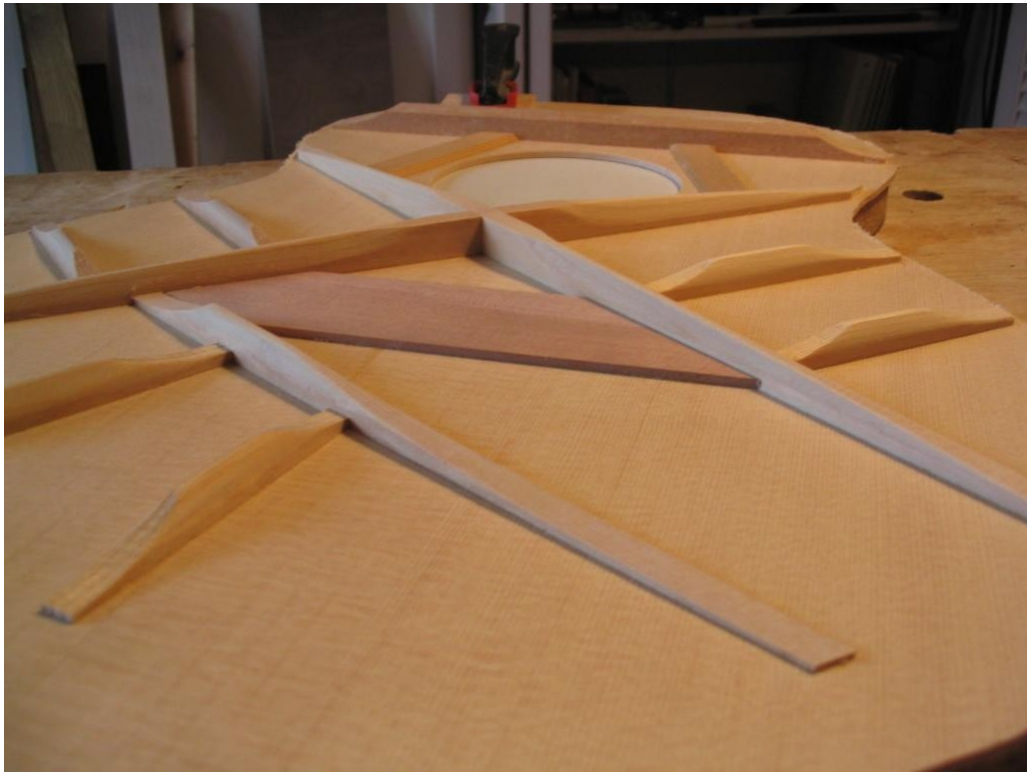
The next few photos show the braces after rough shaping with a sharp chisel. Note the tapering on the braces; they're tapered to a thickness of approximately .090" at the ends, and are tapered bottom to top.





After rough shaping, the braces are sanded to smooth the surfaces. The result is shown in the photos below. Note that the ends of the braces have been trimmed where they meet the periphery; they're trimmed to within the thickness of the sides from the edge.





Chapter 6 - Bending and Joining the Sides

There are two basic approaches to bending the sides of a guitar. The traditional approach is "hot pipe" bending. In this method, the sides are bent by hand over a cylindrical pipe ("bending iron") that's heated with a propane torch or an electric heater. The illustrations below show the front and back view of my bending iron, which is a piece of 4" iron pipe in an L-shaped wooden holder. A propane torch sits in the cradles on the wooden ledge and heats the inside of the pipe. (Not shown is an aluminum baffle that fits in the front of the pipe and keeps the torch from roasting my navel when I'm bending...) Notice the nifty asbestos washers insulating the "tabs" of the pipe where they bolt to the wooden holder.



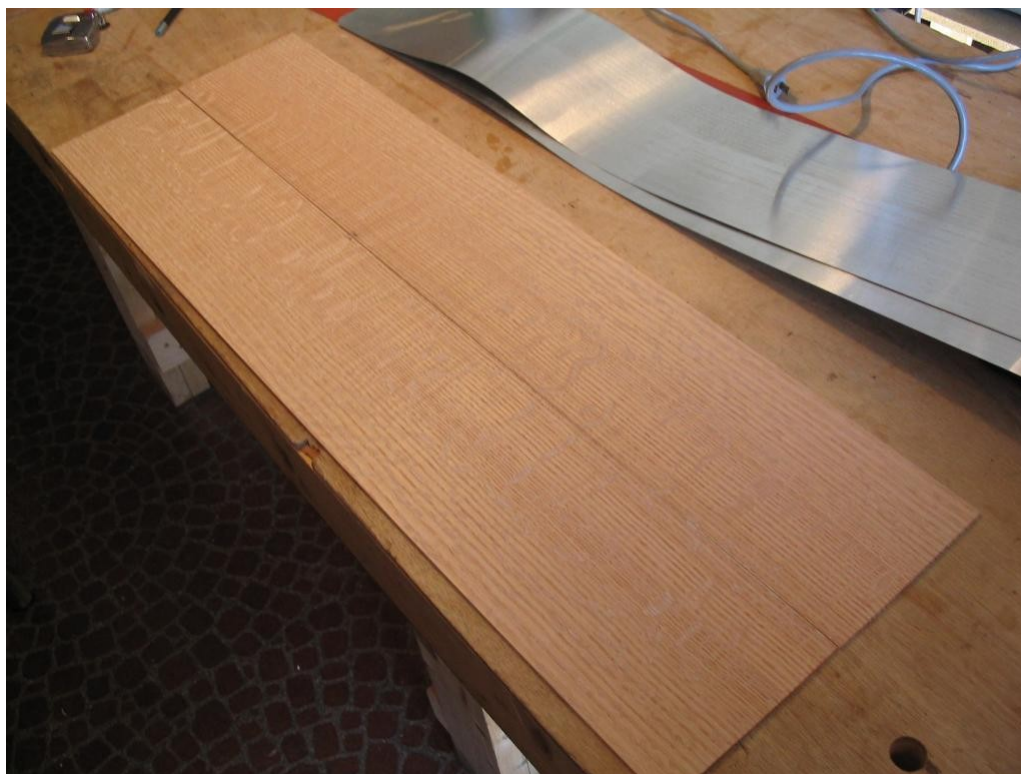
The sides are dampened, mostly to keep them from charring, and are then pressed onto the hot pipe. When the wood reaches the right temperature, it actually becomes plastic; rather than springing back when it's bent, it "gives", and holds the bend after it cools. (My guess is that the resins in the wood soften at a high enough temperature, allowing the cells to slide past one another as the wood bends; when the wood cools, the cells hold the new position, and the wood retains the bend. Probably has no basis in fact, though...). The sides are bent about 6" at a time, starting at the waist, and checking the profile against a template to make sure the profile's right. While this is a very effective and fun way to bend the sides - especially in winter, with the heat from the pipe and the aroma of hot wood - it takes a good bit of experience to bend the wood to the correct profile, without any unsightly "lumps".

I've since switched to a simpler, more accurate method for bending the sides, using a guitar-shaped form and a silicone heating blanket. The form provides the shape and the silicone blanket provides the heat. A blanket of the correct size (36" long by 6" wide) can be purchased from lutherie supply houses like the Luthier's Mercantile. These blankets are thin (1/16" thick) silicone with resistance wires embedded inside that act as heating coils, and a cord that gets plugged into an ordinary electric socket. They heat rapidly, and can generate extremely high temperatures - hot enough for wood to burn!!! Thus, never leave one of these unattended when it's plugged in. In fact, to keep the temperature down, I unplug the cord periodically while bending; there are also heater control units that allow you to adjust the maximum temperature that the blanket will reach.

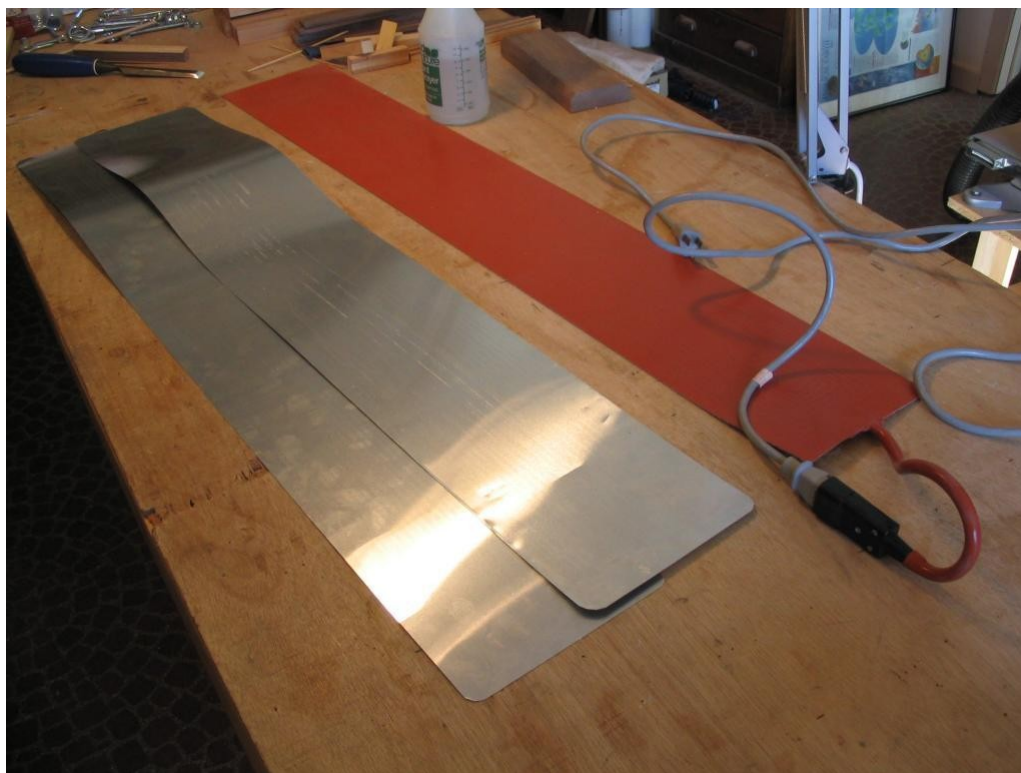
The photo below shows the bending form. This is built from two plywood sides cut to the exact profile of the inside of the side profile - i.e., it's the body profile inset by the thickness of the sides. The sides are joined by 1/2" aluminum rods spaced every 2" or so along the perimeter. The purpose of the eye hooks will become apparent during the bending operation - they're used to secure clamping cauls that hold the sides in the mold while they cool. The red silicone blanket can be seen in the background.



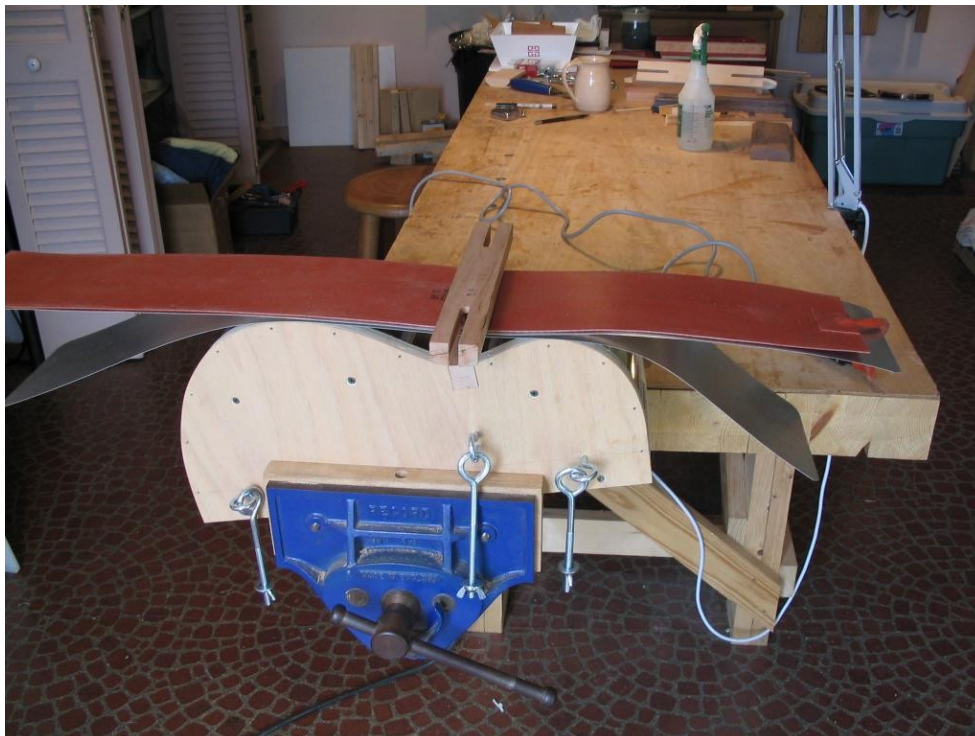
The sides before bending are shown below, next to two aluminum sheets that will sandwich each side as it is bent. Notice that the sides have been marked at the waist to position them on the form.



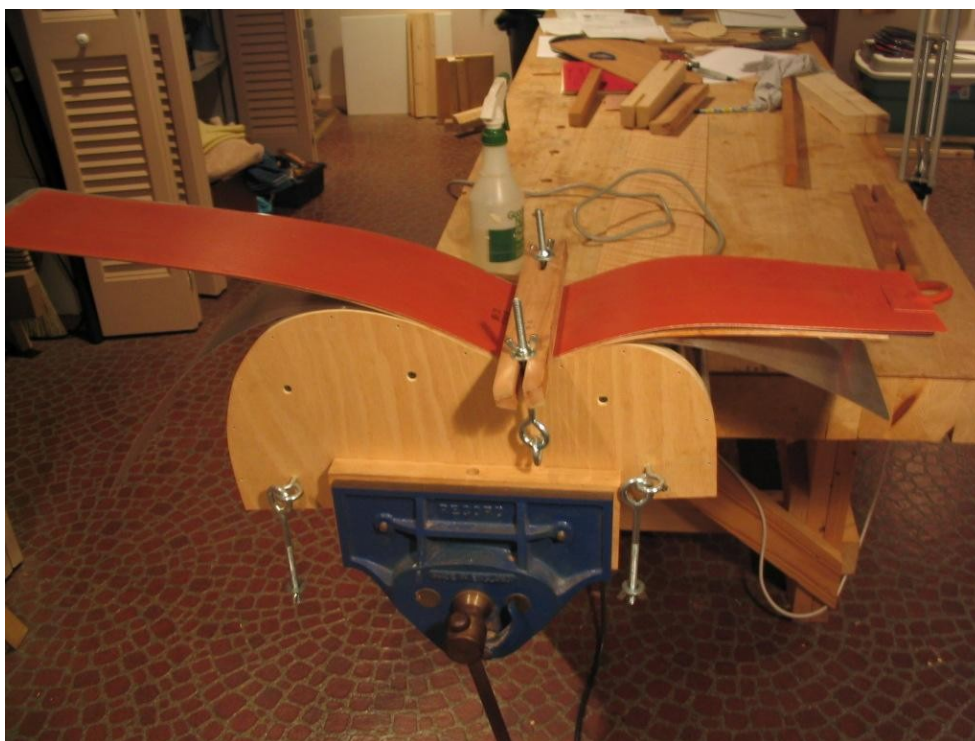
The aluminum sandwiching sheets and silicone blanket are shown below.



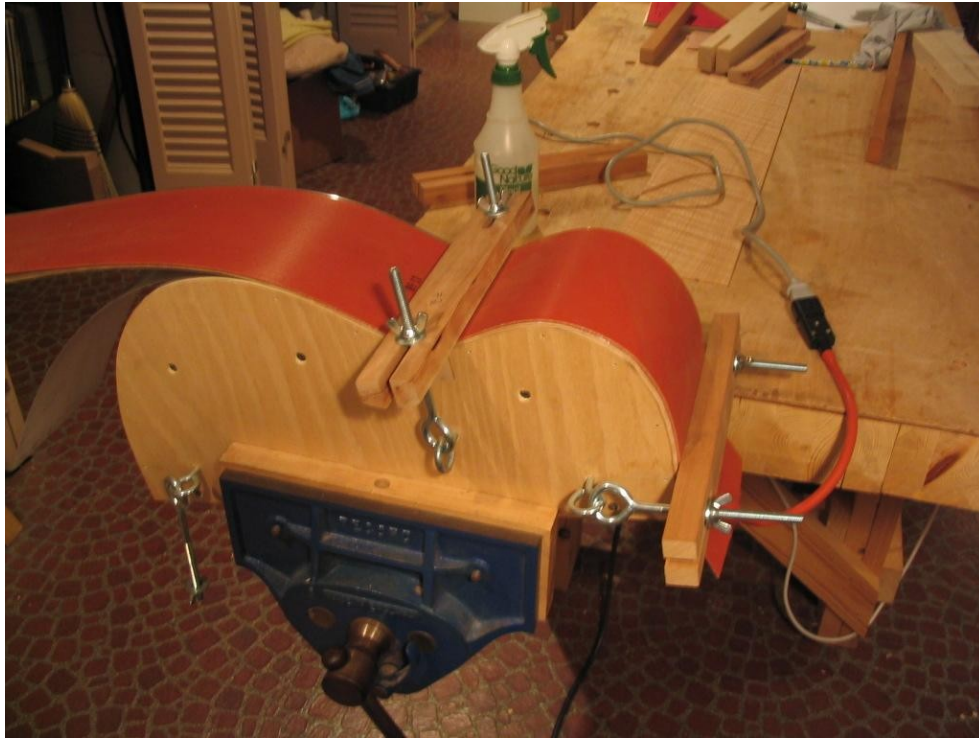
The side to be bent is first wetted thoroughly - I put it in the shower for a few moments - and then placed between the aluminum sheets. The silicone blanket is placed on top, and the whole assembly is set atop the form with the waist marking positioned above the waist in the form. The waist clamping caul is placed on top, and the silicone blanket is plugged in to start the heating.



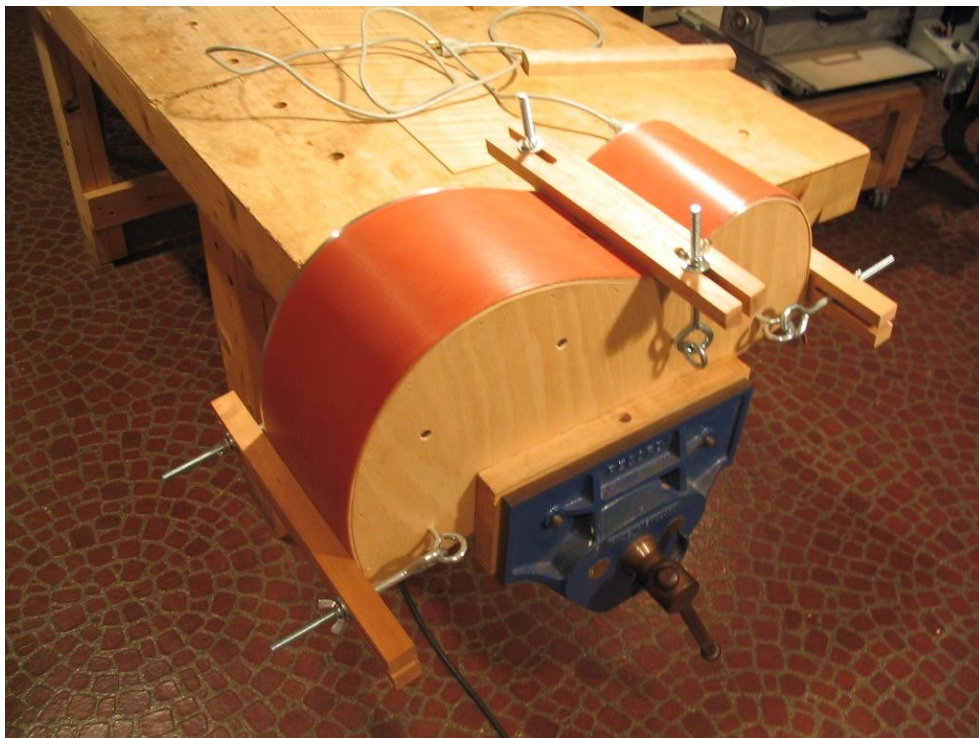
Pressure is applied to the waist caul; when the wood has heated to a high enough temperature, it will "give", and bend down toward the form. At some point it will be possible to bring the eye hooks up and slide them into the slots in the caul. The wing nuts can then be used to snug the side down against the form.



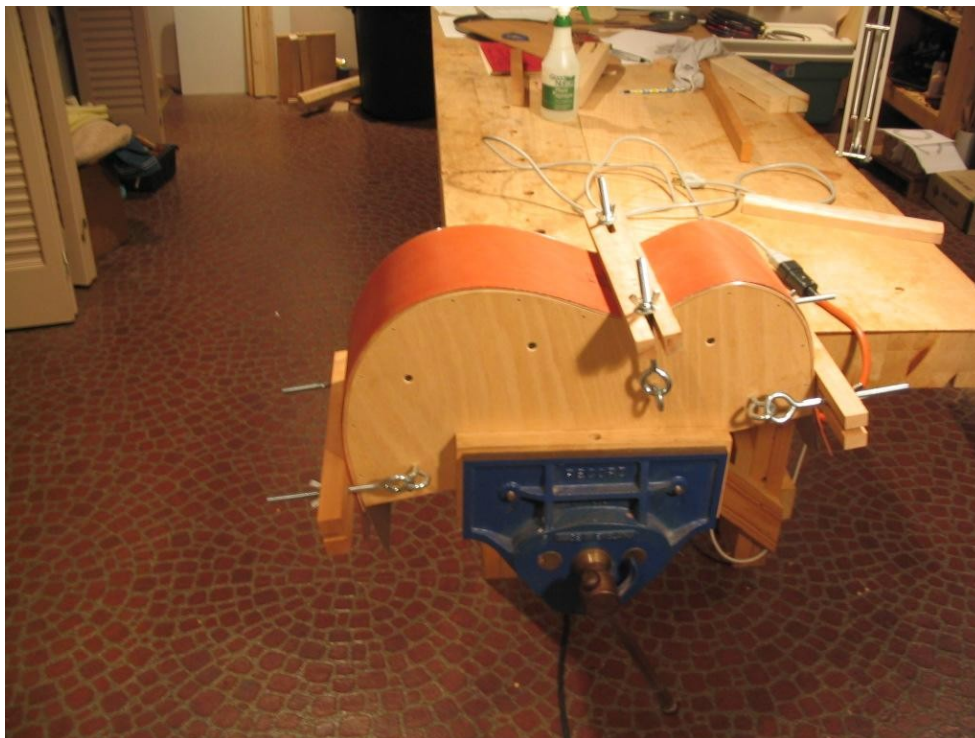
The head caul can now be used to press the upper bout down against the form. Again, the side will be felt to "give", and slowly bend down to the form. The eye hooks can be slid into the caul's slots, and the wing nuts can snug the side to the form.



Finally, the same can be done for the lower bout. The resulting bent side can be seen below, clamped against the form. I leave the side in the form for 30 minutes or so, periodically plugging and unplugging the blanket for the first 5 minutes after clamping to keep the sides hot, to "set" the bend, and then letting the side cool for the remaining time



It will almost certainly be necessary to unplug the blanket at times during this operation; otherwise, it can get hot enough to char the sides. Also, I've found that the heat from the blanket can dry out the lower bout while the waist and upper bout are being bent down to the form. I use the water bottle shown to spray the side to moisten it if it has dried out.



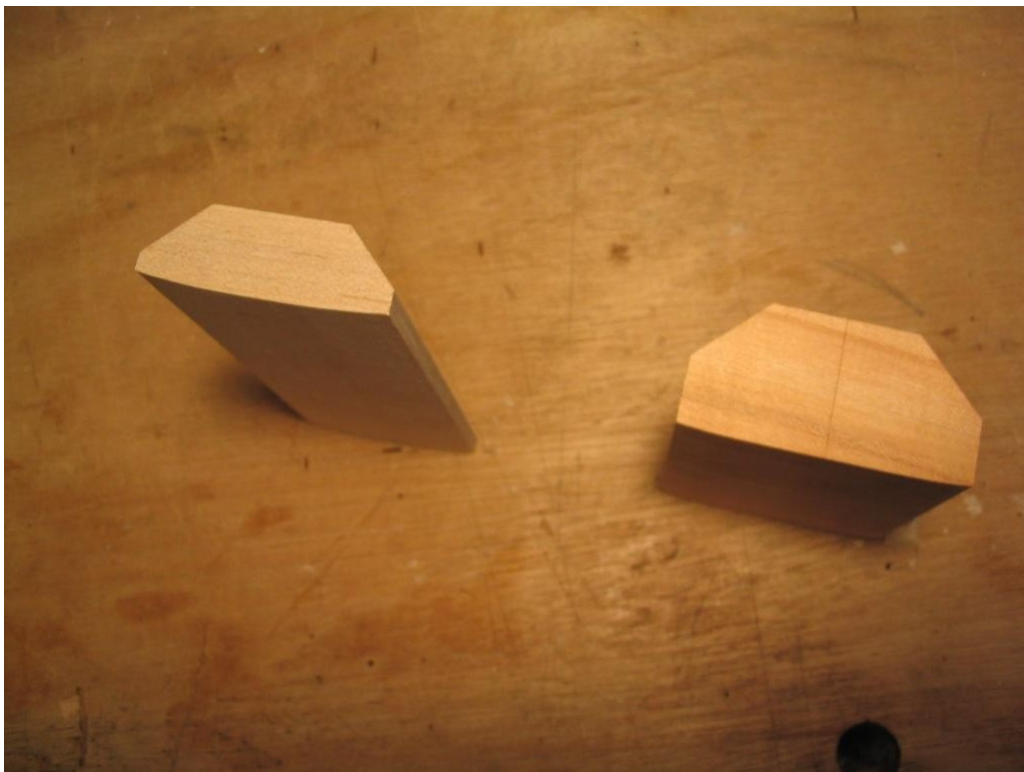
When both sides are bent, the sides can be joined to the end and neck blocks. The sides are first trimmed to the exact size at the head and tail. The sides are marked by placing them in the body gluing jig...



... cut on the bandsaw, and then trimmed with a handplane using the trimming jig shown below.



The end and neck blocks are curved on their faces to match the curvature of the sides at the neck and tail. Note that both are scribed on their centerlines on all four faces, to aid in aligning the sides when they're glued.

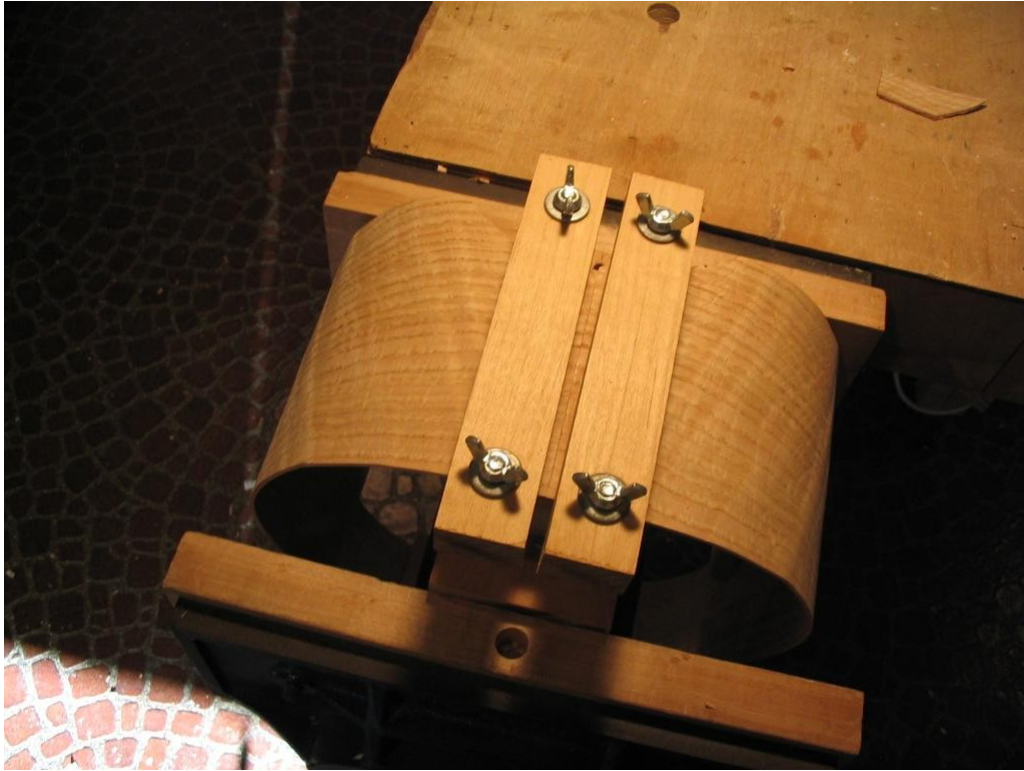


The sides can then be joined to the end and neck blocks. This uses the clamping jigs shown below, which consist of support blocks with a pair of clamping cauls secured with carriage bolts.



The end or neck block is placed on the support block (which is clamped in a vise), glue is applied, and each side is secured with a clamping caul, clamping it to the end/neck block.





When the sides have been joined to the end and neck blocks, the end binding strip can be inlaid. The tail is scribed to fit the binding strip, and the groove is cut.



The strip is then glued in place...



...and when dry, is scraped flush with the sides.



Chapter 7 - Joining the Top and the Sides

With the top braced and the sides glued to the end and neck blocks, the top is next glued to the sides. This requires that the profile of the sides - the edge where the sides will meet the top - be shaped appropriately. If the top were truly flat, this edge would itself be flat, which could be achieved by planing the top edge of the sides with a handplane. However, the top isn't flat - it's slightly arched. Because of this, the edge of the sides where they meet the top will be a slightly undulating curve.

The top edge of the sides can be scribed with a line indicating the correct profile using the arched workboard used to glue the braces onto the top. The arched workboard is placed within the jig used to support the top and sides while they are glued, and the sides are placed inside, with the top edge down. Because the edge of the sides is more or less flat, the sides will not sit flush on the arched workboard, but will touch only at the neck and tail block, as seen below.



A gauge is made from a small piece of thin wood, with a 1/16" hole drilled at a height a little greater than the maximum height the sides sit above the workboard, at the waist. A pencil or thin-line marker is then placed in the hole, and the gauge slid along the surface of the arched workboard along the inner perimeter of the sides. This will inscribe a line that is an equal distance above the arched workboard along the entire perimeter of the side assembly. When the edge of the side assembly is shaved to this line, the sides will sit flush on the arched workboard, and thus on the arched top for gluing.



The side assembly is then flipped upside down, and the edge shaved down to the scribed line using a spokeshave.



The end and neck blocks must be shaved, too, and are not flat on top, but must be angled to sit flush on the arched workboard.



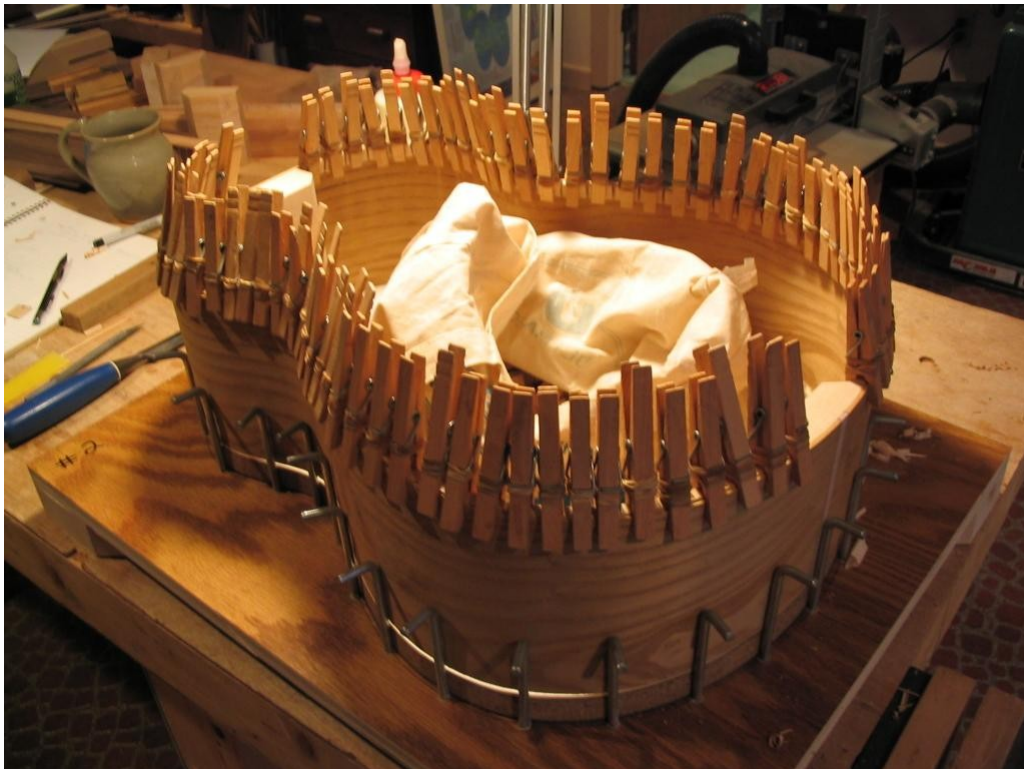
The angle of the end and neck blocks is checked as they're shaved with an arched template stick with the same arch as the arched workboard.



When shaving is finished, the side assembly is flipped and the edge profile checked on the arched workboard. The sides should sit flush on the workboard around the entire perimeter. If there are gaps, the sides can be further shaved.



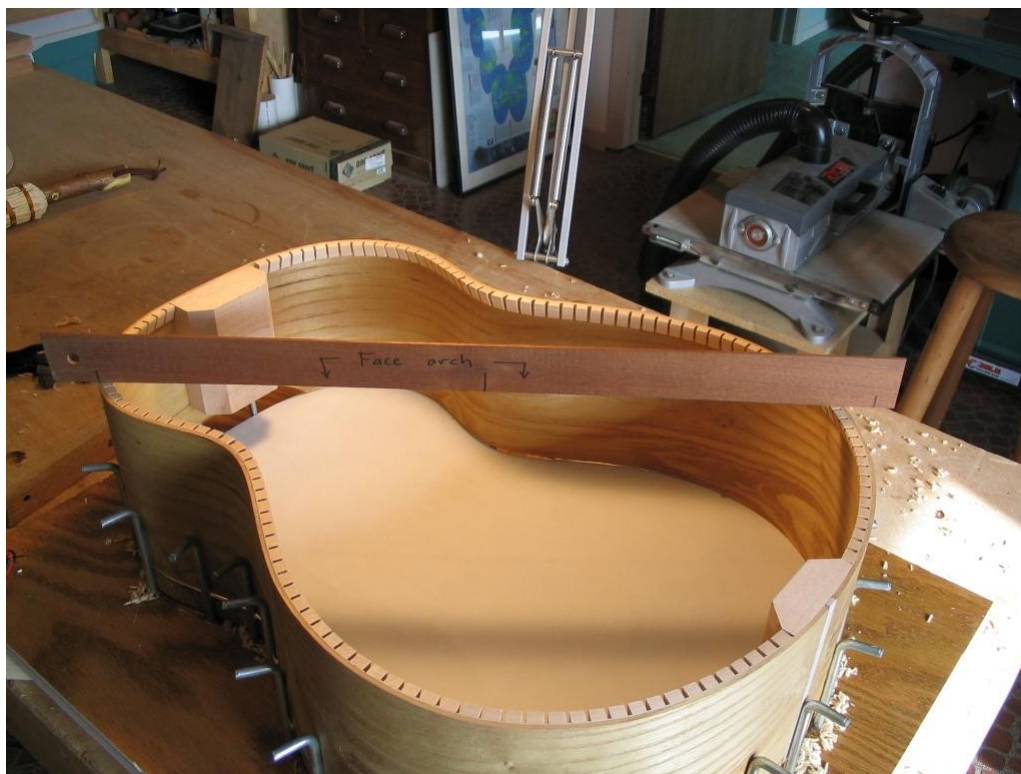
The kerfing can now be glued to the edge to provide increased gluing surface for attaching the top. The kerfing is glued on in short strips (maybe 4 - 6" long), and clamped with clothespins reinforced with rubber bands to give them extra clamping force. Note that the kerfing is glued so that it protrudes slightly above the edge of the sides. This is so it can be shaved down at an angle so it will sit flush on the arched top, just as the end and neck blocks were tapered.



The top with kerfing glued around the perimeter, but not yet shaved.



The kerfing is next shaved down so that it is flush with the edge of the sides, but angled to meet the arch of the top. The angling of the kerfing is checked with the same arched template used to check the angling of the end and neck blocks.



The kerfing must now be notched to accept the top braces where they run to the sides. The top is placed onto the arched workboard, the side assembly is placed on the top, and the position of the braces is marked on the outside of the side assembly.



The sides are then flipped in the jig and the position of the braces marked on the top surface of the kerfing to indicate the outline of the area that must be notched to accept the braces.



The edges of the regions marked are cut with a knife and then notched with a sharp chisel. The depth of each notch is equal to the thickness of the brace where it meets the sides.



When the sides are inverted on the top, the braces should nestle into the notches, and the undulating side profile should sit flush on the arched top (which is on the arched workboard inside the jig).



At this point the sides can be glued to the top. The sides are inverted, and a thin layer of glue is spread on the surface of the kerfing and the end and neck blocks. The side assembly is then inverted onto the top, and the end and neck blocks clamped. You should see an even bead of glue squeeze-out along the perimeter of the end and neck blocks.



A plywood template cut to the shape of the body profile, but overlapping by about an inch all around, is then placed on the sides, and clamps placed all along the perimeter to clamp the sides down onto the top. Note the holes drilled in the template to permit inspection of the interior. Note also the cutouts at the end and neck block positions to clear the clamps already in place there.

As an alternative to the clamps, large rubber bands can be used to provide the pressure to clamp the sides against the top - this is the reason "L" brackets are used in the gluing jig. The rubber bands used are number 107 bands, which are 7" long and 5/8" wide. These bands will put tremendous downward pressure on the side assembly as they are stretched between the "L" brackets. An example of their use can be seen when the back is glued onto the top-side assembly.



When the clamps (or rubber bands) are removed, the top is glued securely to the side assembly.



Don't worry about the rough edge of the top; this will be removed when the body is routed to accept the binding and purfling that will run around the edge of the body.

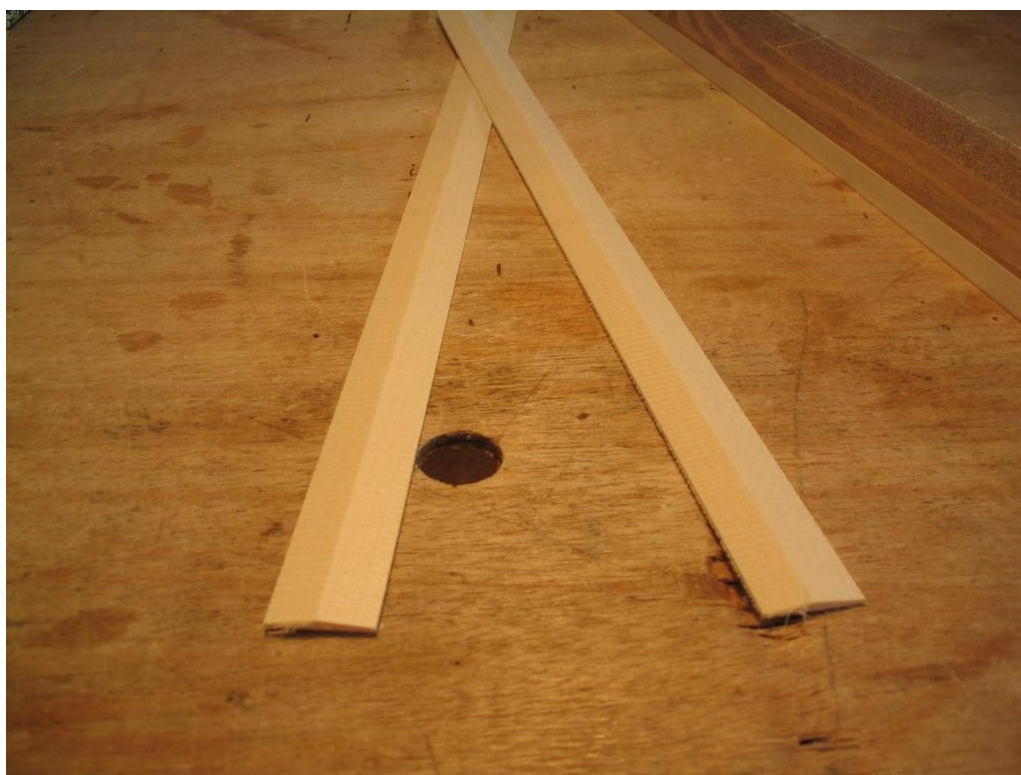
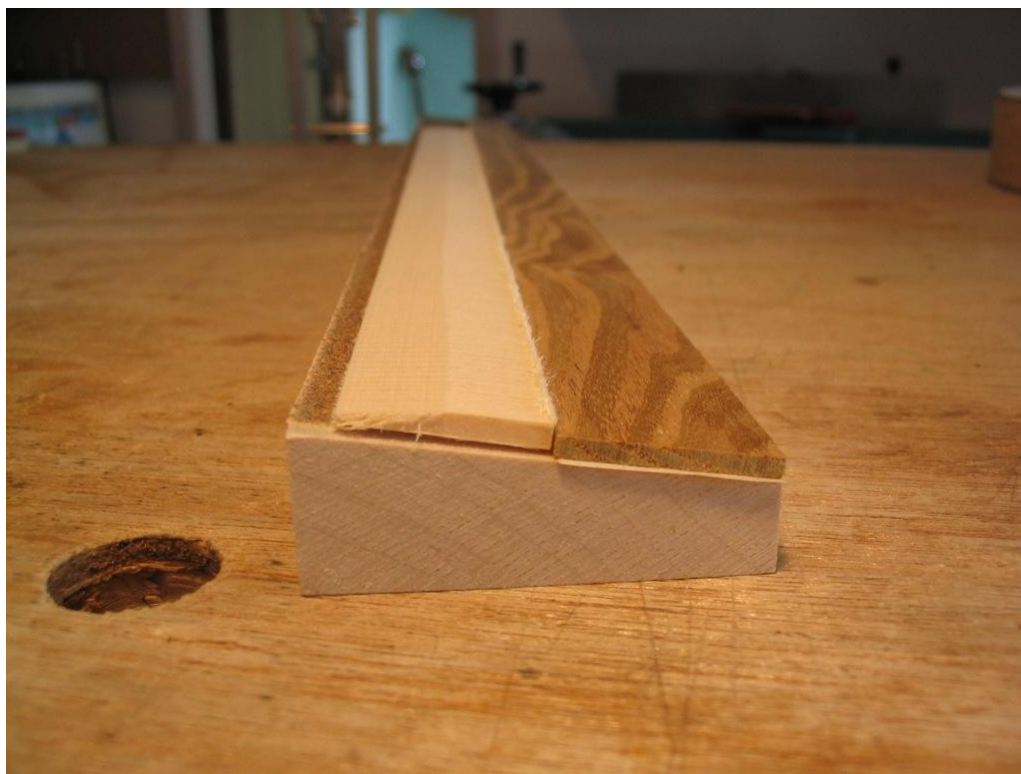


Chapter 8 - Bracing the Back

The back plate next has reinforcement strips glued over the glue joint(s). These strips are made from cross-grained spruce, cut from leftover top material. I usually make them between 3/4" and 1" wide. The strips are tapered so they are slightly peaked along their center line. This is easily done by hand, or by running the strips through the thickness sander on a tapered carriage. The carriage is shown in the photos below with one of the strips on top.



After being run through the sander twice, the strip gets the desired peak. Below, the strip after the first pass.



The strips can next be glued over the seams in the guitar back. The back shown is a four-piece back, so it has three seams. Since the back is to be arched, the strips are glued on while the back is on its arched workboard, and thus an arched clamping caul is used. Since the center strips are peaked, the clamping caul has narrow cork strips glued to its outside edges so it puts pressure on the outside edges of the reinforcement strips.

The back with attached reinforcement strips is shown below.



The reinforcement strips must now be notched so the back braces can be glued. Note that the back braces are made in the same way as the top braces, being arched in the same fashion. My dimensions for back braces are usually about $5/16$ " wide by $1/2$ " high for the narrow braces at the upper bout and $5/8$ " wide by $7/16$ " high on the lower bout. The guitar shown uses just three back braces; I've also made guitars with four braces. The material for these braces in the photographs is maple; I've also used walnut, mahogany, and spruce. The material used doesn't seem to be critical to the instrument's tone.

The brace positions are marked using a ruler and square, and the reinforcement strips are scribed with an Xacto knife on both sides of each brace.



The material between the scribe marks is removed with a chisel.



The next two pictures show the braces glued to the back, with the back laid on top of the arched back workboard.





When the glue on the braces has dried, the protruding ends can be cut flush with the edge of the body profile on the back. The ends of the braces are then tapered to about .100" at their ends, with the taper beginning 3" or so from the ends. Note that this back use 4 braces instead of 3 as illustrated above, and uses walnut rather than soft maple as the brace material.



The brace ends are then trimmed so they end the thickness of the sides from the body profile line on the inside of the back (recall that the back was cut about 1/8" bigger all around).



Chapter 9 - Joining the Back to the Sides

The braced back is next joined to the top-sides assembly. The sides must first be shaped to have the correct edge profile to meet the arched back, just as the edges of the sides had to be shaped to join up with the arched top. The process of marking and shaping the sides is largely the same as the process used for the top edge, except that the arched workboard for the back is used instead of the workboard for the top (since the arching of the top and back are different), and the correct side heights need to be met at the end and neck blocks.

The first step involves marking the side heights at the neck and end blocks so the completed body will have the desired thicknesses at these points. In the next two photos, you can see pencil lines indicating what the finished body thickness is to be at the head and tail of the guitar. Below the body thickness is marked at the head of the body (where the neck will attach), in this case 3 1/2".



In the photo below the line marks the side height at the tail of the guitar - in this case, 4".



Next the body is placed on the arched back workboard, and shimmed so that the two pencil marks, at the head and tail of the body, are the same height off of the workboard. The tail of the guitar is generally where blocking is needed to raise it up off of the workboard, since the body is generally thicker at the tail than at the head.



When the assembly has been shimmed so the two pencil marks are the same height above the workboard, as drawing gauge is made, consisting of a thin piece of stick with a 1/16" hole drilled at exactly this height from the end, as shown below. This will be used to mark the sides to have the profile needed to join with the arched back. You can see in the photo below this gauge with a pencil in the hole. The gauge will be slid on the workboard around the perimeter of the guitar; since the workboard has the same arch as the back, the line traced will be gently undulating to match this arch.



Below you can see the line traced using the gauge, with the gauge in position (but without the pencil). Note that it's important to keep the top-side assembly from shifting on the arched workboard as the gauge is used to draw the line.



The line traces the entire periphery of the top-side assembly.



With the back-side profile traced, the sides can now be cut down to this profile. Since there's a lot of material to remove, I generally start with a drawknife, as shown below. The top-side assembly is placed into the gluing form to hold it during this operation. (If this doesn't hold the assembly securely enough, a waist brace can be put in to "clamp" the sides in the jig.)



You need to watch the grain while using the drawknife, as it's easy to split off a bigger chunk than you intended...



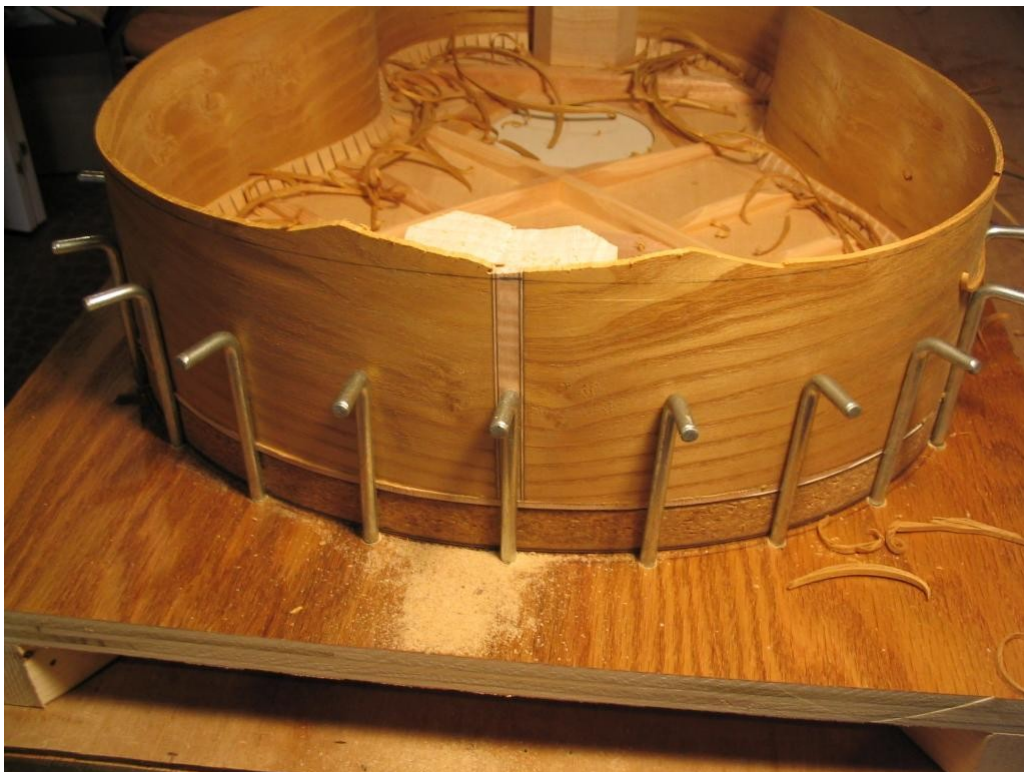
In the photo below, the sides have been cut down to within about 1/4" of the scribed line, except at the neck and end blocks. Since the end block protrudes significantly, it will be cut with a saw before shaping proceeds with a spokeshave.



The tail block is rough-sawn with a bow saw. Note the clamp to help secure the assembly during this operation.



The tail block after sawing - ugly, but easier than trying to spokeshave all that material off. (Got kind of close to the line, though...)



Shaping now proceeds with a spokeshave. This allows fine shaving, to shape the side profile right to the line.



The end and neck blocks need to be tapered so they will match the arch of the back - they're not horizontal on top, but arched slightly. A gauge cut with the longitudinal arch of the back is used to check the taper as they're shaved.



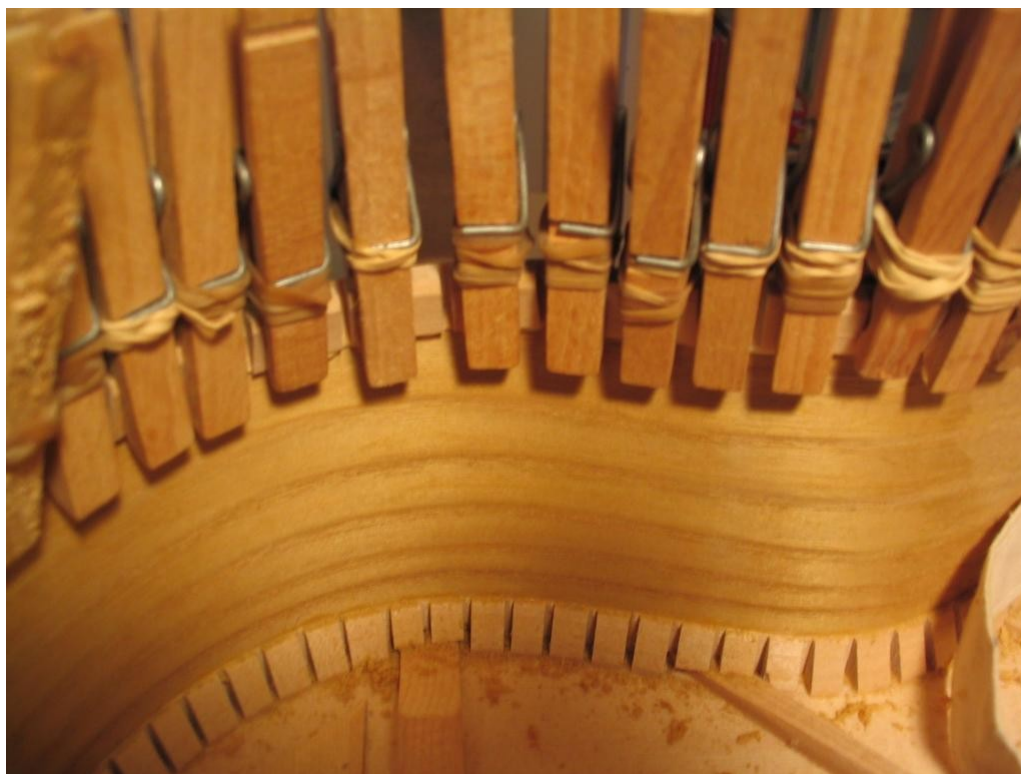
Here's a close-up of the taper being checked on the neck block.



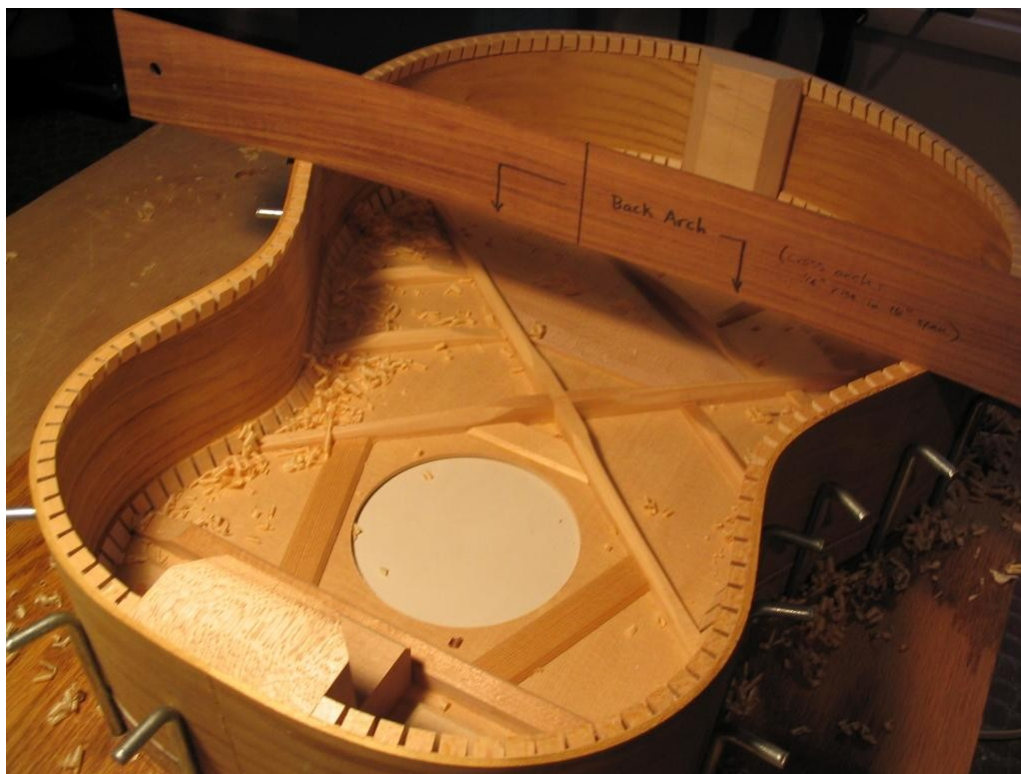
When the side profile has been shaved to the reference line with the spokeshave, the profile should now match the arched profile of the back. This is checked by inverting the assembly on the arched workboard. The assembly should sit evenly on the board, with no gap showing at any point. If there are significant gaps, the assembly can be placed back in the jig and shaved further. Note that the fit is less critical than with the top, since the back is flexible and will conform to slight irregularities in the profile when it's clamped during gluing.



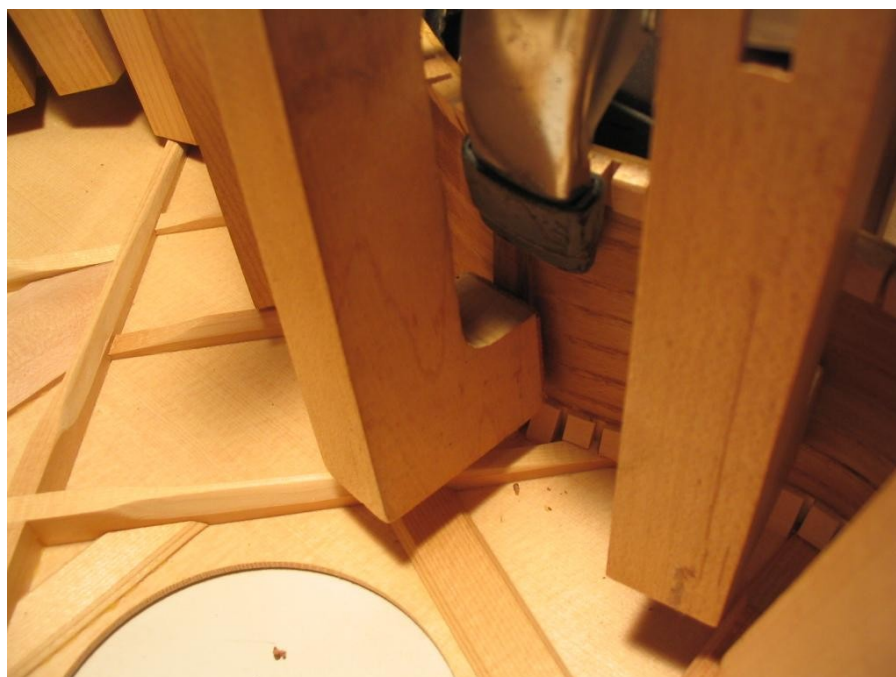
Next kerfing is glued along the edge of the sides, using clothespins reinforced with rubber bands to give them a little greater clamping power. Note that as before, the kerfing is glued on so that it sits a little above the edge of the sides, since it must be shaved to a taper that matches the arch of the back (as was done with the neck and end blocks).



The kerfing is now shaved down to the profile of the sides, but is angled so that it matches the arch of the back. This angling is checked with a template that matches the cross arch of the back.



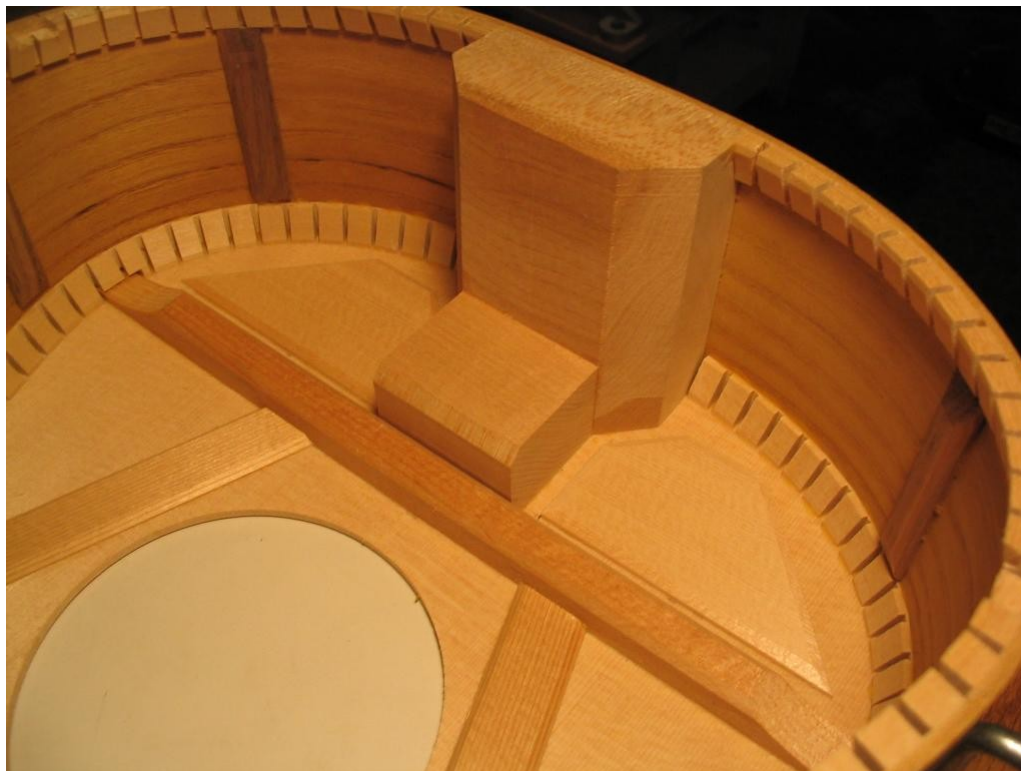
Next side reinforcement strips are glued on. These are thin and narrow strips of wood glued vertically at intervals along the inside surface of the sides. These serve to help prevent the sides from cracking due to an impact. You can just barely see the strip peeking out from beneath the clamps. The strip that is glued at the waist (shown) must have its gluing surface scraped to a concave profile so it will fit flush on the convex surface of the sides at the waist.



The neck block reinforcement can now be glued on. This is a block that fits against the neck block and top, and provides additional support for the portion of the top that will be supporting the fingerboard. Since the top is arched, the angle formed by the top and the neck block isn't a right angle, and the block must be planed to the correct angle to contact both the top and neck block. The reinforcement block is the maple block below the cherry clamping cauls in the picture below.



The following picture shows the reinforcement block after gluing.



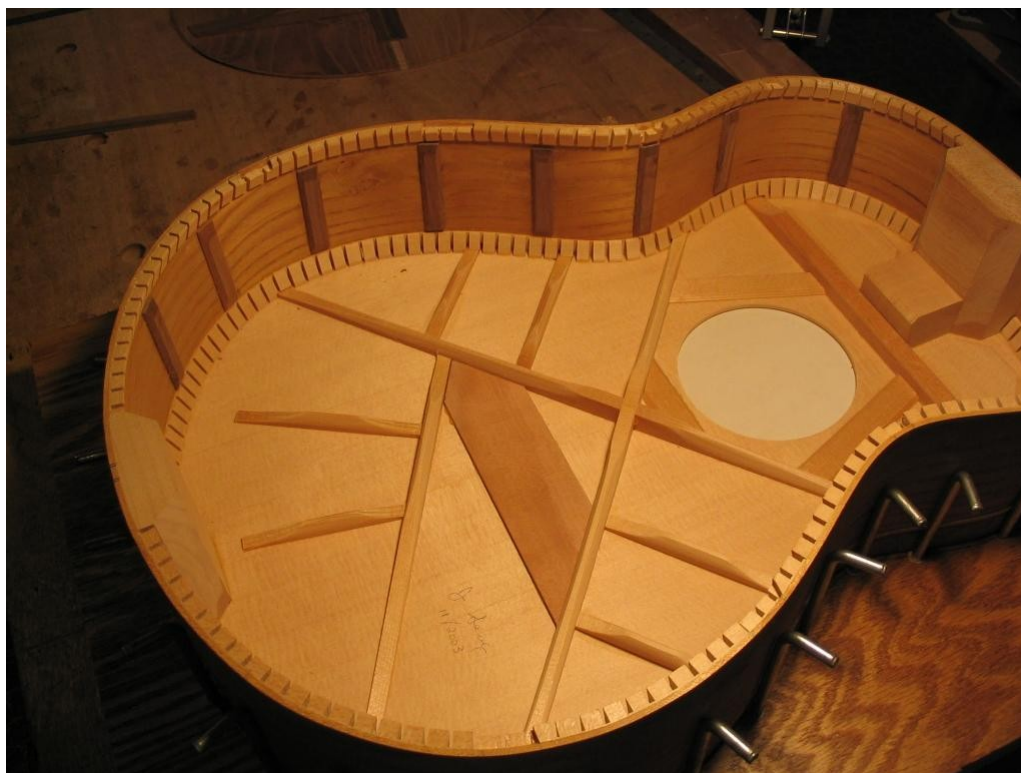
The kerfing must now be notched to accept the back braces where they meet the sides. The back is placed on the side assembly, and the position of the braces is marked on the sides.



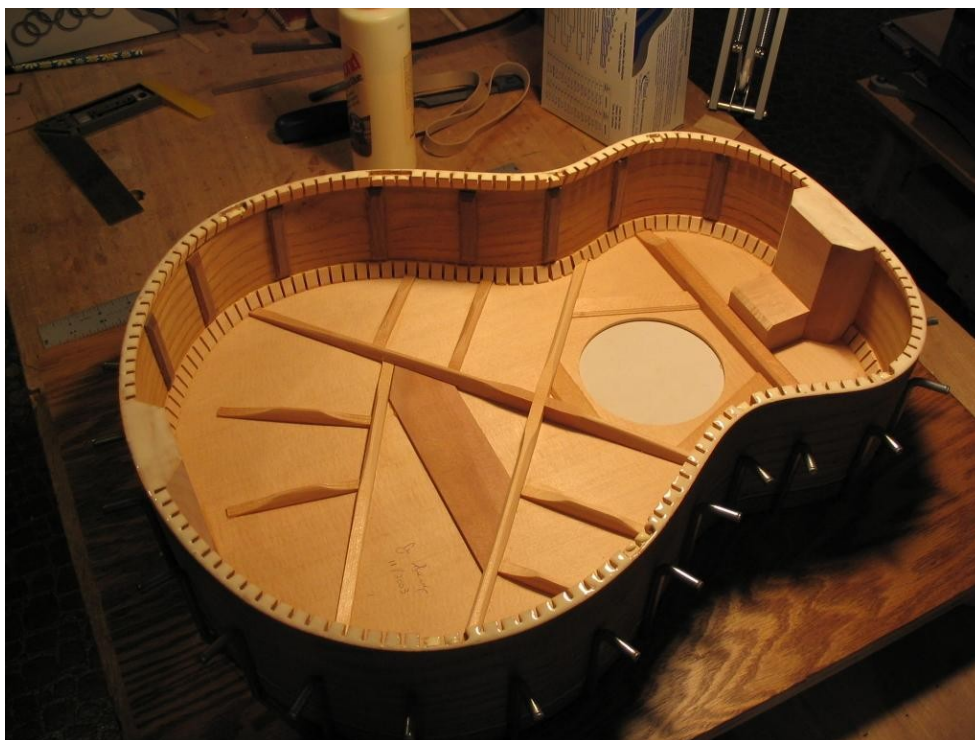
The brace positions are then transferred to the top surface of the kerfing.



The marked lines are cut with a knife, and the kerfing is then notched with a sharp chisel in the location of the braces. The depth of the notches is equal to the height of the braces where they meet the sides.



At this point, the back can be glued to the top-side assembly. Glue is spread evenly on the kerfing and end and neck blocks. The glue should be applied with care so that it doesn't drip through the gaps in the kerfing. Glue should also be spread in the notches for the brace ends.



The next two photos show the back placed on the assembly, aligned so the binding strip in the back lines up with the binding strip at the tail. The number 107 rubber bands are then stretched between pairs of "L" hooks on the jig to apply clamping pressure.

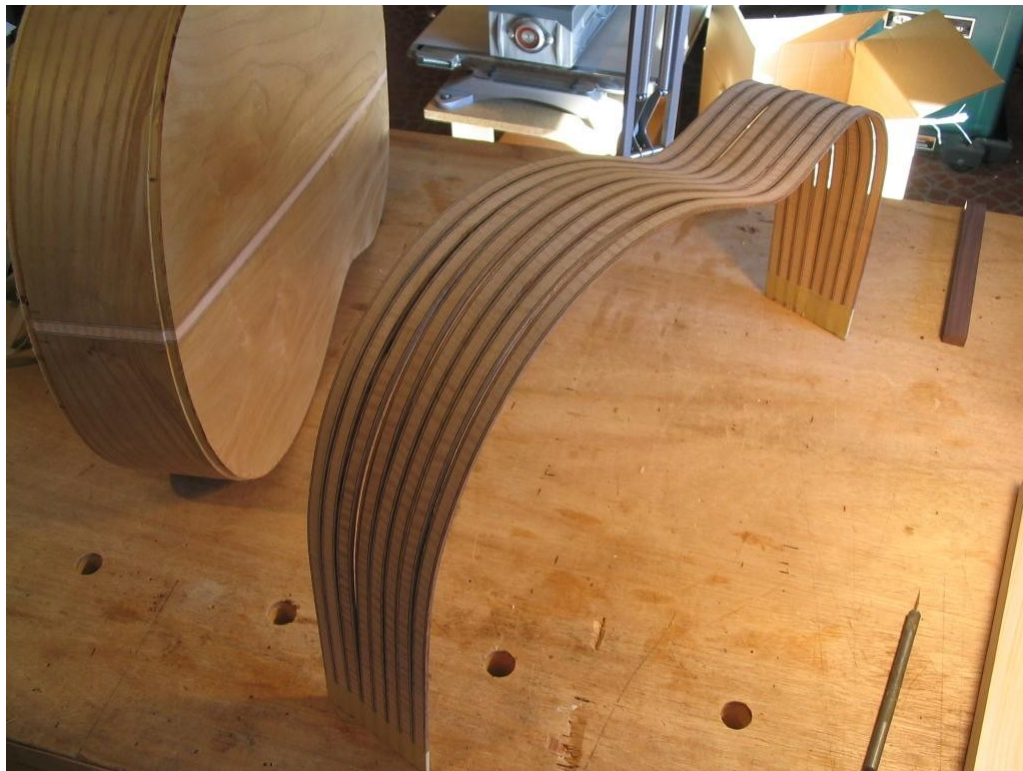




Chapter 10 - Binding the Body

When the body is complete, with top and back glued to the sides, binding can be applied to the body edges. The binding is wooden striping that wraps around the edges of the body, providing both decoration and protection. The purfling consists of thin bands of wood adjacent to the binding, used primarily just for decoration (though some have suggested that it "loosens" the joint between the top and sides).

The binding strips are made with purfling glued to the edges by creating a "sandwich" of the binding material and purfling veneers and then slicing it into the binding strips. These strips are then taped together and pre-bent in the side bending jig so they'll easily conform to the profile of the guitar body. Shown below are the binding strips for two guitars. BTW, I glue the purfling material to both edges of the binding so I don't have to worry about left- and right-handedness. The unneeded purfling strips will be scraped away after gluing.



The binding process starts by cutting grooves around the edge of the body to receive the binding and purfling. Because all of the surfaces are curved - the sides, and arched top and back - it's hard to find a way to cut the square-edges groove. I use the jig pictured below, which mounts a router and uses the guitar sides as the guide surface.

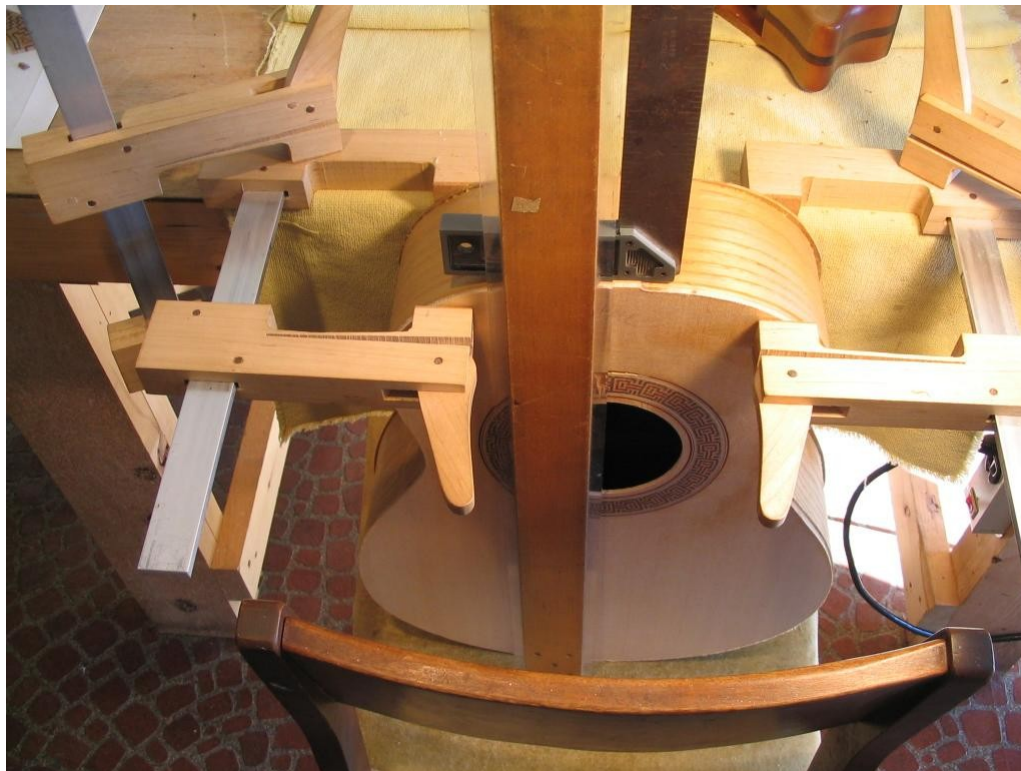


The guitar rides on the brass rod shown, as the yellow router bit cuts the groove. The Brass rod has spacers on each end to make the width of the cut (which is equal to the radius of the router bit minus the radius of the rod spacers) the appropriate depth.

Before cutting the binding and purfling grooves, however, a flat is planed at the top of the guitar body where the neck will attach. The body is clamped to the workbench as shown (I also support it from below on a chair). (Note that in the photo below I began routing the binding groove before remembering to plane the flat...)



The flat is planed such that the centerline of the neck will align with the centerline of the guitar body. This is measured using a square and a straightedge, with the square resting on the planed flat and the straightedge placed along the guitar body centerline.



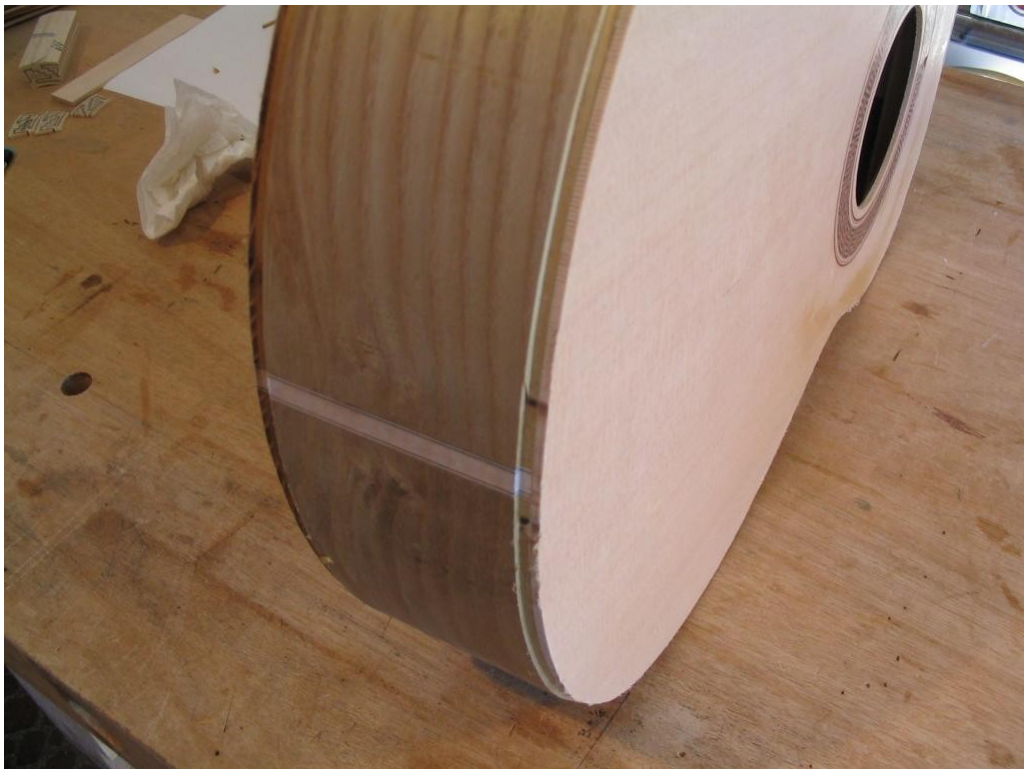
The flat is then adjusted with the plane until the edges of the straightedge and square line up perfectly.



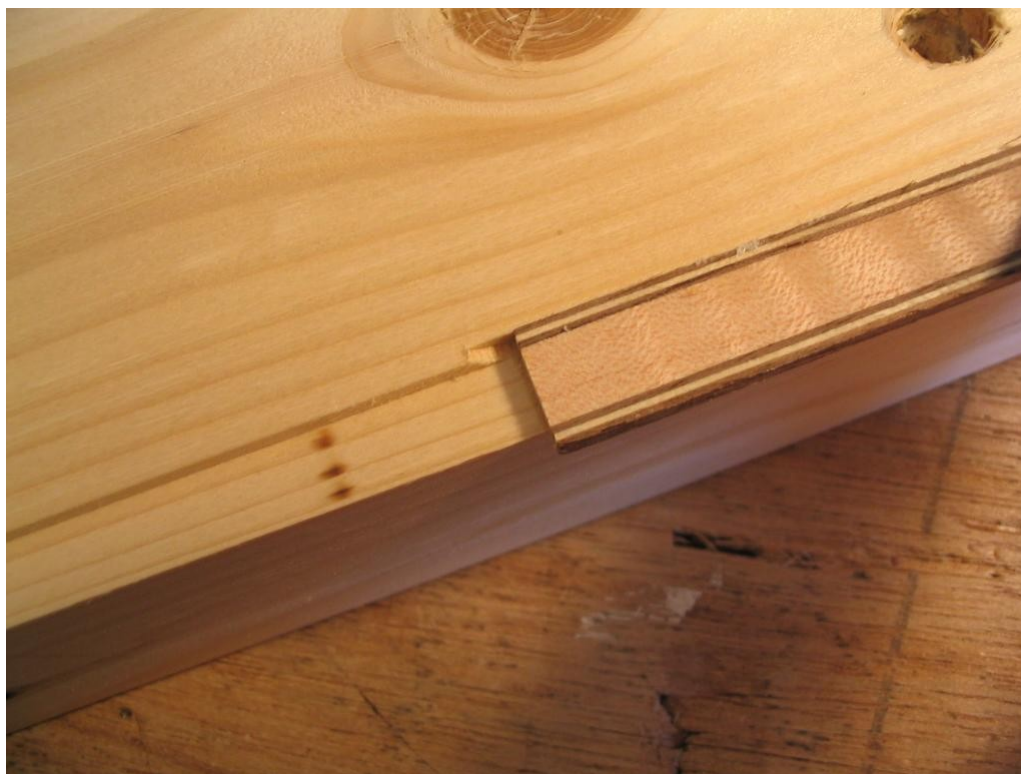
The routing jig is now set to cut the binding groove. A piece of scrap wood is used to test the groove depth and width to ensure they are a little less than the binding height and thickness (the binding is left slightly proud, and then scraped flush).



The guitar body is then slid along the brass rod on the jig, with the router bit cutting the groove. Below, the binding groove is shown routed around the perimeter of both the top and back.



The depth of the cut is now increased to the depth of the binding plus the glued-on purfling. The scrap wood from before is used to adjust the depth, as shown below.



The top and back perimeters are then re-routed, but stopping shy of the end binding strip that was previously glued in.



The top and back purfling grooves can now be routed, setting the depth of cut appropriately by removing the spacers from the brass guide rod. As before, the groove is stopped shy of the back inlay strip.



The purfling grooves can now be chiseled up to the back and end binding strips.



The purfling is now mitered at the ends of the grooves. This is easily done with a sharp chisel, using the back of the chisel as a mirror - when the angle is exactly 45 degrees, the reflection of the purfling on the back of the chisel will form a right angle with the purfling.



The first pre-bent binding strip (with side purfling attached) is marked at the butt of the guitar and cut to length. The attached side purfling is then marked and mitered to meet perfectly with the purfling on the end strip.

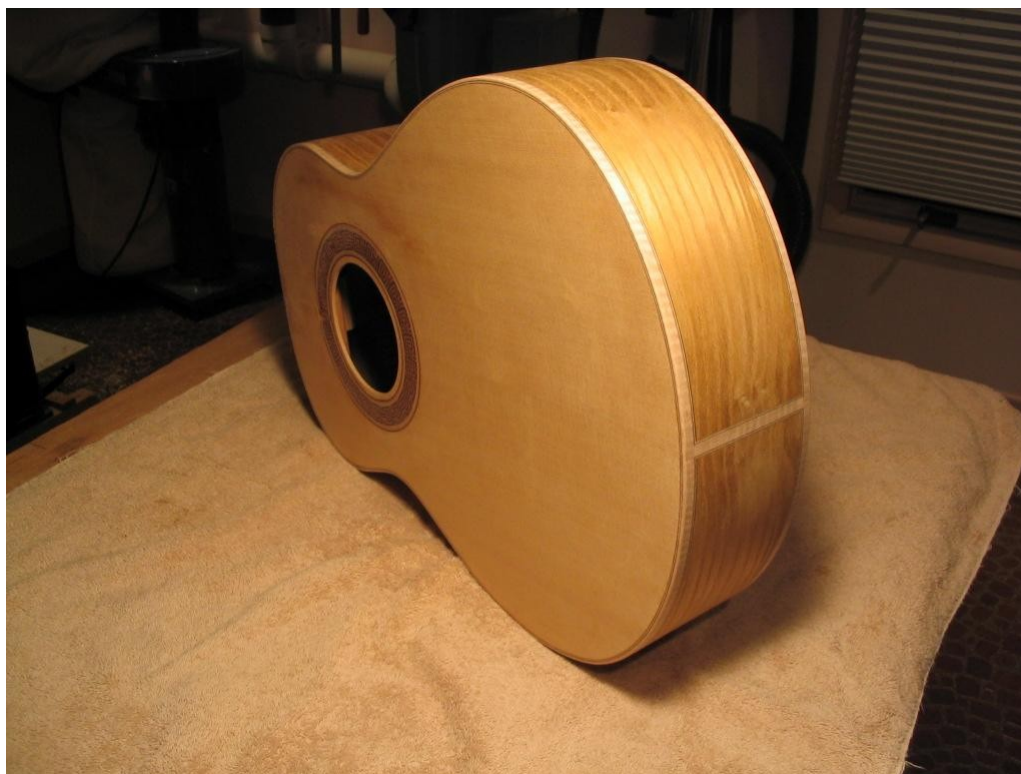


The back purfling strips are also mitered, and we're ready for gluing. Glue is applied to the back purfling strips and the binding, and these are then placed into the groove and secured with fiberglass reinforced packing tape. Glue is only applied to about 6" at a time. It's a bit tricky at the start, getting the binding secured and the back purfling strips in the groove and both mated tight with the mitered purfling on the end and back strips. But once the first few inches are glued and taped, the rest goes pretty easily. Make sure to press tightly when taping so as not to leave any gaps.



The other binding strips are fit and glued similarly. When the glue has dried, the tape is removed (being careful not to lift the grain, especially on the spruce top). The binding is now scraped flush with the sides, top and back. I find it useful to brace the guitar body against a towel placed on the edge of the workbench as I scrape the binding flush with the sides; I wedge the body in with my leg and hips (OK, and gut...)

The edge of the binding strip is then rounded slightly with 100 grit sandpaper. The bound guitar body is shown below.

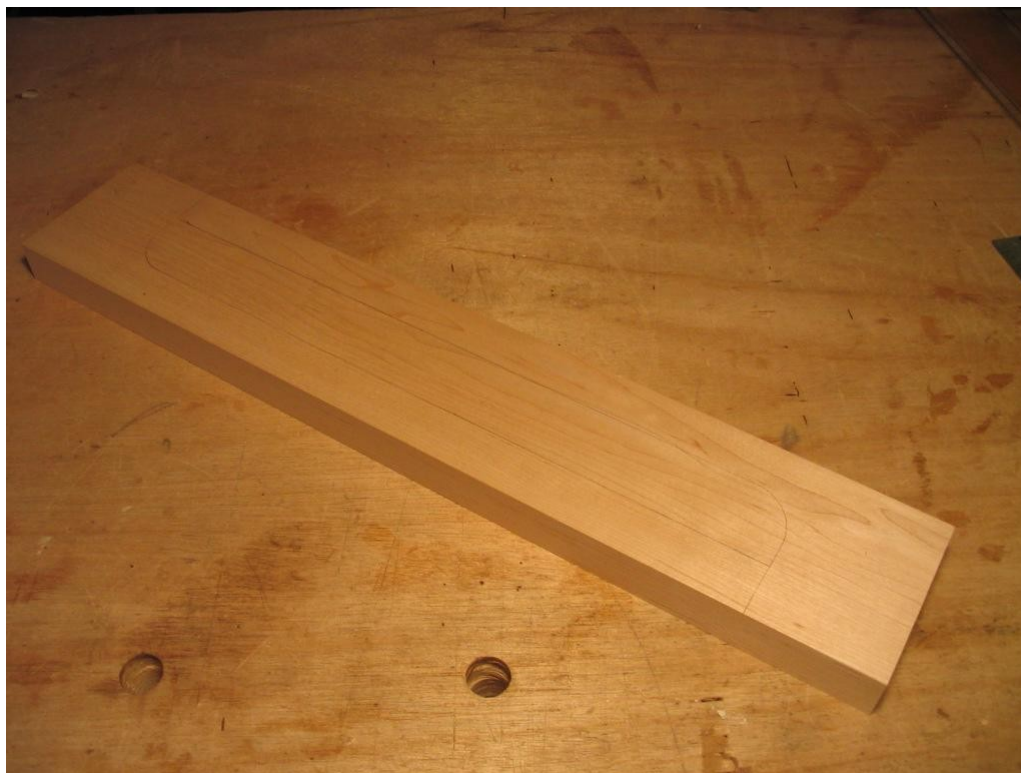


The following picture shows the detail of the binding and mitered purfling joints at the junction of the back center strip and the end strip.

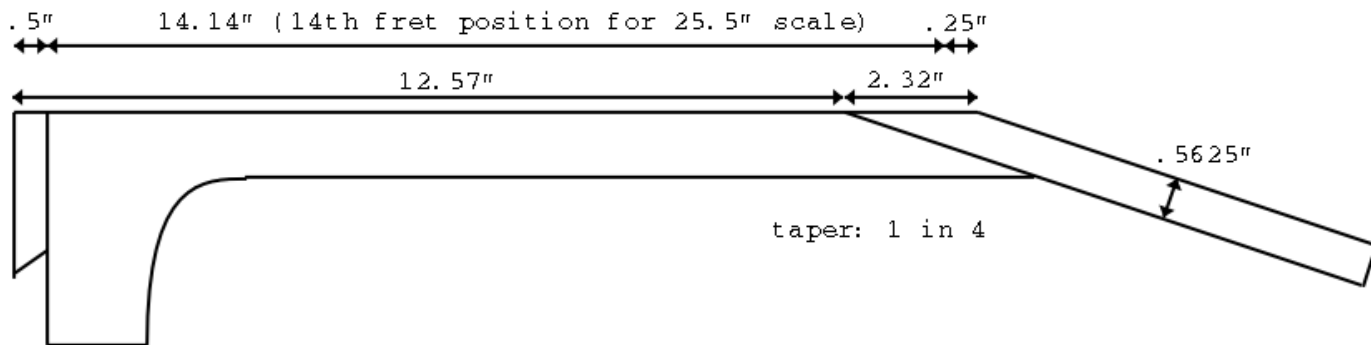


Chapter 11 - Constructing the Neck Blank

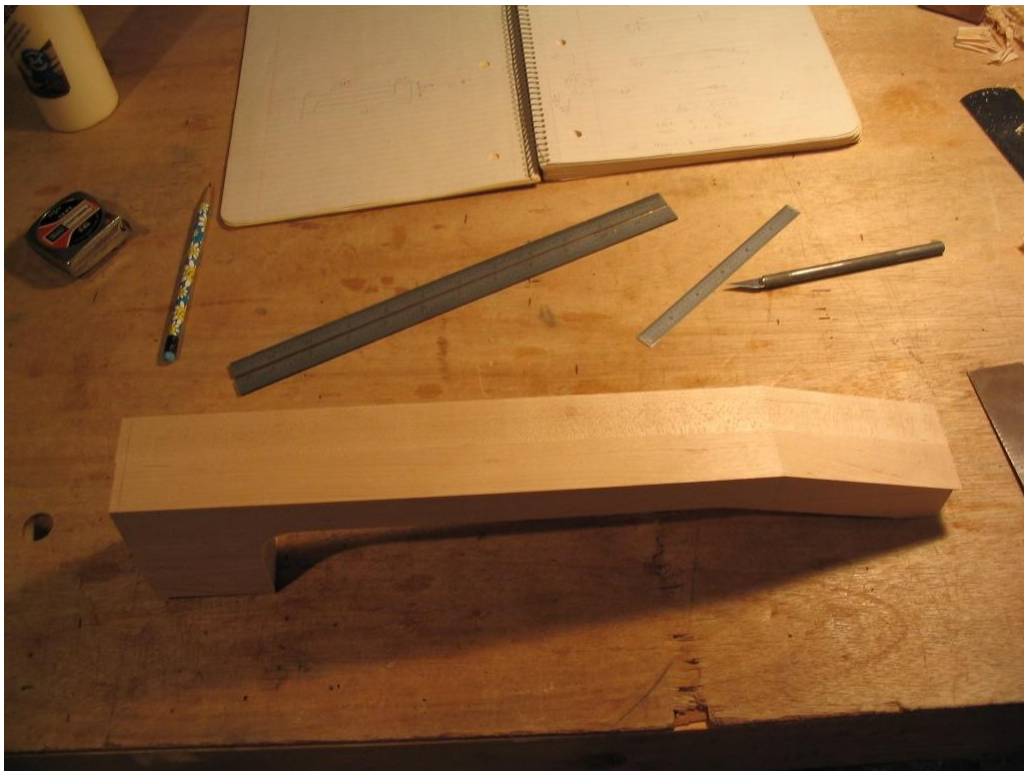
The neck is made from two halves glued together along the neck centerline, with the headstock glued on using a scarf joint. The photo below shows the neck halves laid out on a piece of 5/4 stock - maple, in this case. Other neck woods I've used are mahogany and walnut.



The halves are cut out and glued together, and the top surface is flattened. The angled joint for the peghead stock is then cut and smoothed. The taper on the peghead joint is 1" in 4". The trick with this joint is to know where it should be placed on the neck so the end of the fretboard will be at the desired position once the peghead is glued and the top surface is flattened. Using a thickness of 9/16" for the peghead stock, the length of the top surface of the neck that will be on the peghead stock is 2.32 inches. Assuming the scale length for the guitar is 25.5", the 14th fret, where the neck will attach to the body, is 14.14 inches from the nut. Using a 1/2" depth for the dovetail joint and a 1/4" thick nut, the total distance from the end of the dovetail to the end of the nut is 14.89 inches. Subtracting 2.32 from this gives 12.57 inches; thus the taper should begin at a distance of 12.57 inches from the end of the dovetail.



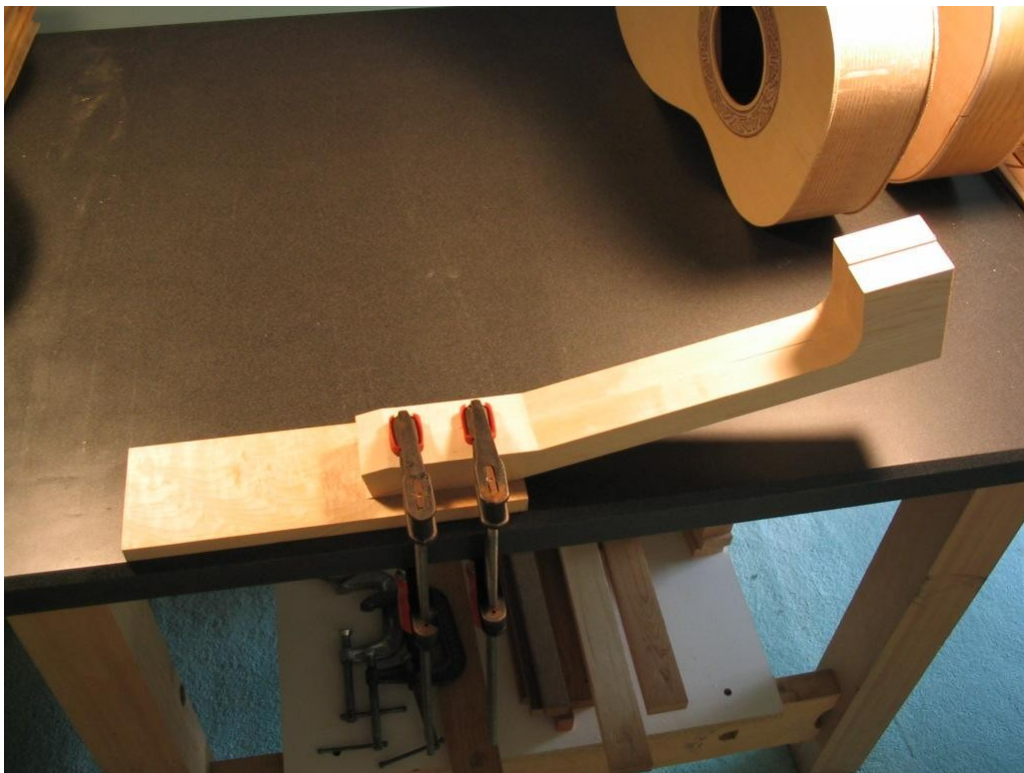
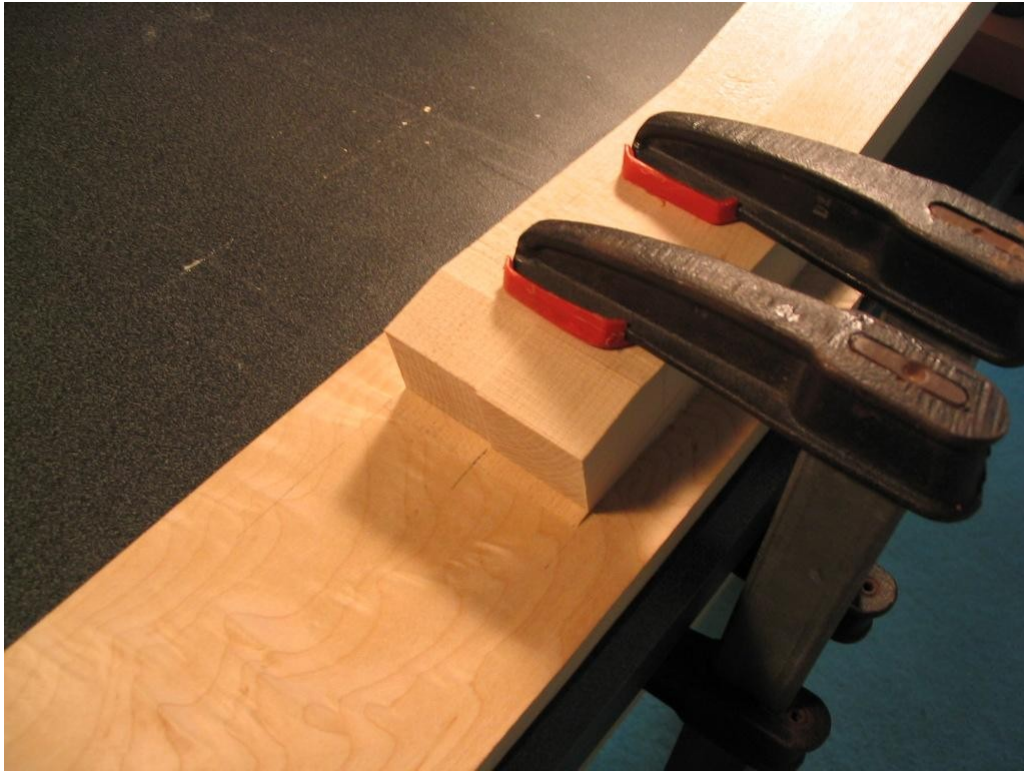
The angle is cut with the bandsaw, and then smoothed with a handplane. The photograph shows the cutoff piece attached to the bottom surface of the neck with double-faced tape. This helps to support the neck while planing the angled joint, and is used as a clamping caul when the neck and peghead are glued.



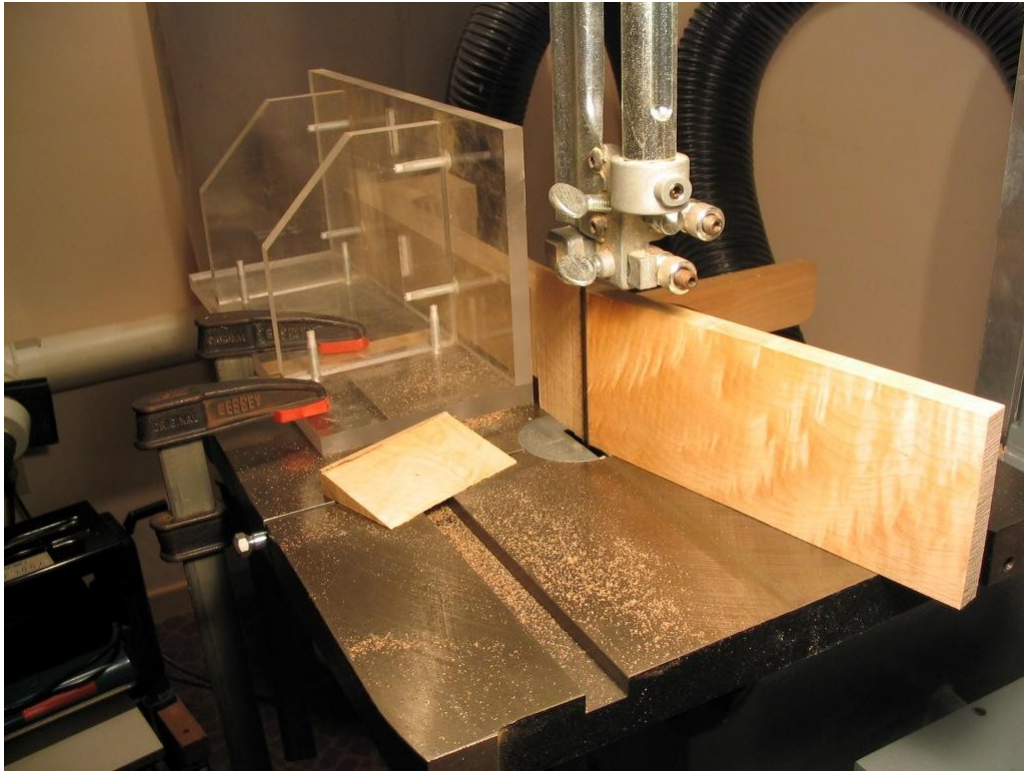
The peghead is then glued to the taper. The headstock is 9/16" thick, and alignment lines are drawn to align the neck stock for gluing.



The peghead is then glued to the neck stock - or rather, as the pictures show, the neck stock is glued to the peghead. Notice the block taped to the neck stock for the clamping caul, so the clamping surface will be parallel to the headstock surface.



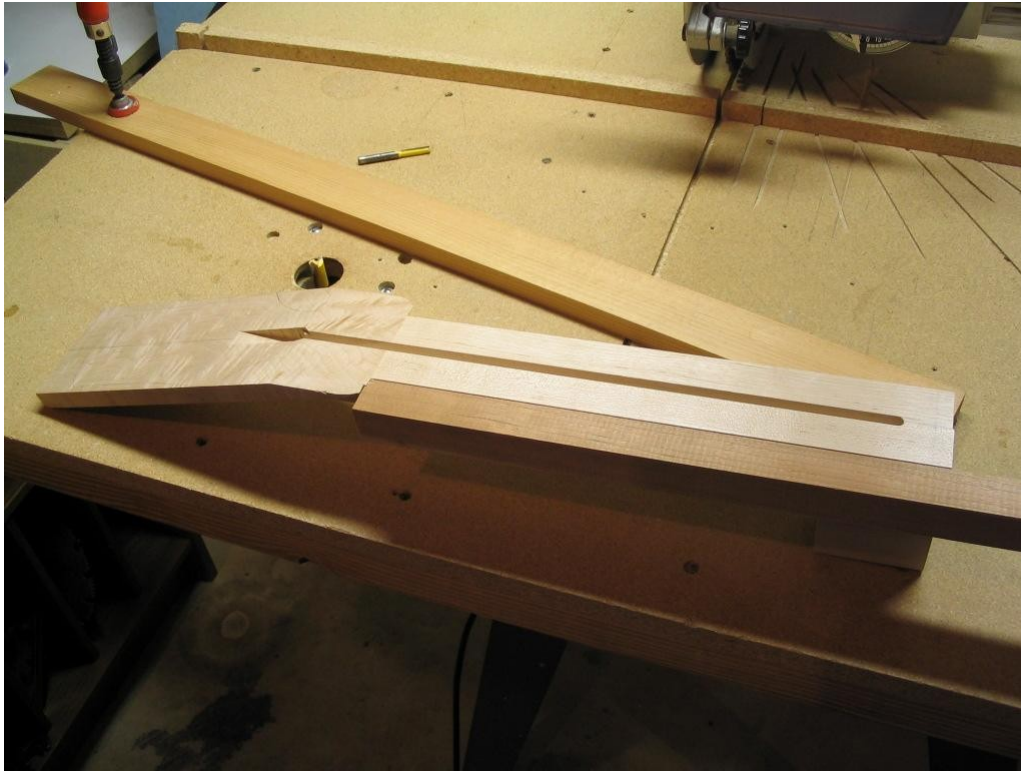
Once the peghead is glued, the portion of it that protrudes above the top surface of the neck needs to be cut off. The cut is made on the bandsaw, with the top surface of the neck moving against the Plexiglas jig shown.



The cutoff portion of the peghead is then planed flat with the surface of the neck.



The groove for the truss rod can now be cut down the center of the neck. This is done on a router table, with the table's fence set so the groove will be on the exact centerline of the neck. Because the peghead protrudes beyond the edges of the neck blank, a rectangular spacer is attached to the side of the neck with double-faced tape. A 1/4" wide groove is cut first, to a depth of 7/16" (in several passes). A 1/2" wide groove 1/2" deep is then made just to the position of the nut, to provide space for the end block of the truss rod. The end of this groove is then squared with a chisel.



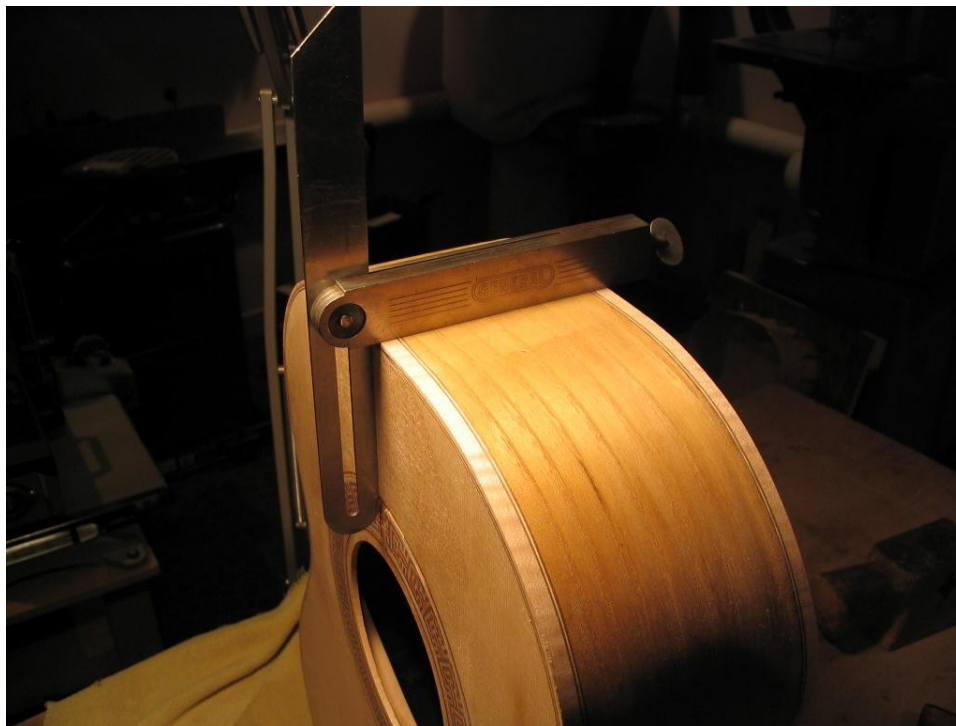
Chapter 12 - Cutting the Neck Dovetail Joint

The neck is attached to the body with a tapered sliding dovetail joint. This is the traditional joint for neck attachment. There have been a number of different approaches introduced in recent years, including bolted and pinned straight tenons, and even flat butt joints attached with epoxy. While these are easier to cut than the tapered sliding dovetail, and the bolted necks are easier to repair when a neck reset is needed (the epoxy-glued necks are virtually impossible to remove), the dovetail is a strong, self-locking joint that's not that difficult to cut or adjust.

The tenon part of the joint is cut on the end of the neck stock, which was made an extra 1/2" longer for this purpose. The mortise of the joint is cut into the end of the guitar body, which has a substantial neck block to accept the mortise. What makes the cutting of the joint particularly challenging is the fact that the surfaces involved don't meet at right angles. Because the top of the guitar is arched, the top of the guitar and the sides form an angle that's greater than 90 degrees. In fact, the top isn't even planar, being a portion of a sphere, and the sides are themselves curved. To allow the fretboard to lie flat on the top, a small flat is planed on the top where the fretboard will lie. (Recall that a similar small flat was planed on the sides at the top of the body, before the binding was applied, to facilitate the cutting and fitting of the neck joint.)



For the top of the neck to be flush with and aligned with this flat, it is necessary for the end of the neck to be cut to the complementary angle to that made by the guitar top and the sides. The angle isn't measured in degrees, but rather transferred with a marking gauge. The gauge is held against the guitar body, and tightened at the correct angle; though the angle in the photograph looks like a right angle, it's not. Notice that the blade of the gauge is roughly in the middle, forming a "tee". The leg that's off of the body has the complementary angle, and will be used to mark the angle on the neck.



The marking gauge is then used to mark the end of the neck blank with the complementary angle. The angle is transferred to both sides of the neck, with a square used to mark the top and bottom faces.



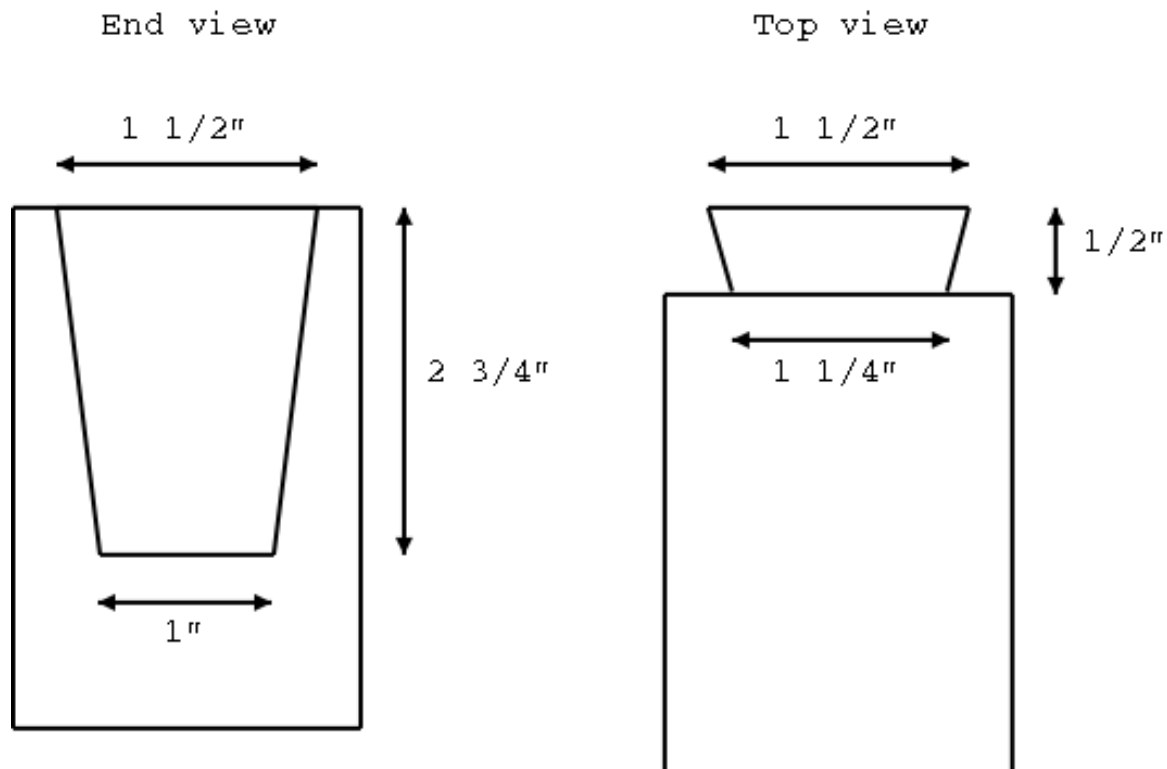
Even though the scribe mark looks as if it's just a right-angle cutoff of the neck stock end, it's not.



The neck can now be cut off at the mark. I use a bandsaw, and then plane the cutoff end flush with the marks. A very sharp plane is helpful for planing the end grain.

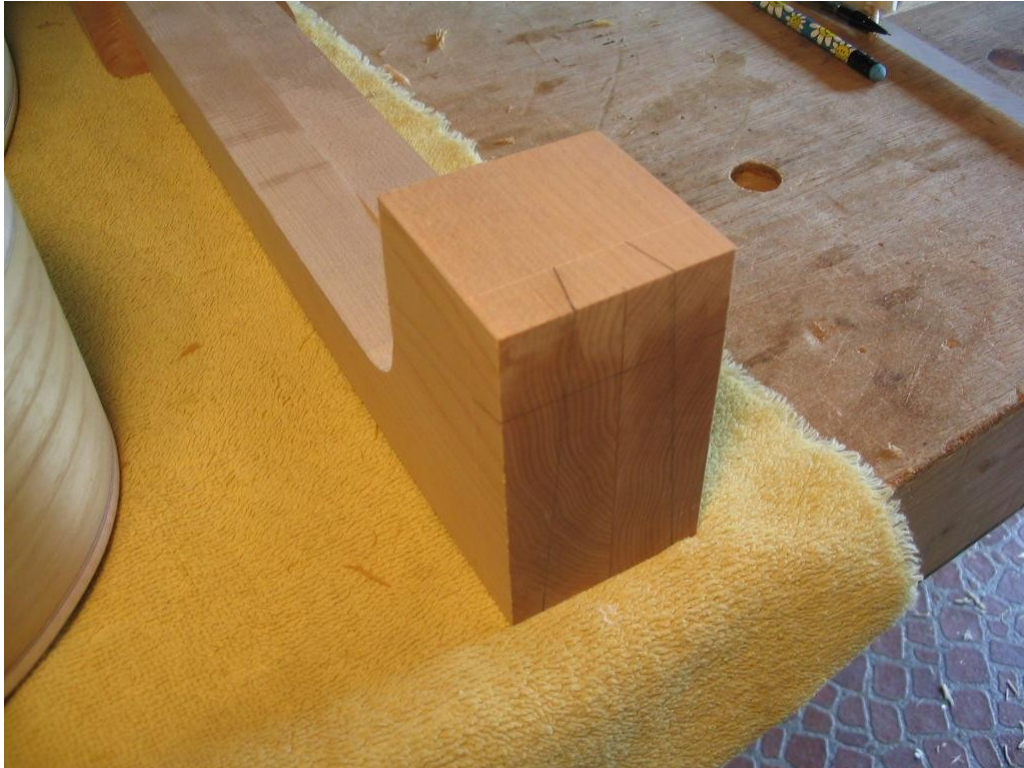


The dimensions used for the dovetail are shown in the following diagram.



The dovetail can now be marked on the end of the neck blank. Note in the following two pictures that the length of the tenon is scribed $\frac{1}{2}$ " in from the end using a marking gauge.





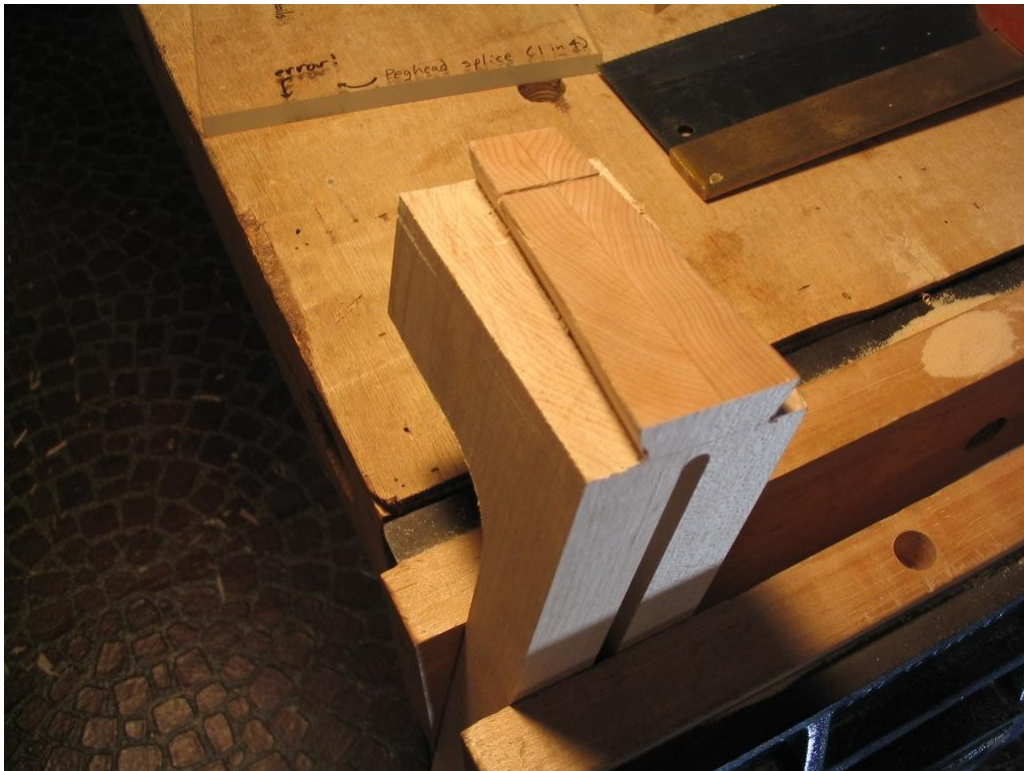
The dovetail joint is then cut, using either a dovetail saw or a fine backsaw. I don't try to cut right to the line, expecting to finish the joint by paring with a sharp chisel after sawing. The two long angled cuts, which form the "cheeks" of the dovetail, are cut first. Notice how the neck is angled in the clamp so the saw cut will be on the vertical; I find this helps in keeping the cut straight, being easier than trying to angle the saw blade.



The bottom of the dovetail is cut next. Note that these three cuts have been rip cuts - the saw is cutting with the grain, rather than across it.



The "shoulders" of the dovetail are cut next - these are crosscuts, going across the grain.



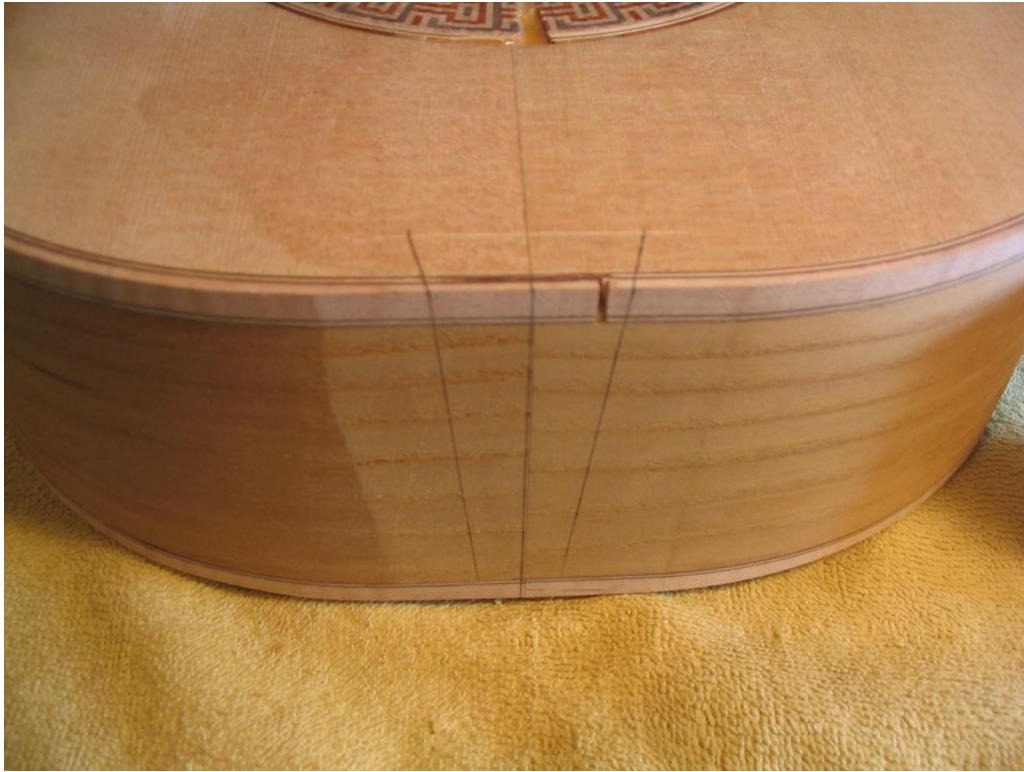
Finally, the small remaining chunk at the bottom is cut off.



The dovetail is then cleaned up with a sharp chisel. The surfaces are all smoothed, with particular attention paid to getting the shoulders to be planar - that is, the flat area that the tenon rises out of should truly be flat. This can be achieved using a straightedge to find any high spots. The angles on the dovetail can also be checked with a small gauge. When completely cleaned up (which takes a little while - and watch your fingers with the sharp chisel!!), the dovetail should look like that below.



The mortise to receive the tenon can now be cut in the body. The joint is first marked on the body (the line delineating the bottom of the joint is missing in the photo).



The "cheeks" of the joint are now cut with a backsaw or dovetail saw. Note that only half the surface of the cheek can be cut, since the joint is actually "half blind".



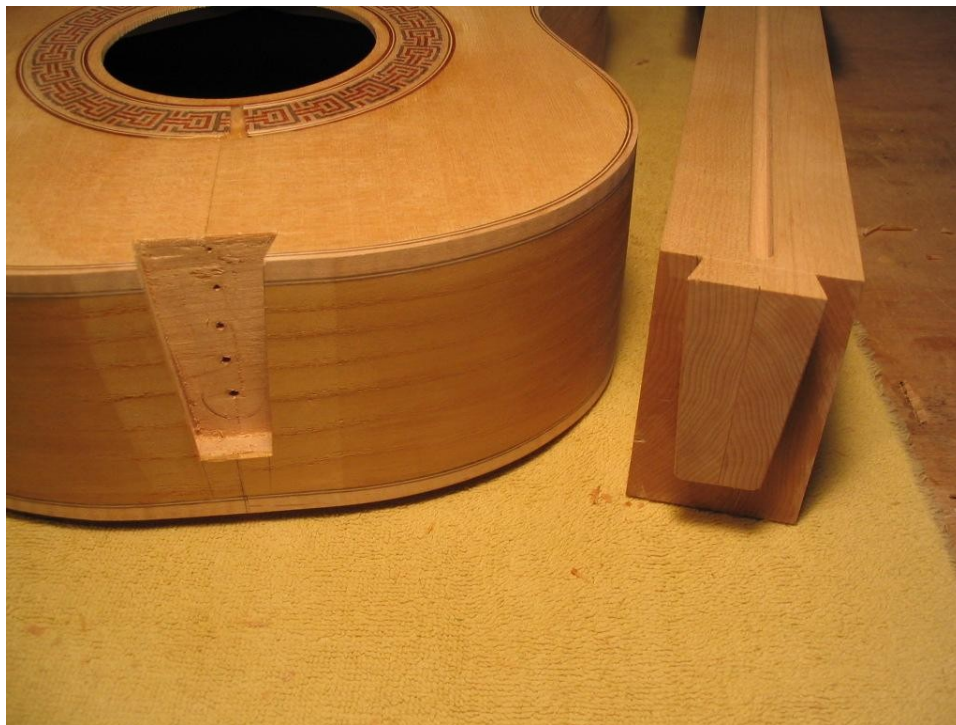
The bulk of the mortise can now be wasted away using a large-diameter drill bit in a drill press. The piece of stock is clamped on the top of the body to keep the bit from breaking out. The depth of the holes should be about $\frac{1}{2}$ " plus $\frac{1}{16}$ ". The mortise will be deeper than the tenon is long, so there will be some space at the bottom of the mortise. The bottom mortise surface isn't important in the strength of the joint - in fact, if it's not deep enough, this surface will actually interfere with the fitting of the joint. Plus, leaving some space makes the joint a little easier to take apart if this is needed in the future to remove the neck for a neck reset or other repair; the gap lets steam used to soften the glue penetrate deep into the joint.



The remainder of the mortise is now chiseled out. With the body clamped as shown, the neck block absorbs the impact of the mallet when chopping the mortise (but don't be too heavy-handed about it...) Again, the depth of the back face of the mortise (with the little divots left by the drill bit) isn't critical, as long as it's deep enough for the face of the tenon to clear it. The angled sides of the mortise are important, though, and should be trimmed carefully. The bottom face is also not critical, but again needs to be deep enough so the tenon can seat in the mortise.



When finished chopping, the mortise should match the tenon.



The tenon can now be fit into the mortise. If the tenon is left a little large (or the mortise a little small), the tenon (or mortise) will need to be shaved a bit to get the top of the neck to be flush with the flat on the top of the body. This also permits alignment of the neck: a straightedge laid along the neck's centerline should run along the centerline of the body. The neck alignment can be adjusted by taking a little more off of one side of the tenon. In addition, the fit of the joint should be tested as the mortise and tenon are shaved. If the joint is tight at the top but loose at the bottom, the tenon is a little too wide at the top, and a little should be shaved from the upper portion of the tenon cheeks to rectify this.



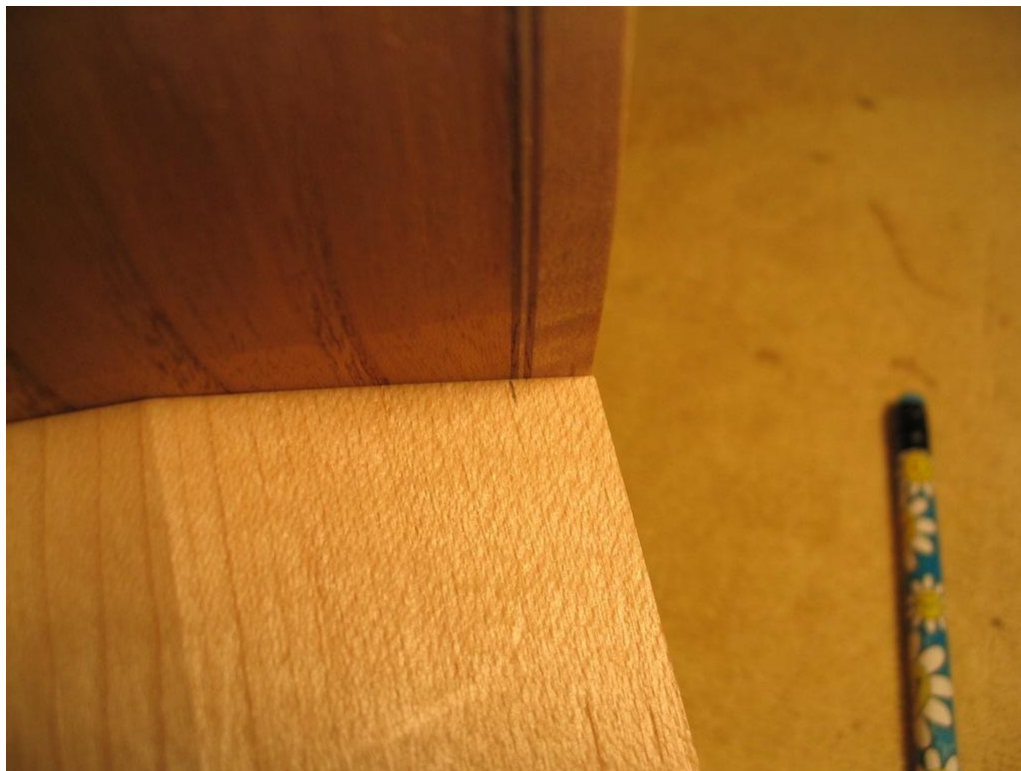
Sometimes the tenon needs to be shaved so much to get the proper fit and alignment that the top surface of the neck falls below the surface of the body. This is easily remedied using shims that can be cut from a sheet of veneer. For very fine adjustment, I've even used thick plane shavings.



When finished, the joint should fit tightly all along the line where the neck dovetail's shoulders contact the sides of the body.



The neck can now be marked to be cut for the heel cap.



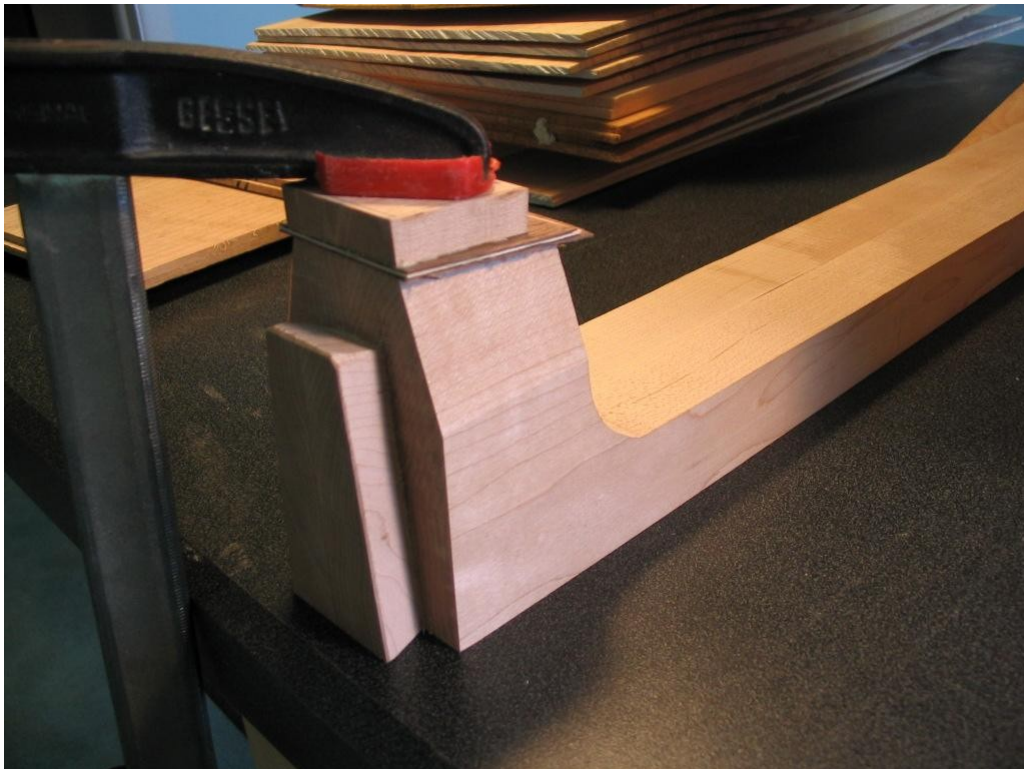
The heel cap can be glued so it's at a right angle to the sides, but I prefer to angle it back so it matches the angle of the back. The appropriate angle can be obtained with the marking gauge in the same way that the angle was transferred from the top to the neck.



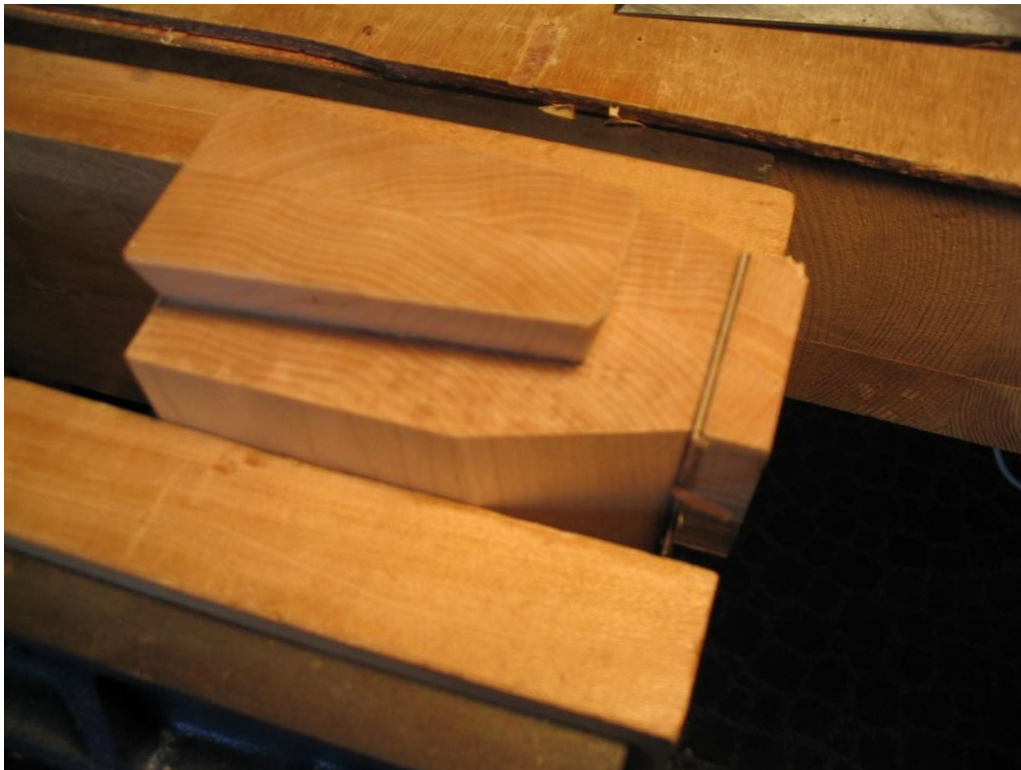
The complementary angle is transferred to the neck stock, and the stock is cut and planed flat.



The heel cap is then glued onto the planed flat. I like to include several layers of veneer to match the purfling on the binding on the body.



When the glue is dry, the heel cap is pared to be flush with the shoulders of the dovetail.



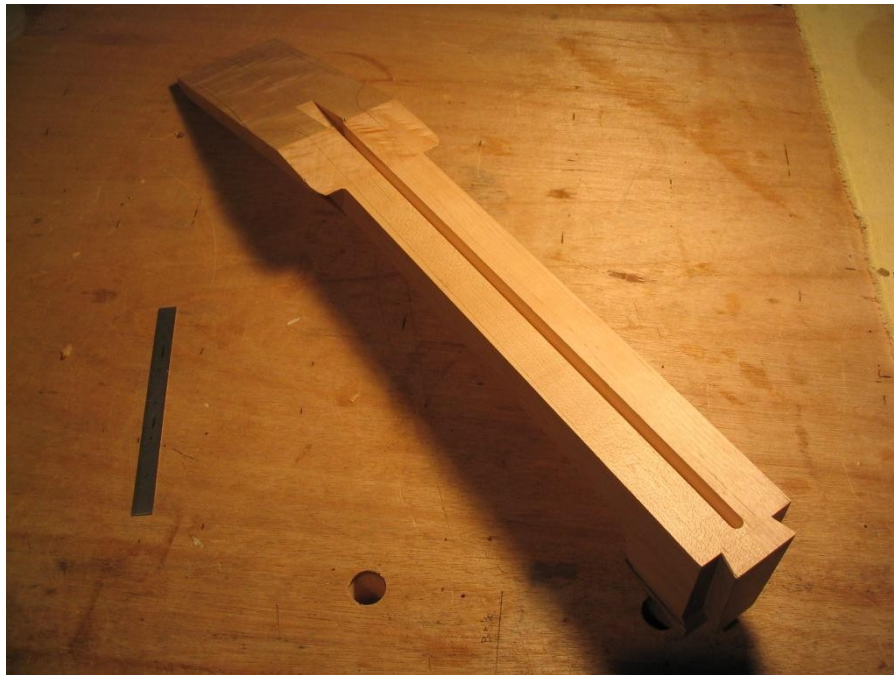
Finally, the fit of the neck is checked.



Chapter 13 - Carving the Neck

Carving the neck is one of the most enjoyable parts of building a guitar. The blocky, chunky neck blank is turned into a sleek, smooth guitar neck.

The neck stock is first tapered. I use a neck width of 1.7" at the nut, and 2.1" at the 14th fret, where the neck joins the body. The neck taper is marked, and the peghead outline is drawn on the peghead stock.



The lower portion of the taper is sawn first.



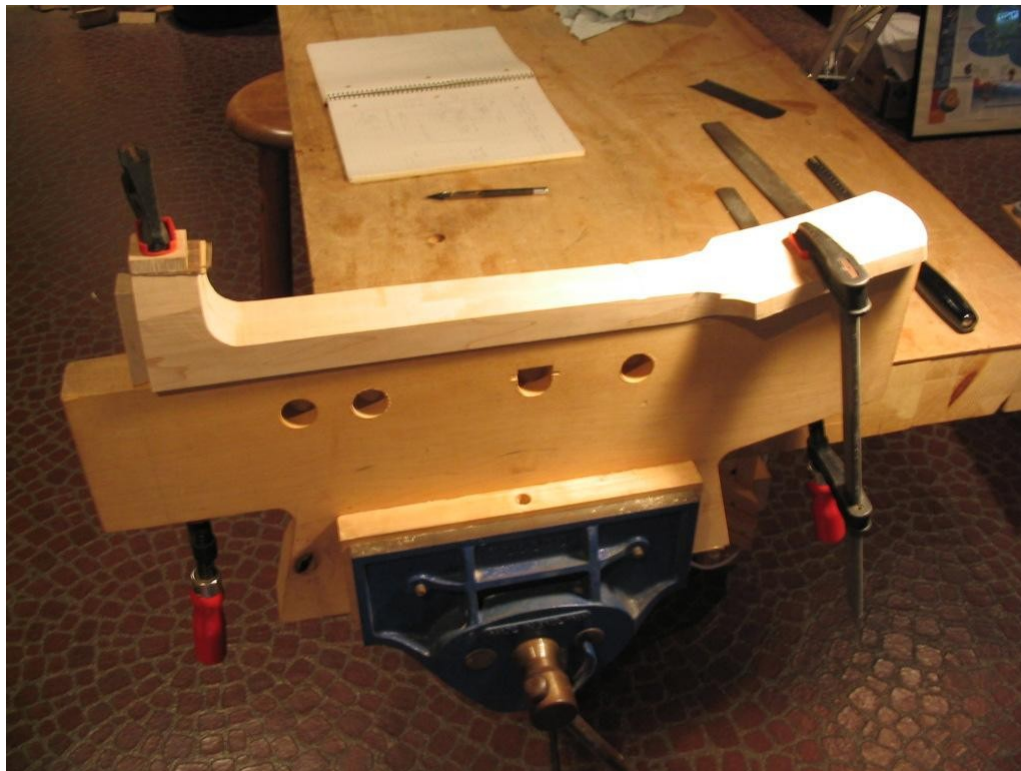
Then the peghead outline is cut, and smoothed with a spokeshave and rasp.



The taper on the neck is now finished with a plane and files; the file is needed since the curve of the peghead will prevent the plane from reaching that end of the fretboard. The sides of the taper should be made absolutely straight.



For carving, the neck is clamped to a carving jig. There's a wedge underneath the peghead to support it.



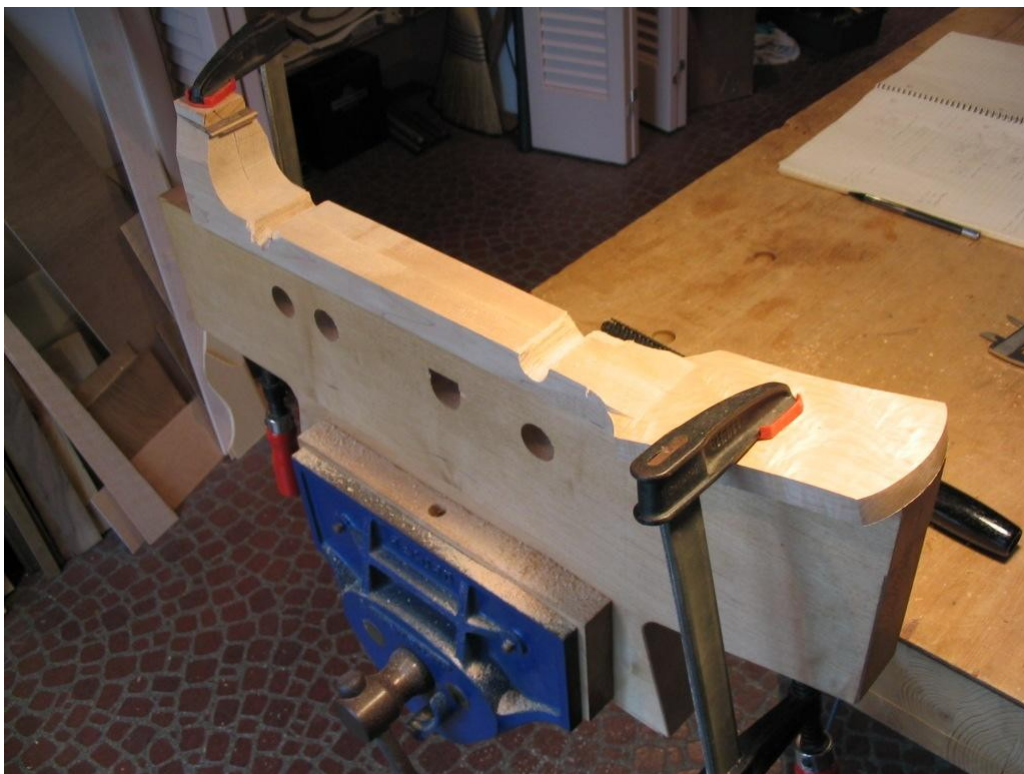
The neck thickness is first established at the 2nd and 10th frets by cutting grooves at these positions to the correct depth. For this neck, I'm using thicknesses of .550" at the 2nd fret and .600" at the 10th fret.



The neck thickness is measured as the groove is deepened. The hole underneath the groove position is exactly 1" from the top surface of the jig to make measurement easier.



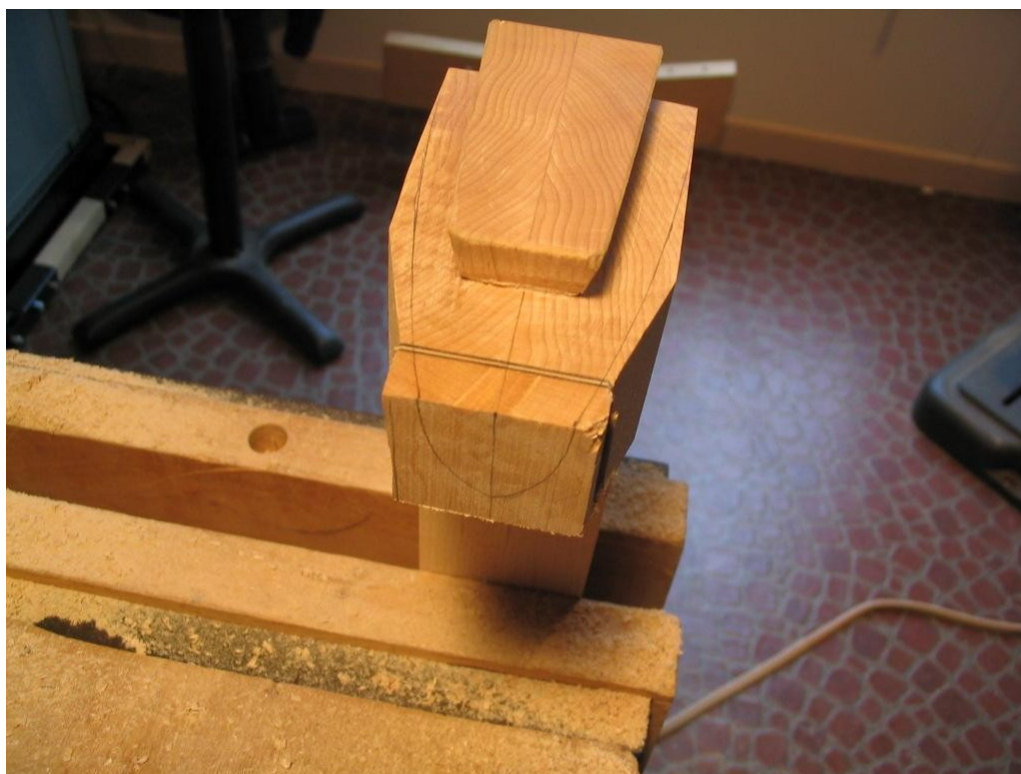
The neck after the grooves have been cut - ugly, but the depth references are important to ensure the neck is thinned to the correct thickness.



I then lay out a pattern for a curved-diamond detail on the underside of the neck-peghead joint, below where the trussrod groove ends. This helps to strengthen the neck in this area, and provides a nice sculptural detail.



The heel profile is marked on the heel of the neck blank.



The neck is now thinned with a drawknife and spokeshave. The neck is thinned linearly between the two grooves.



The neck taper is checked to make sure the surface is straight between the two grooves.



The heel is rough-shaped with a bow saw, then shaped with drawknife, chisels, rasps and scrapers.



The peghead diamond detail is trimmed next.



The neck is shaped further by carving facets on either side. The facets here are $\frac{11}{16}$ " wide, and extend down to $\frac{3}{16}$ " from the top surface (i.e., there's a $\frac{3}{16}$ " facet left on the sides of the neck).



The neck is finally smoothed between the facets with a spokeshave.



The peghead diamond shaping is completed, merging it with the neck.



Chapter 14 - Constructing the Fretboard

The fretboard is generally made of quartersawn rosewood or ebony, and has a finished thickness of approximately .230". After being thinned to the correct thickness, one side of the fretboard is trued to act as a reference edge when cutting the fret slots. The positions of the fret slots are marked on the fingerboard blank using a ruler graduated in 1/100ths of an inch. This level of accuracy is sufficient to ensure the correct intonation of the fretted notes.

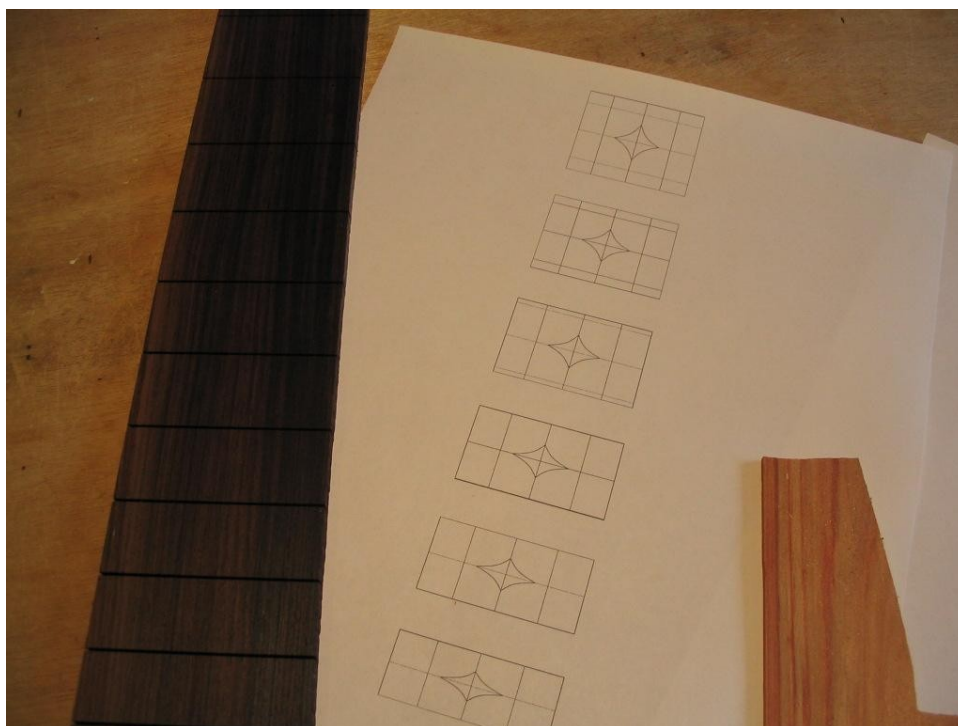
The positions of the frets are based on the 12th root of 2, and depend on the scale length chosen for the guitar. There are a number of fret-position calculators available on the web; a spreadsheet that calculates the positions is available [here](#).



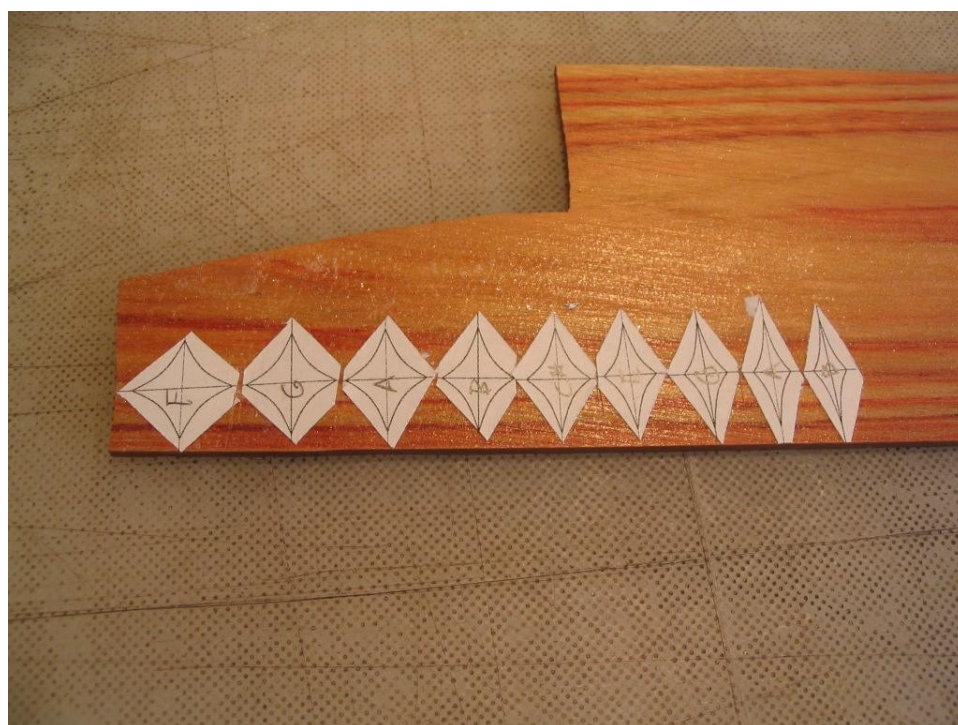
The fret slots are next cut using a custom miter box. The slots are cut with a dovetail saw whose kerf is the correct thickness for the frets. Since I use an epoxy fretting method, the kerf is equal to the width of the fret tang plus the barbs on the sides, so the fret will slip into the slot with little resistance. The epoxy will fill the rest of the slot, forming a casting around the tang and barbs to hold the fret securely in the slot. Traditionally, the fret has been hammered into the slot, with the barbs gripping the sides of the slot to hold the fret in, and the slot has consequently been cut to the width of the tang not including the barbs. But the hammered-in frets are prone to "popping" out of the slots since they're held just by the barbs, so I prefer the epoxy method.



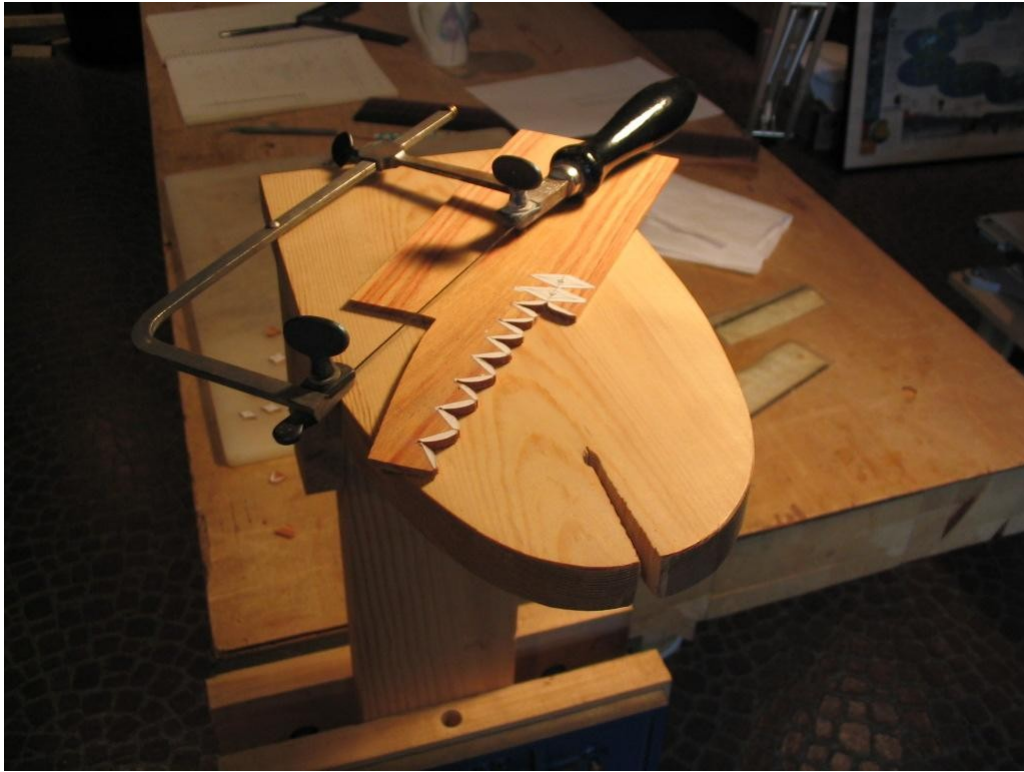
Once the fret slots have been cut, the fret position markers can be inlaid into the fretboard. The markers are usually placed at the F, G, A, B, C#, E, G, A and B fret positions. Rather than using simple dots or some other identical shape for each marker, I use software called [Fretmarker Design](#) to design the inlays. This program allows the shape to be designed, and then scaled in size to the corresponding fret rectangles; thus the diamonds in the photo below decrease in height and increase slightly in width.



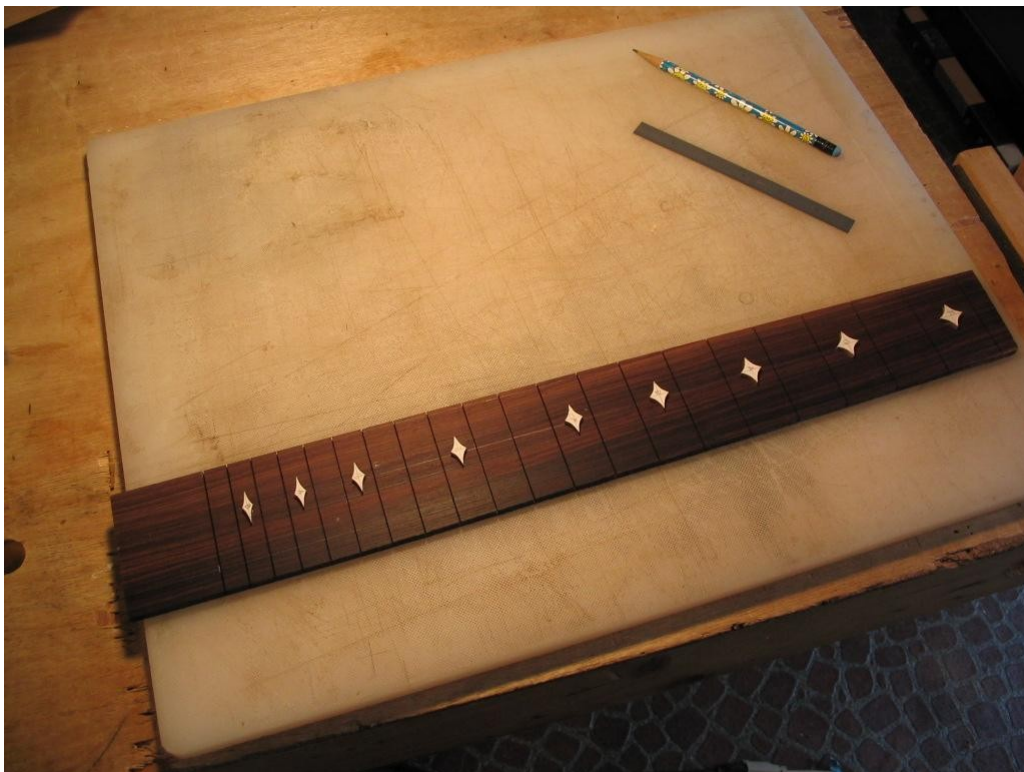
The fretmarker designs are glued to the marker material using spray adhesive. In this case, the fretmarker material is 1/8" tulipwood. Other materials commonly used for inlays are abalone and mother of pearl.



The inlays are cut out using a jeweler's saw and a "bird's mouth", a platform with a small slot and hole to support the fretmarker material while sawing.



The inlays are then placed on the centerline of the fretboard, and their outlines scribed with an Xacto knife. I attach the inlays to the fretboard with spray adhesive to keep them from slipping while scribing.



The recesses for the inlays are routed using a Dremel tool with router base attachment and small bits. The depth of the recesses is set to be slightly less than the thickness of the inlay material so the inlays will sit very slightly above the fretboard surface and can be pared flush after gluing.



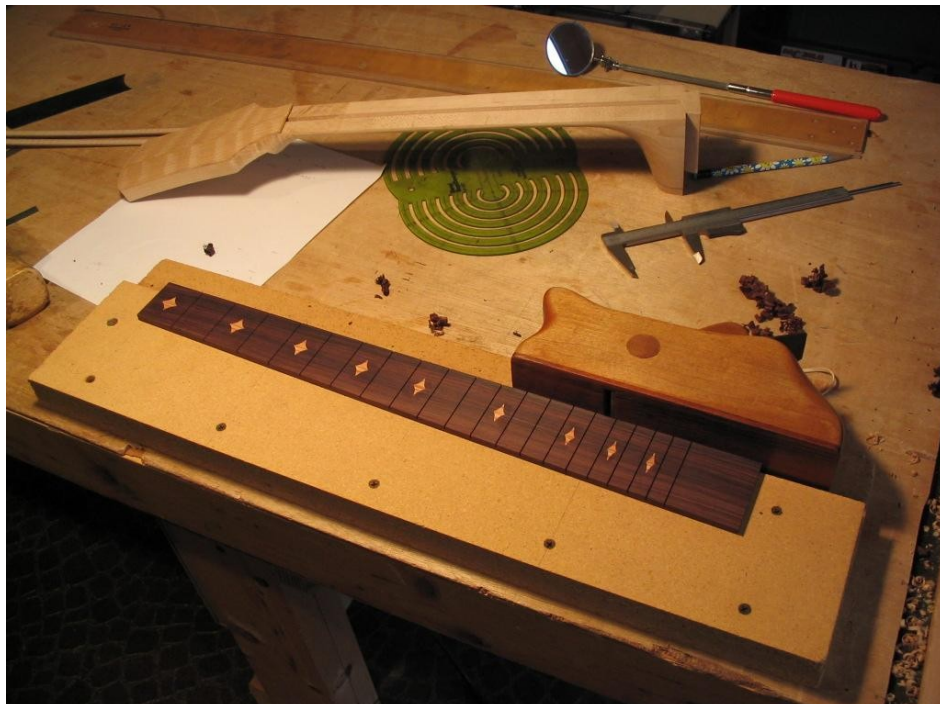
Since the bits can't reach into the sharp corners of the design, these must be finished with an Xacto knife.



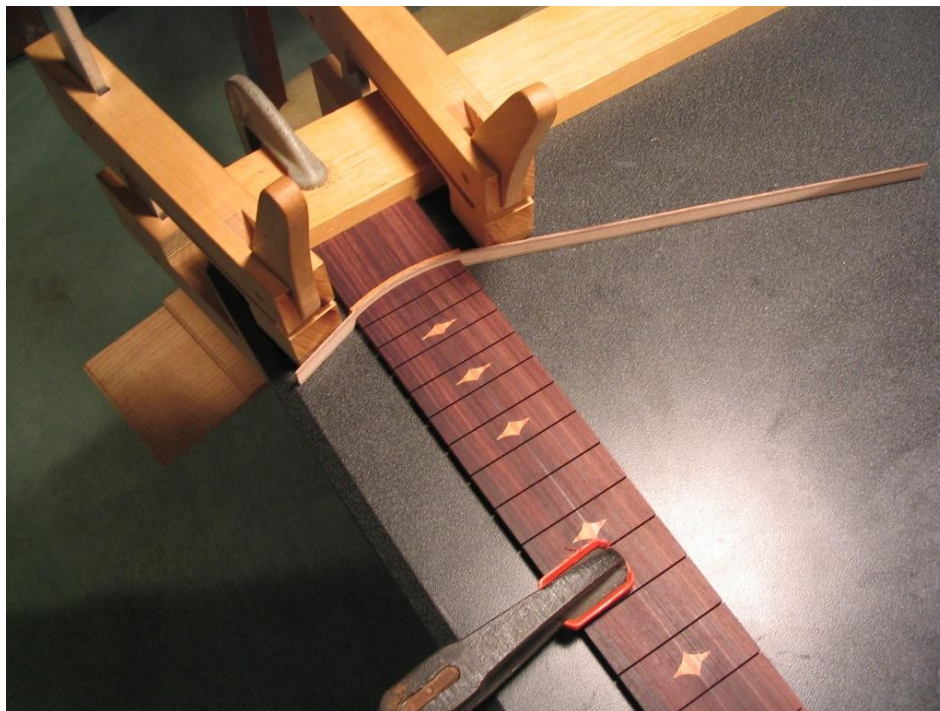
The inlays are then glued into the routed recesses. The bottom edges of the inlays are chamfered slightly to allow them to enter the recesses more easily, and the inlays are pressed into the recesses using a hand clamp. The inlays are then pared flush with the surface of the fretboard using a sharp chisel.



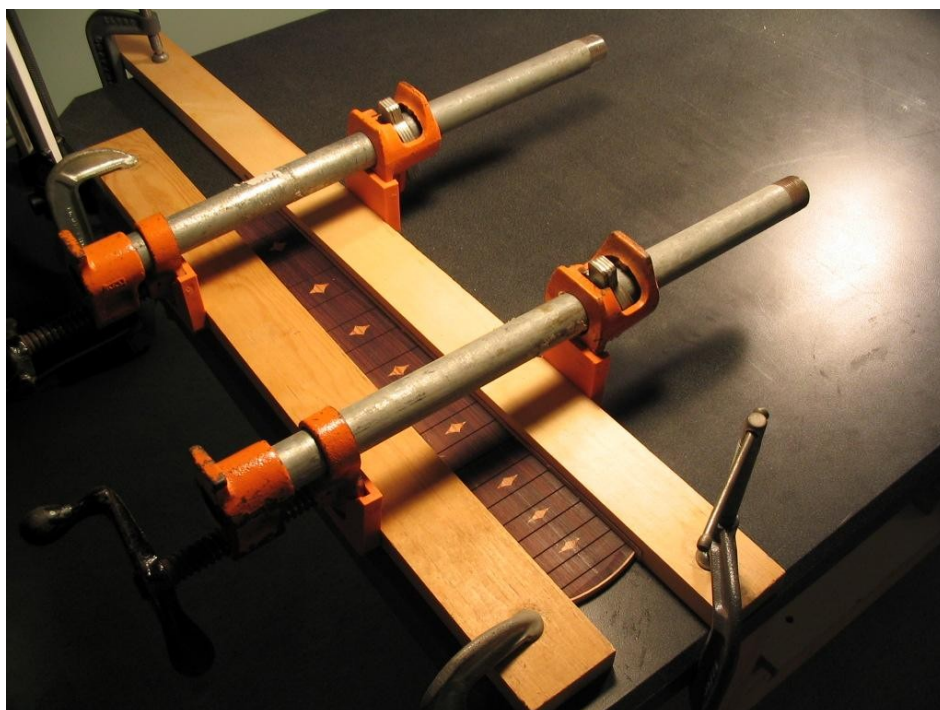
The fretboard is next cut and planed to the appropriate width; note the use of a shooting board in the photo below to keep the edges of the fretboard square. The width at the nut and 14th fret (where the neck joins the body) are measured on the neck with a veneer caliper, and used for the corresponding fretboard widths. However, since binding will be applied to the fretboard, the thickness of the binding is subtracted from the widths in tapering the fretboard. I try to match the neck widths to within a few thousandths of an inch.



The body end of the fretboard is cut next. The length must be determined so the fretboard doesn't extend over the soundhole, but covers the gap in the rosette at the top of the body. The fretboard binding material is then glued to the bottom edge of the fretboard. The binding material is taller than the thickness of the fretboard, and will be trimmed flush after gluing. Here the cutoff piece from the bottom of the fretboard is used as a caul (with a thin piece of cork on the contact surface - you can get sheet cork at an auto parts store, where it's sold as a gasket material).



The fretboard binding is next glued to the sides of the fretboard. Any glue squeeze-out that gets into the fret slots should be removed with a thin blade - I use an Xacto knife blade with the edge ground flat. When the glue is dry, the binding can be trimmed flush with the surface of the fretboard.



Chapter 15 - Attaching the Neck and Fretboard to the Body

With the body, neck and fretboard completed, the three components can now be joined. The neck is first attached to the body with the tapered sliding dovetail joint, and the fretboard is then glued to the neck and body.

The fit of the sliding dovetail joint can be adjusted with thin shims placed along the "cheeks" of the dovetail; the fit should be such that the top surface of the neck is flush with the top when the dovetail is tight. The shims can be thin slices of veneer if the dovetail is particularly loose or thick plane shavings if the joint is closer to a good fit. A pair of shims can be seen lying on the face of the guitar in the photo below, one a veneer shim and one a plane shaving. Another shim can be seen in position in the fitted joint, held in place with a piece of masking tape so it doesn't move when the dovetail is slid into place.

Attaching the neck to the body is quite simple; glue is applied to the appropriate surfaces of the dovetail, the dovetail is slid into the mortise, and the neck is clamped in place with a single hand clamp. One important point is that glue is applied only to the two cheeks of the dovetail, i.e., only to the surfaces on which the shims are placed (and to the shims themselves). Glue is not put onto the other surfaces, for several reasons. First, the glue is only needed to keep the dovetail from sliding out of the mortise. The glue doesn't add any mechanical strength - the joint is plenty strong enough just from the dovetail in the mortise. Second, the joint can become extremely difficult to disassemble in the future for repairs that involve removing the neck. Such a repair is not uncommon - the neck is removed and the joint re-cut to change the neck angle in what's called a "neck reset", which can be necessary if the guitar top bulges outward from the string tension on the bridge as the instrument ages. In fact, some luthiers and manufacturers have switched to removable neck joints (glue-less pinned or bolted joints) specifically to facilitate this type of repair. In any case, if you put glue on all the "obvious" surfaces, it can make it very difficult to remove the neck in the future. Thus glue should be put only on the "cheeks".

When glue has been applied, the shims are inserted into the mortise and the dovetail is slid into place. A clamp is then used to fully seat the dovetail in the mortise; the caul on the top of the guitar allows the clamp to seat the joint, but stop when the neck surface is flush with the top surface.



A caul is similarly used on the bottom of the guitar body, to raise the clamp up so the heel cap won't interfere with the joint sliding into place.



When the joint is fully seated, the purfling on the body should just line up with the veneer shims glued under the heel cap.



When the glue has dried, the shims can be trimmed where they protrude from the joint, and the neck top surface and guitar top can be lightly surfaced with a sharp hand plane.



The heel cap is deliberately made overly thick so that it can be trimmed flush with the back of the guitar after the neck is attached. Note the U-shaped clamping caul on the neck used to secure the guitar while the heel cap is trimmed.





At this point the edge of the soundhole can be rounded to soften it with 150-grit sandpaper.



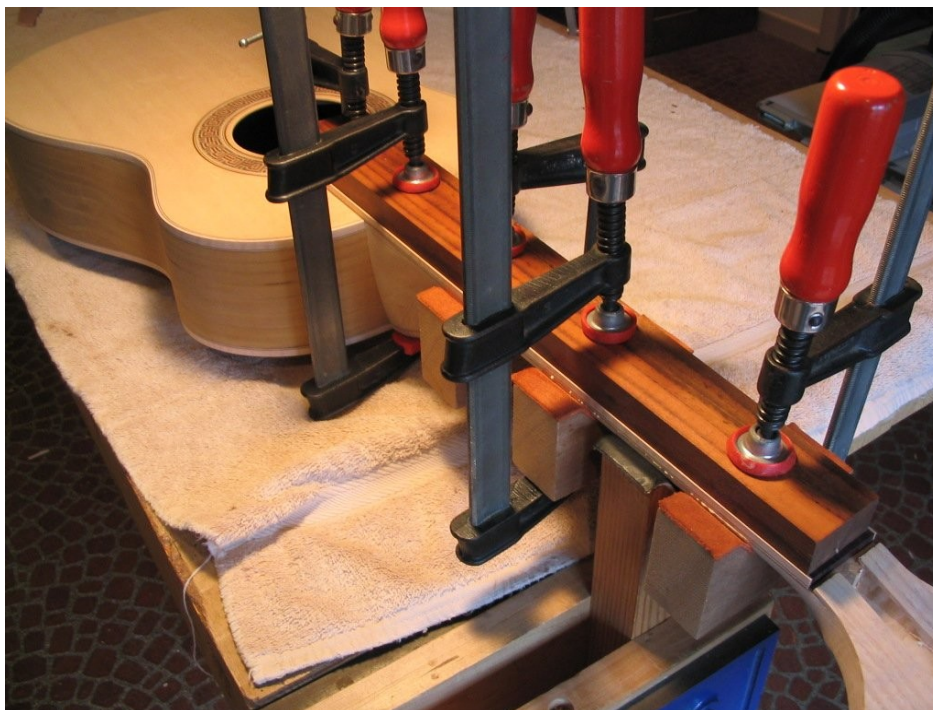
Once the neck is attached, the fretboard can be glued onto the neck and body. The bound and inlaid fretboard is shown below.



The fretboard is attached using a straight stiff clamping caul for the top, and V-shaped cauls lined with leather for the neck undersurface. The V-shaped cauls help to put pressure toward the outside edge of the neck, tending to counteract the tendency for the neck gluing surface to become slightly convex across its width when the glue is applied. This happens because the glue is water-based, and thus tends to swell the wood slightly at the point of contact.



Glue is applied to the neck surface, being careful to keep it out of the trussrod channel. Glue is also applied to the fretboard, on the portion which extends over the body. The fretboard is then placed onto the neck and body, and clamped in position. A small mark should be placed on the side of the fretboard to make sure that the 14th fret falls exactly on the neck-body joint. Note that the fretboard will tend to slide around as the clamping pressure is applied, especially if too much glue is used. The proper alignment can be maintained by tightening the clamps slowly and checking that the fretboard hasn't moved out of position, either side-to-side or lengthwise.



The portion of the fretboard which extends over the body is clamped with the use of clamping cauls within the body, sized to protect the braces. Glue squeeze-out can be cleaned up once the clamps have been tightened.



When the glue has cured, the clamps can be removed and any glue residue scraped and sanded away.

The peghead inlay is next. The design for the inlay is transferred to the inlay material (rosewood, in this case), and the pieces to be inlaid are cut out using a jewelers saw and "bird's mouth". For better visibility, I create the design on paper, and then glue this to the inlay material with spray adhesive.



The pieces to be inlaid, cut from the inlay material.



The inlay design is also transferred to a template in the shape of the peghead, to aid in positioning the inlay. The dark areas are cutouts used to make marks with a pencil to mark specific points on the inlay.



Below, the registration marks have been penciled through the cutouts, and the first inlay piece is placed in position. The piece is then traced with an Xacto knife, and the resulting inlay groove is routed with a Dremel tool and small bits. The sharp corners are finished up with an Xacto knife. The depth of the groove is less than the thickness of the inlay material, so the inlay will stick up above the peghead surface after being glued.



The photo below shows one inlay piece being glued into its groove, and the groove for the second piece. The inlay is trimmed flush with the peghead surface when the glue has dried.



The peghead when the inlay has been completed.



At this point, the guitar is completed "in the white", ready for the finish to be applied.



Chapter 16 - Applying the Finish

The woodwork of the guitar is now mostly finished (except for the bridge). At this point, the guitar is completed "in the white", and needs to have a finish applied to protect the wood and enhance its appearance.

Finishes

Many different finishes are used on guitars. The traditional finish, and one that's still used on classical guitars, is called French polish. This is a finish that consists of layers of shellac that are successively applied with a "rubber", a cloth "sponge" that lays down a thin coat of shellac and smooths any lines left in the application of the previous coat. A few drops of linseed oil are used to keep the pad from sticking as each new coat is applied. The finish builds slowly, and the final topcoat is leveled with very fine sandpaper (traditionally, pumice was used) and then rubbed to a high gloss. A well-done French polish has a glass-like appearance, with beautiful reflectivity and gloss. Unfortunately, the finish takes a long time to build to the final thickness, and some experience is required to learn the technique. In addition, the finish is somewhat fragile - it's very resistant to water, but easily damaged by contact with alcohol since that's the solvent for shellac.

On steel-string acoustic guitars, the traditional finish has for some time been lacquer, specifically nitrocellulose lacquer. This is a fast-drying finish that gives a beautiful gloss. The finish is usually sprayed onto the guitar, since it dries so quickly that brushing leaves brush marks and lines where adjacent brush strokes overlap. Spraying requires appropriate equipment, but allows the finish to be applied quickly and evenly. However, one problem with spraying nitrocellulose lacquer is that its solvent is extremely flammable. The finish must be sprayed outdoors, or in a special explosion-proof spray booth. In addition, the evaporating solvents are essentially air pollutants, and large-scale users of such finishes (such as automotive refinishers and furniture manufacturers) have been required to reduce the amount of these volatile organic solvents they produce. This has led to the development of alternative finishes with reduced VOC (volatile organic content).

One recent and very promising set of finishes are the water-based lacquers. These are very similar to solvent-based lacquers, but have been engineered as emulsions of tiny droplets of finish suspended in a water-based solution. When sprayed, the water evaporates, causing the droplets of finish to flatten against one another. The droplets contain just enough of the organic solvents to cause them to "melt" together to form the final film before the organic solvent evaporates. These finishes have a number of advantages - they are generally non-flammable and of lower toxicity than the solvent-based lacquers (though it's important to always check the Material Safety Data Sheet (MSDS) for a finish to find out about its flammability and toxicity). The initial water-based lacquers tended to have some problems with appearance and film hardness; however, the latest finishes are equal to the solvent-based finishes, and superior in some ways (ease of sanding between coats, e.g.). However, one noticeable difference between water-based and solvent-based lacquers is the "depth" of the finish when applied to bare wood. Solvent-based lacquers, and French polish, tend to bring out the grain in the wood, seeming to give it a "glow" from penetrating below the surface. The water-based finishes don't seem to penetrate the wood in the same way, and thus don't give the wood quite the same sheen.

To get the benefits of water-based lacquer with the depth of finish of the solvent-based finishes, I use water-based lacquers over a washcoat of shellac. The shellac gives depth to the finish, and the water-based lacquer provides the protective finish and gloss.

Finishing process

To prepare for the application of the finish, the entire surface of the guitar is sanded with 150- and 220-grit sandpaper to remove any tool marks and unevenness in the surface.



Since the bridge must be glued to bare wood to ensure a good bond, the bridge location is masked before the finish is applied. The location of the saddle is marked on a piece of masking tape applied to the top, and the edges of the fretboard are extended to the tape and used to find the bridge centerline.



The bridge profile is printed on paper, and positioned on the masking tape. The outline is traced with an Xacto knife, leaving a tape mask in the exact profile of the bridge.



The fretboard is also masked on its top surface.



The soundhole is sealed to keep the finish out as it's sprayed. I use a plastic coffee can lid with a block of soft foam underneath to push the lid tight against the inside of the top.



Before the finish is applied, the pores of open-grained woods must be filled. This involves forcing a substance into the pores of the wood so the finish will sit on top of it rather than sinking into the pores and having a pitted appearance. Only woods with prominent pores need to be filled; this includes many of the woods used in lutherie, such as rosewood, mahogany, bubinga, and non-traditional woods such as oak, ash and walnut. In particular, spruce and maple do not need to be filled before finishing - their pores are very small and are filled by the finish itself. The guitar shown has back and sides of mulberry, which has large pores that need filling. The most natural appearance comes when clear filler is used. There are a number of fillers commonly used, including cyanoacrylate glue ("crazy glue"), epoxy, and thickened nitrocellulose or acrylic lacquer. Whichever is used, it is applied to small areas of the back and sides and "squeegeed" off with a plastic scraper, leaving the filler in the pores while scraping it off of the surface.

(Picture was not viewable on website)

When it has dried, the filler is then sanded to remove any material that is not in the pores of the wood. A coat of shellac is then brushed onto the guitar, as an undercoat for the water-based lacquer. As discussed above, this helps to give "depth" to the appearance of the finish. The shellac is brushed on, as its solvent, alcohol, is very flammable. The shellac should be applied in a room with good ventilation to ensure that the vapors from the evaporating alcohol don't build to dangerous levels.



The appearance of the wood will change markedly (for the better!) as the shellac is applied. There will inevitably be some brush marks in the shellac finish. However, the finish can be sprayed over the brush marks, as subsequent sanding (described below) will even out the surface. Any drips and runs should be removed, however.



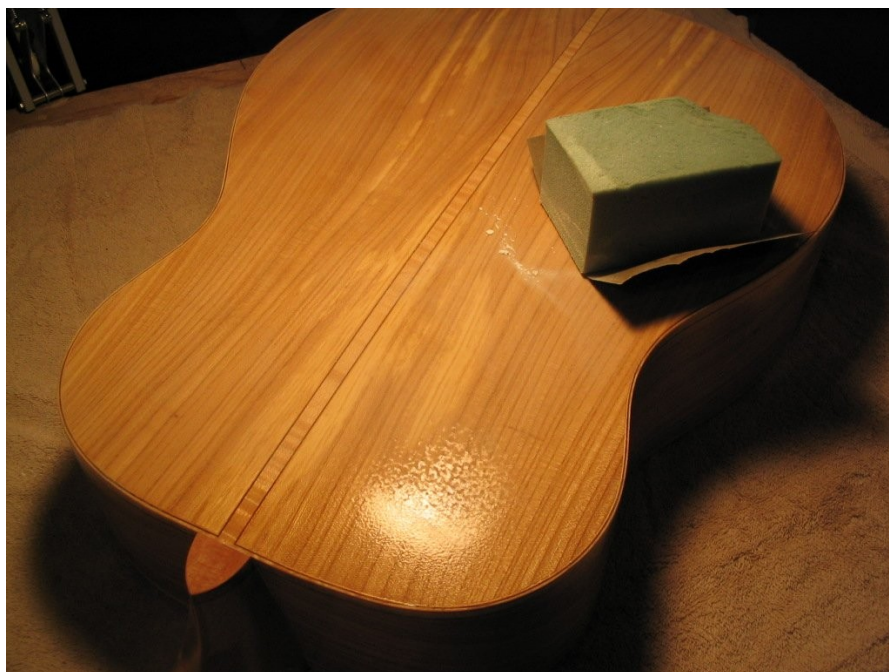
The first two coats of water-based lacquer can now be sprayed onto the guitar. I use a high-volume low-pressure (HVLP) spray system, which helps to minimize overspray. Because I spray only non-flammable water-based lacquers, the low-tech setup shown suffices to exhaust any overspray. This arrangement is not acceptable for spraying any solvent-based finish - these require either a dedicated explosion-proof spray booth, or they must be sprayed outdoors. In addition, even though most water-based finishes are relatively non-toxic, an approved mask must be worn to keep from inhaling the overspray; these finishes are "relatively" non-toxic, not completely non-toxic!



The spray application will leave a high-gloss finish, but one that likely has a somewhat rough surface termed "orange peel" due to the similarity of the texture to the peel of an orange. The surface is leveled by sanding with fine-grit sandpaper - 320 or 400 grit - before the next coats of finish are applied. The sanding can be done either dry or wet, with water as the lubricant. Wet-sanding is generally done to keep the finish from clogging the sandpaper; however, the latest water-based finishes tend to dry-sand very well, with very little clogging (but producing a fair amount of dust). The finish is sanded until it has a uniformly dull appearance, indicating that all of the orange peel has been leveled flat. It's important to be careful at the edge of the instrument, as it's easy to sand through the finish; if this happens, the spot is touched up with shellac before the next finish coats are sprayed. In addition, any spots which need additional filling - pores which were incompletely filled, e.g., will be apparent as glossy spots in the dull finish, and can be filled before the next coats are applied.



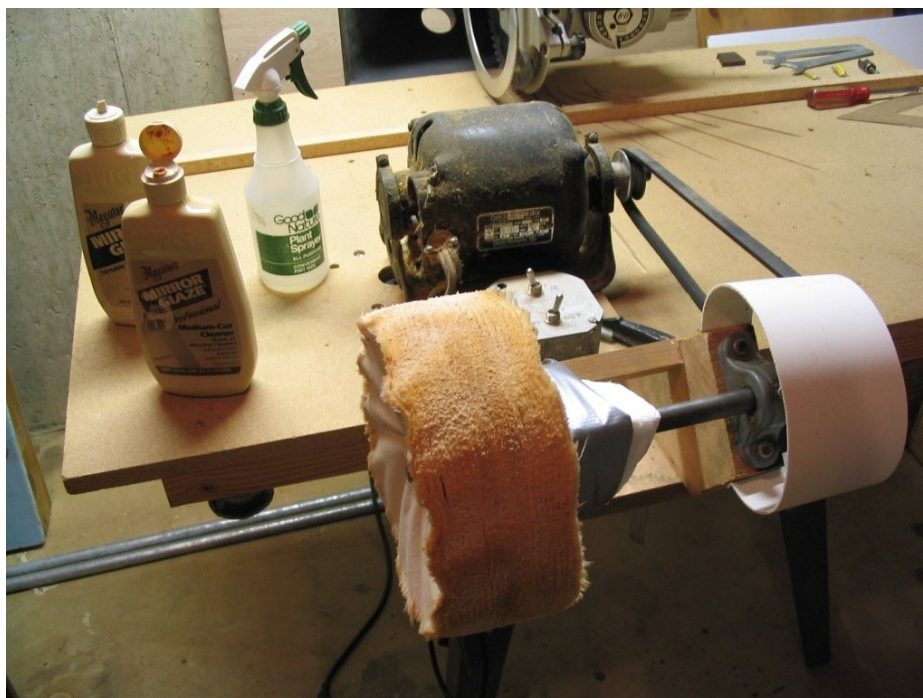
A close-up view of "orange peel", before it is sanded flat.



When the finish has been sanded flat to remove all of the orange peel, the next coats of finish can be sprayed. The sand-and-spray cycle is repeated until the desired number of coats of finish have been applied. I try to keep the finish thin; too thick of a finish will dampen the sound of the instrument. With water-based lacquers, I usually apply 4 to 6 coats, two coats sprayed at a time, with sanding between each spraying. The final coats are sanded with 600 grit sandpaper; at this point, the finish is smooth and flat, but with a dull appearance from the sanding.



The finish is then buffed to return it to a high gloss. A buffing wheel is used, along with various polishing compounds. I use Meguiar's automotive polishes; a wide variety is available, from those formulated to polish out the scratches left by the final sanding to those designed to bring the finish to a mirror gloss. I've found that just two of the compounds are needed: #1 medium-cut cleaner to buff out the sanding scratches, and #3 glaze to produce a mirror finish.



A spray container of water is used as needed; buffing requires a bit of experience to know how much compound, water and pressure to apply. After the #1 compound has been used to buff out the scratches, the finish will look great; however, it's after the #3 compound is used that the mirror finish appears.

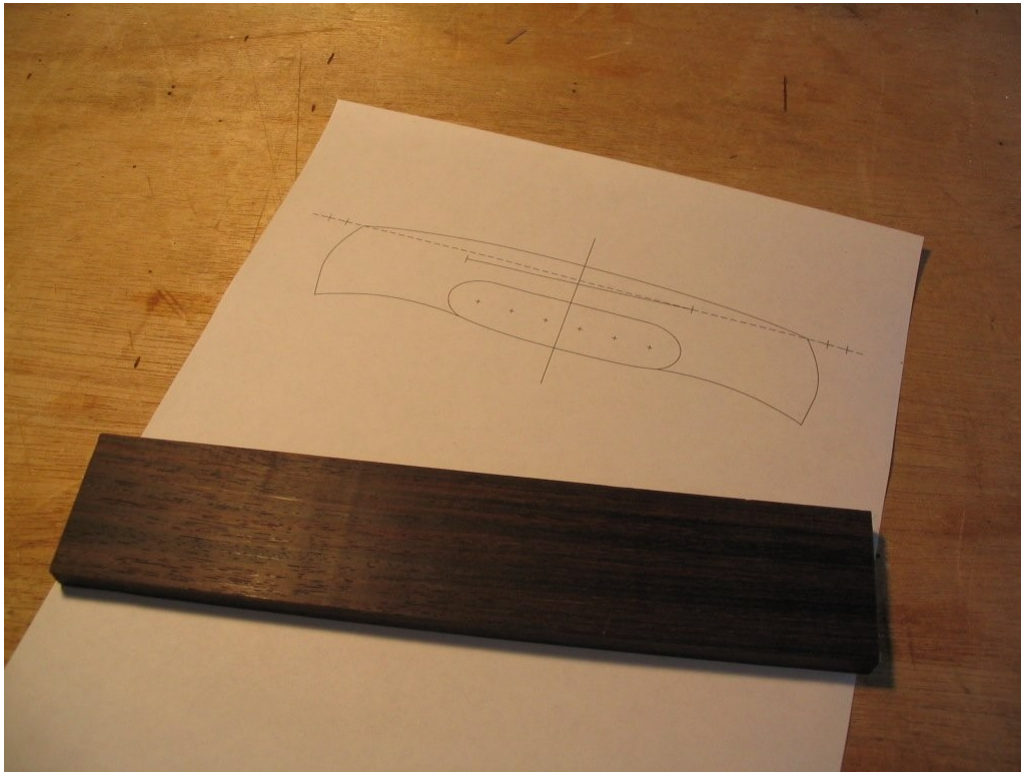


All of the sanding between coats to level the finish really pays off in the final mirror gloss!

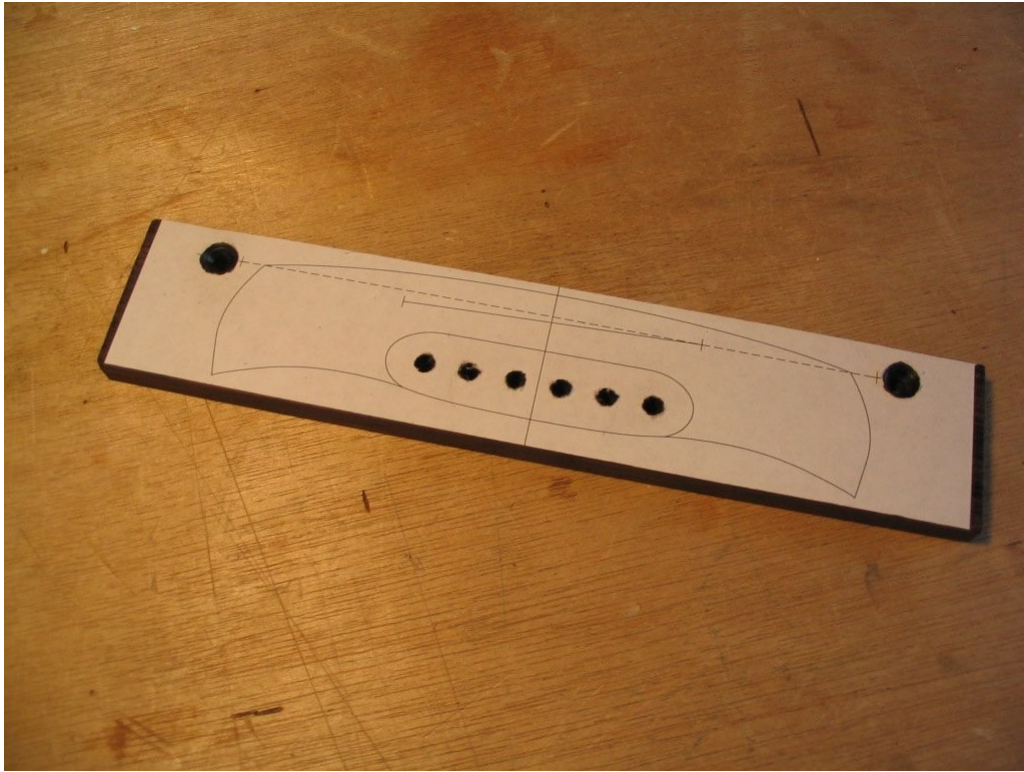


Chapter 17 - Fabricating and Attaching the Bridge

The bridge is made of a hard wood, generally the same as is used for the fretboard. I use a blank 3/8" thick, and a CAD drawing of the bridge. The CAD drawing precisely positions the bridge pin holes, which determine the spacing of the strings. The drawing also indicates the position of screw holes used to attach the bridge to jigs for subsequent machining operations. The design is printed out and attached to the bridge blank with spray adhesive.



The bridge pin holes are drilled with a 3/16" bit, and the holes for the screws used to secure the bridge during subsequent machining operations are drilled and countersunk.



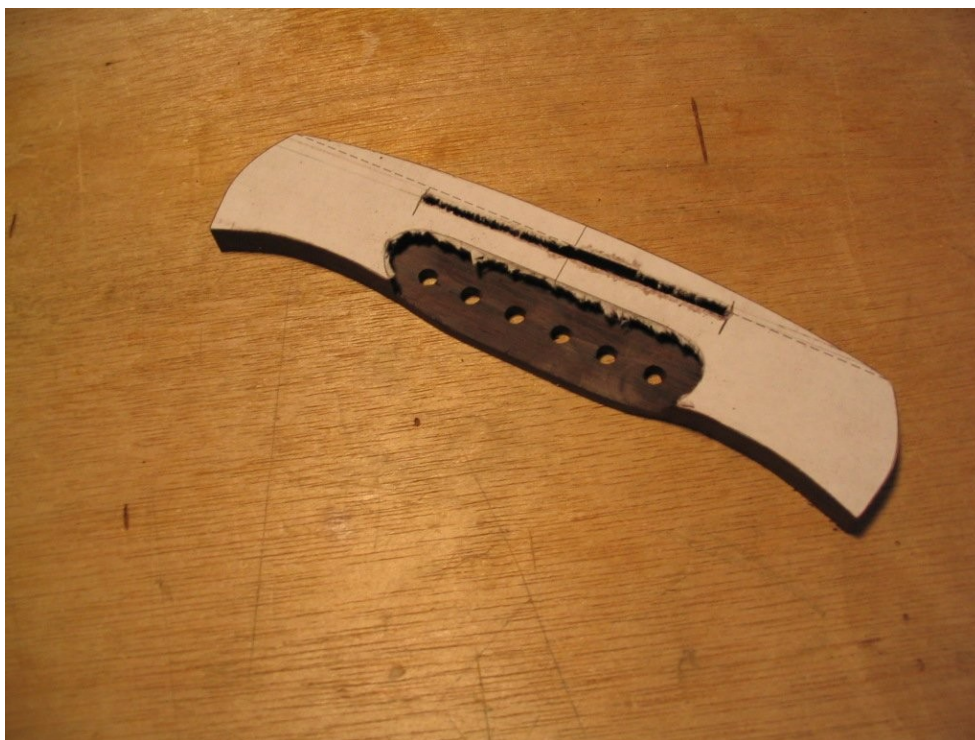
The bridge blank is then attached to a jig used to guide a router as the shelf for the bridge pins is cut. Note that the back profile of the bridge is cut first, as the outline is destroyed by the router cut.



The bridge is then shifted to a second pair of mounting holes so the saddle groove can be cut with a 1/8" bit. The saddle groove is angled to provide compensation for the strings. The saddle is set back 1/8" on the bass side, making the bass strings slightly longer than the treble strings to compensate for a change in intonation when the strings are pressed against the frets.



The outline of the bridge is cut and shaped with scrapers and files.



The bridge blank is then attached to a workboard with double-faced tape for carving.



The bridge is carved with chisels, scrapers and sandpaper,



When carving and sanding is complete, the bridge is polished with fine-grade steel wool.



The bottom of the bridge must be made concave to fit onto the arched guitar top. This is accomplished by attaching coarse sandpaper to a convex-curved caul whose arching matches that of the guitar top, and sanding the bridge bottom to the desired arch.



Pencil lines on the bridge bottom are used as indicators, and are sanded off when the arching is complete. Below, more sanding is needed.



The completed bridge is then glued to the guitar top. The bridge profile was masked before finishing.



The bridge outline is cut with an Xacto knife, and the masking tape is removed to reveal clean wood for a gluing surface.



The bridge is dry-clamped in position and two of the outer bridge pin holes are drilled through the top. Short lengths of 3/16" dowel are placed in the holes during gluing to keep it from slipping out of position when clamping pressure is applied. This isn't absolutely necessary, but can make positioning the bridge during gluing simpler. The positioning dowels are drilled out when the glue has dried and the other pin holes are drilled through the top.



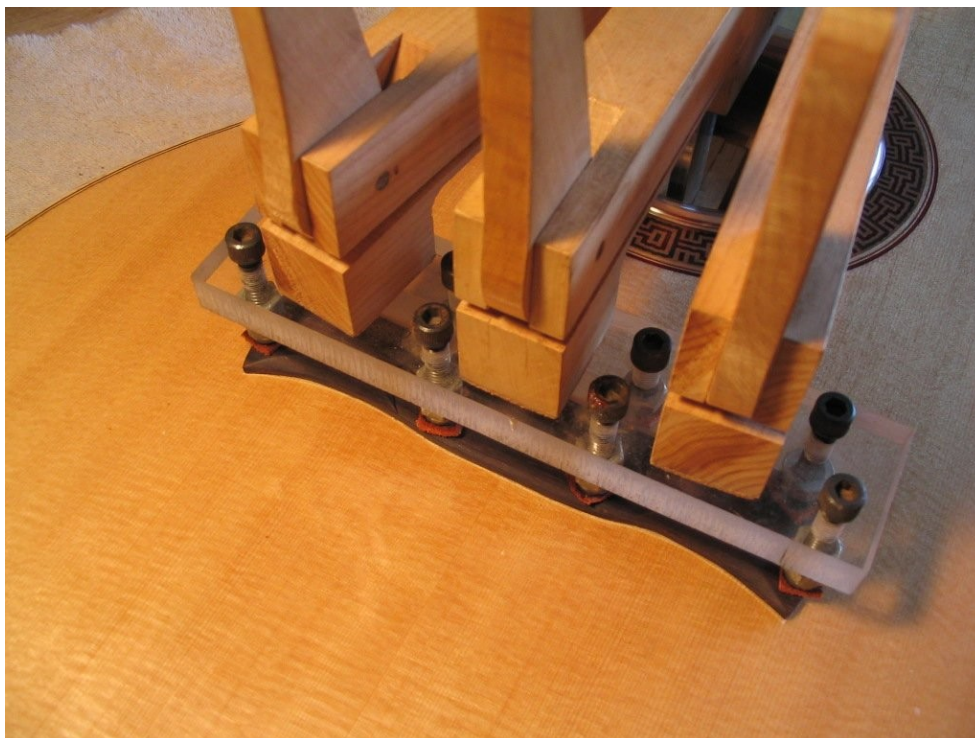
A caul is attached to the bridge plate on the underside of the top with small pieces of double-faced tape. The caul is the same as that used to attach the bridge plate to the top when the braces were attached. Recall that the surface of the caul was made convex to match the arching of the top.



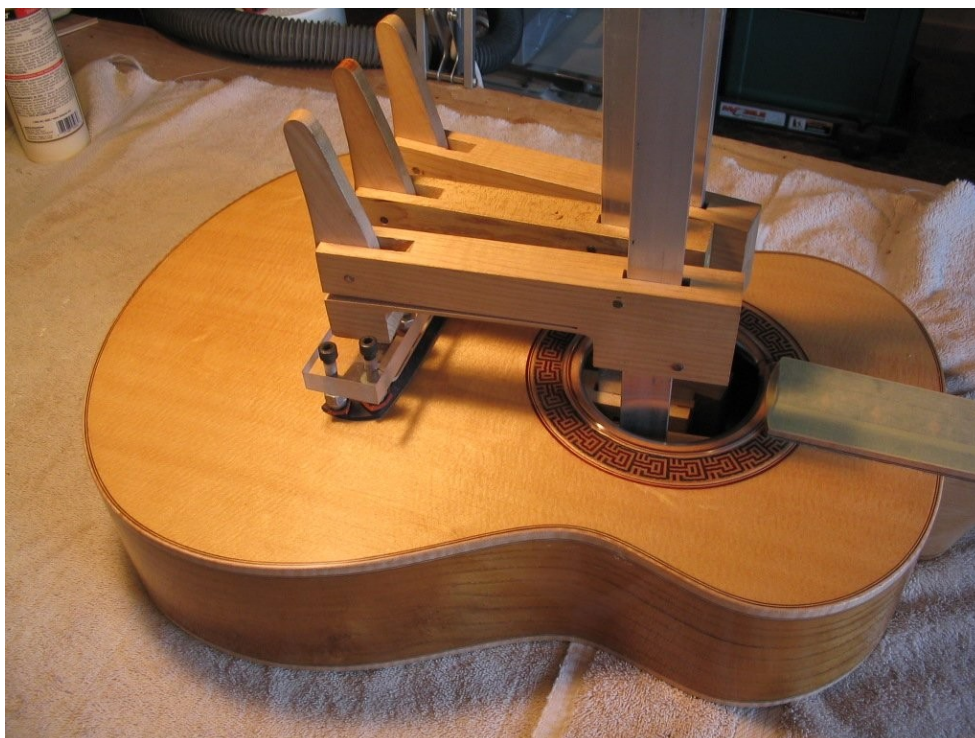
Titebond glue is applied to the bottom of the bridge, it is placed in position, and the short lengths of dowel are placed into the predrilled pin holes to position the bridge. The bridge is then clamped with three cam clamps, using a custom Plexiglas caul.



The following picture shows a close-up of the Plexiglas caul. The caul has eight hex-head screws threaded into it; each screw has an acorn nut at the end with a piece of leather glued over it. The screws are used to accommodate for the irregular top surface of the bridge, so that each contacts the bridge when clamping pressure is applied. The leather on each acorn nut protects the bridge surface.



A small detail visible in this picture is the protector placed around the soundhole, so the clamps won't bump and dent the edge of the soundhole when they're inserted or removed. The protector is simply a length of clear vinyl tubing, slit lengthwise.



When the glue has dried, the clamps are removed. The middle clamp is then reattached to hold the bridge caul in place while the bridge pin holes are drilled through the top. When this is finished, the caul is removed from the bridge plate. The pin holes will be tapered later when the pins are fitted when the guitar is strung up for the first time.

Chapter 18 - Fretting

The frets on a guitar are strips of specially shaped wire with a "T" cross-section, whose "tang" fits into the fret slots cut in the fretboard. The tang has small bumps or barbs on its sides. The traditional way of affixing the frets to the fretboard is to cut the slots to the width of the tang without the barbs; the frets are then hammered into the slots, and the barbs grip the sides of the slot to hold the frets in. Unfortunately, the barbs not infrequently lose their grip, and the frets pop out of the slots, leading to buzzing while playing. Epoxy adhesives provide an alternate method for attaching the frets: the slots are cut to the width of the tang plus the barbs, and the frets are glued in with epoxy. The epoxy forms a little casting around the barbs, and thus holds the frets firmly in place, eliminating the tendency for them to pop out of the slots. The following illustrates this epoxy fretting method.

Surprisingly, the epoxy fretting method makes fret removal easy when it is time for the guitar to be re-fretted when the frets have become worn. Epoxy loses its strength when heated, so the frets are easily pulled from the fretboard if they are each first heated. This is accomplished with a soldering iron run back and forth across the fret surface. The epoxy which remains in the slot is then removed with a fine bit in a Dremel tool. With the traditional method, the barbs have a tendency to cause the fretboard to chip at the edges of the slots when the frets are pried from the fretboard; this doesn't occur with the epoxy fretting method, since the width of the slot includes the width of the barbs.

The fretboard is prepared for fretting by being surfaced so that it is straight along its length and arched across its width. To achieve both ends, a sanding block is used that has the desired convex arch across its width. The block is shown below, made from layers of plywood laminated together into the desired arched profile and faced with Formica.



A plastic protective mask is placed on the guitar top to protect it during surfacing and fretting.



The surfacing of the fretboard is begun using very coarse sandpaper - 40 or 60 grit. As the fretboard is surfaced, the outer edges will be cut first due to the curved profile of the sanding block. Pencil "witness lines" are drawn across the fretboard, which disappear when the sandpaper has cut the complete arched profile. The lines can still be seen in the middle of the fretboard in the photo below, indicating that the arching is not yet complete (the center of the fretboard is still flat).



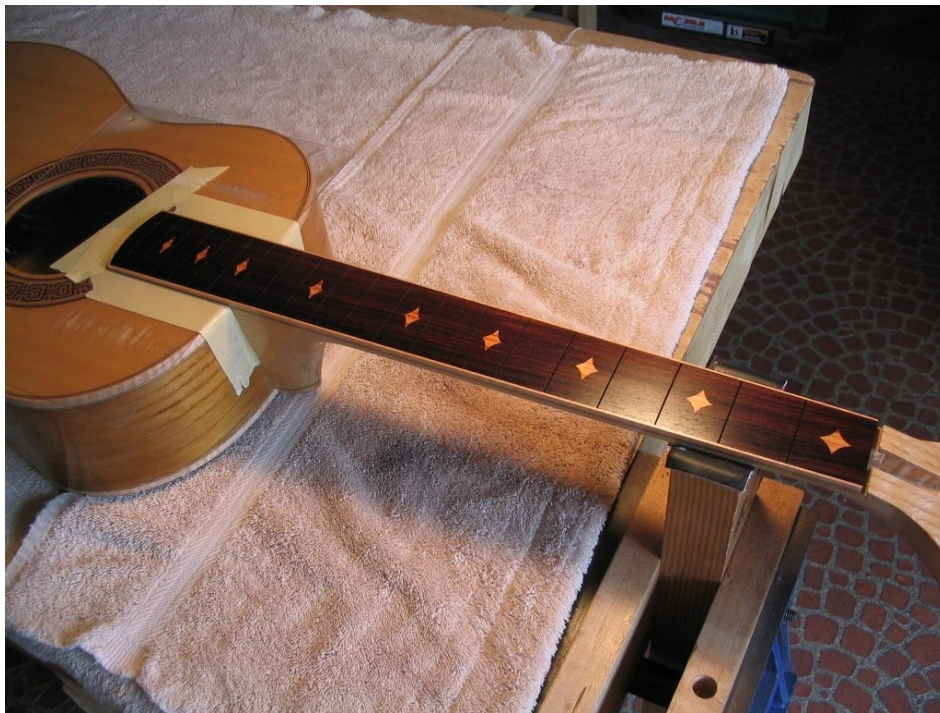
The straightness of the fretboard is checked with a straightedge as surfacing progresses. I try to get the fretboard perfectly flat; some builders put a little "relief" in the fretboard, surfacing it so there's a little space under the center of the straightedge, i.e., so the fretboard is curved up slightly.



When the fretboard surfacing is complete at the coarsest grit, the surfacing continues with a succession of finer grits up through 220 grit. Pencil witness lines are drawn at each stage to make sure the scratches left by the previous grit are removed by the next.



The final sanding is done by hand with 320 grit paper, followed by polishing with steel wool. I then apply a light coat of a mixture of linseed oil and varnish, which makes it easier to remove any epoxy squeeze-out after the frets have been glued. It's important to make sure none gets into the fret slots, where it would interfere with the adhesion of the epoxy used to attach the frets.



The fret wire is usually supplied in straight 2-foot lengths. I curve each length of fret wire into the desired arch to match the profile of the fretboard, since it's easier to bend the long piece of wire before it is cut into appropriate lengths for the frets. The curving is facilitated with a block with a curved top surface and a groove for the fretwire tang to fit into; the block is illustrated two photos down.



The pre-curved fretwire is then cut into appropriate lengths, with each fret being slightly longer than the corresponding fretboard width.



Because the fretboard has binding along the edges, each fret must have its tang notched at the ends so the top surface will extend onto the binding. This also illustrates the block used to curve the fret wire into an arch corresponding to the fretboard arch.



The following picture shows the fret notched to fit within the binding.



The notched frets laid in the fret slots, but not yet glued in the fretboard.



I next chamfer the top corners of each fret slot, using a bent file. This helps to prevent any chipping at the edges of the slots when the frets are removed, which occasionally happens with the epoxy fretting method if the slot is a little too narrow.



The edges of the fretboard are taped to catch any epoxy squeeze-out from the ends of the frets.



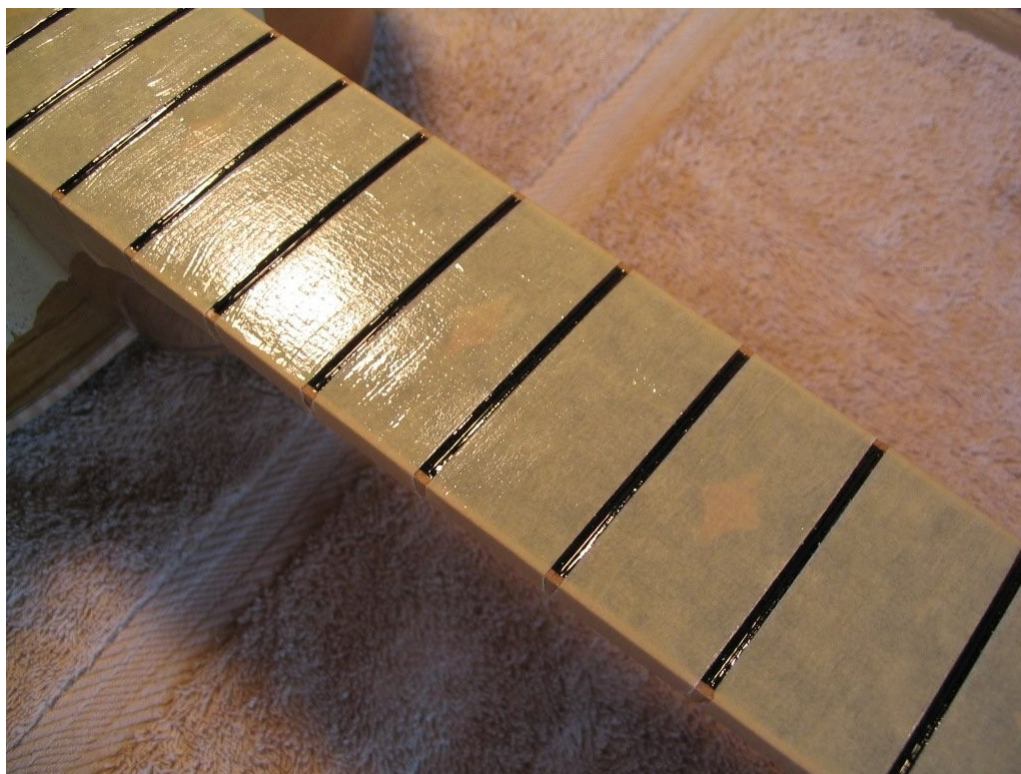
The frets are then placed in the fretboard, and masking tape is applied between the frets to keep epoxy from getting onto the fretboard. Some luthiers don't bother with this taping, instead cleaning and scraping the fretboard after gluing in the frets.



The frets are clamped into place when glued using a special clamping caul. The caul consists of 1/4" Plexiglas tapered in width to match the fretboard, with Plexiglas strips along the edges and a cork strip in the middle. The caul thus applies pressure at the outer edges of each fret where the Plexiglas edge strips contact, and at the middle from the pressure of the cork.



Epoxy is mixed and spread into the fret slots. The frets are then placed into their slots, and any squeeze-out is wiped off with a paper towel dampened with denatured alcohol.



A sheet of plastic wrap is placed over the frets to keep the epoxy from contacting the clamping caul, and the caul is placed onto the frets.



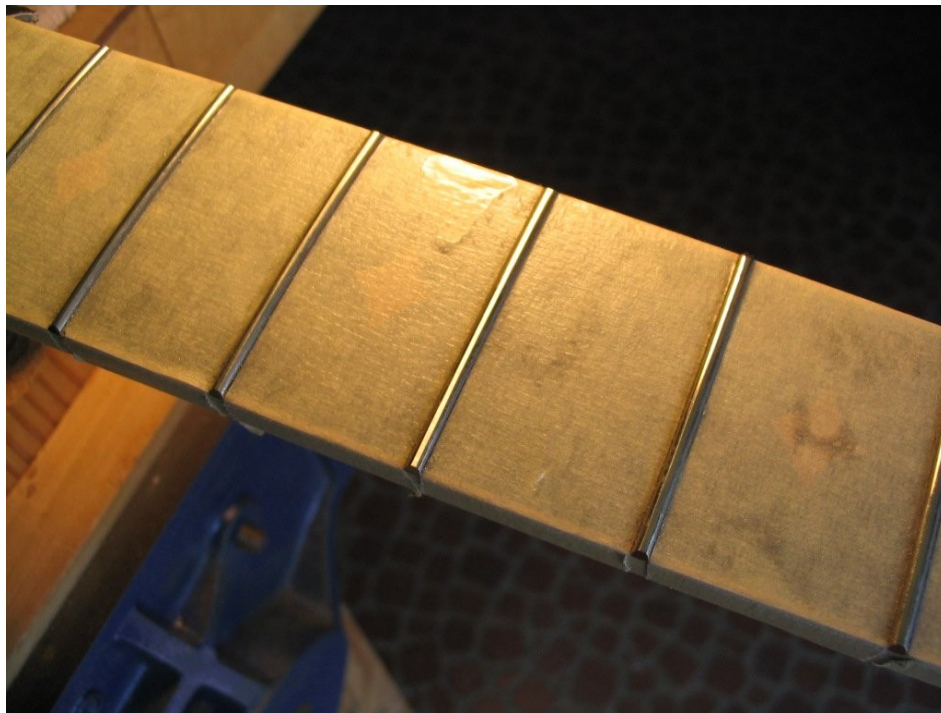
A solid caul is placed over the flexible Plexiglas caul, and the frets are clamped into the fretboard. Note that the protective mask has been removed from the top to allow access to the soundhole for clamping.



When the epoxy has set, the clamps and cauls are removed, and the fret ends are trimmed to the width of the fretboard. The ends of the frets are trimmed flush and angled with a file.



The fret tops are leveled with a sanding block with 320-grit sandpaper glued to the face with spray adhesive. Leveling starts at the body end of the fretboard, and continues to the nut. The frets are surfaced until each shows a flat on its top, which indicates that the frets are all at the same level. The flat appears as the shiny stripe on the fret in the picture below.



The edges are taken off of the flat on each fret using a block with a V-groove cut in it. Sandpaper is held over the groove, and the groove is run along the top of each fret, which rounds off the sharp edge of each flat without taking material off of the top of the fret. In the photo below, a narrow flat can still be seen on the crest of each fret after this operation.



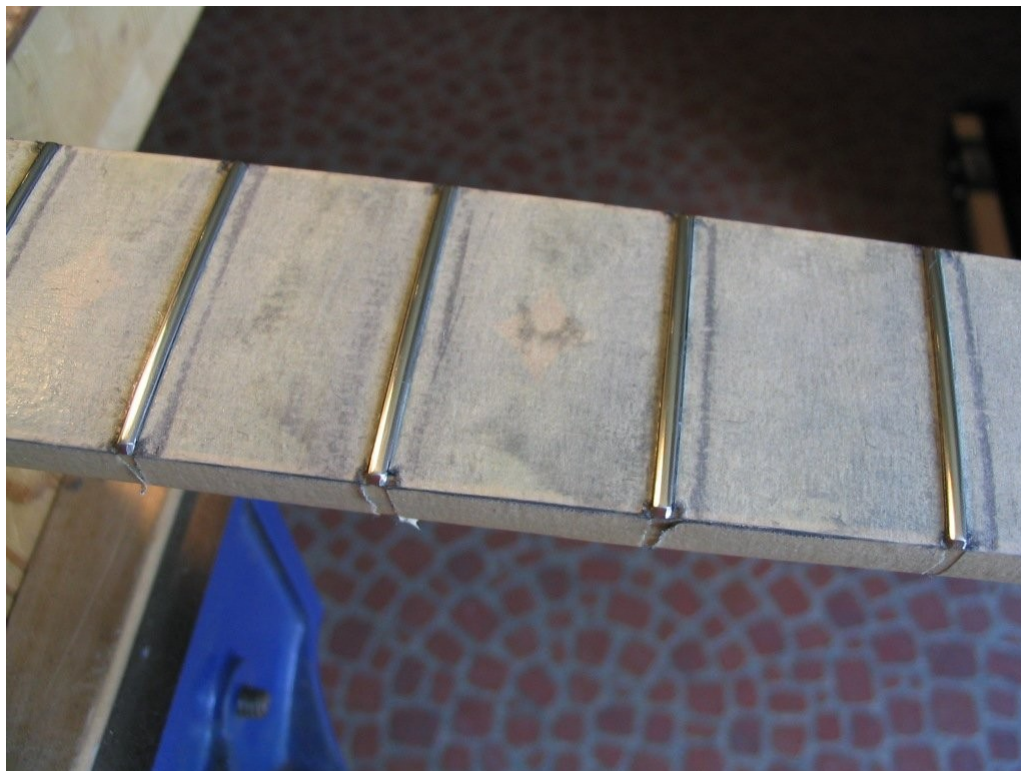
The fret ends are filed to remove the sharp points at the corners.



The frets are then polished with successively finer sandpaper, starting with 320-grit and going to 600-grit. The same number of strokes are used on each fret to ensure they stay at the same height.



The frets are finally polished with fine steel wool.



The masking tape is removed, and any remaining epoxy squeeze-out is removed from along the frets edges with a sharp chisel. The fretboard and frets are then polished with fine steel wool, and a final coat of oil and varnish mixture is rubbed into the fretboard.



Chapter 19 – Final Assembly

The guitar is now just about completed. Just a few additional fabrication steps are needed: construction and installation of the neck reinforcing truss rod and cover plate, installation of the tuning machines, fabrication of the nut and saddle, and attachment of the pickguard.

Truss Rod

The truss rod is a reinforcing rod that is placed in the neck of a guitar to help to counteract the tendency of the strings to cause the neck to "bow" or arch toward the fingerboard. The strings place a great deal of tension on the neck - for light gauge acoustic guitar strings in standard tuning, the strings exert approximately 150 lbs of force on the neck. Since the strings pass over the fretboard and are consequently offset from the centerline of the neck, they cause the neck to bow slightly, just as the string of an archer's bow causes the bowframe to curve. For an archer's bow, this bending is of course the desired effect, but for a guitar a significantly bowed neck makes the instrument difficult to play as the strings will be high above the (arched) fretboard and consequently difficult to push down onto the frets.

However, paradoxically, a slight bow in the neck is actually desirable to allow the action to be set low without the strings "buzzing" on the frets. When the strings vibrate, they naturally move more in the middle of the strings than at the ends, since the ends are fixed at the nut and saddle. In fact, the motion of the string forms an oval-shaped "envelope" from end to end, with the ends being motionless (resting on the saddle and nut) and the center moving up and down the most. As the string flexes up and down, it will be curved up when it's at its highest point (furthest from the fretboard) and curved down when it is at its lowest point (closest to the fretboard)). It is at this low point that the string can hit the frets and cause a buzz. A slight bow in the fretboard can keep this from happening by having the fretboard arch match the curved envelope of the vibrating string. This slight arching of the fretboard is called relief, and can be seen by sighting down along the fretboard from the peghead. On a properly set up instrument, the frets will be seen not to lie exactly in a plane, i.e., the fretboard will not be perfectly flat.

Thus the string tension actually does something that we want - putting relief into the fretboard - but will generally induce too much bowing. The trussrod is intended to counteract the tendency of the strings to bow the neck, and create just the amount of relief that we want (more on the correct amount in the section on setting up the instrument). Two different types of truss rod have been used: fixed and adjustable. A fixed truss rod is just a stiffening rod embedded into the neck to help keep it from arching when the strings are brought up to tension. While this will help keep the strings from putting too much bow into the neck, it provides no adjustability if the amount of bow isn't exactly as desired. An adjustable truss rod applies a bending force in the neck that opposes that of the strings by tightening a screw or nut. Adjustable truss rods can further be subdivided into "one way" and "two way" adjustable rods. A one way adjustable rod can only apply force to counteract the bending applied by the strings, while a two-way rod can apply a force in either direction, to bow the neck either up or down. The latter is useful in cases where the strings don't exert enough force to put sufficient bow into the neck to give us the relief (arching) that we need to prevent the strings from buzzing; in this case a two-way rod can actually help the strings to put a little additional bow into the neck. But this is usually necessary only if the neck has warped to take on a "back bow", or if the neck is too heavily built to begin with. I use just a one-way adjustable rod, since I build relatively thin necks that the strings have no difficulty putting plenty of bow into with their natural tension.

The one-way rod that I use is ingenious and pretty much foolproof - I believe the original concept is attributed to luthier Michael Gurian. In this design the rod is not even glued to the neck, so is easily removable if there are ever problems (which I've never had), and applies just a pure bending moment to the neck without any compressive forces as in earlier "bent rod" designs. Finally, it's easy to make. The theory of Building an Acoustic Steel-String Guitar

operation is quite simple, too. If you have two bars attached at the ends, one above the other, and you shorten the bottom bar but not the top, then the two-bar assembly is going to bend itself downward to form a circular arch. If this assembly is inside a guitar neck, it will try to push the neck into this arch as well.

The rod consists of a piece of 3/16" steel rod, threaded at one end, doubled back on itself, and installed into a special brass end block with a brass nut. The photo below shows the brass end block. This consists of a 1/2" brass cube that has two 3/16" holes drilled right next to one another. The only thing special is that one of the holes is "stopped" - it doesn't go all the way through to the other side of the block, but stops about 1/8" from the end. The photos below show the two sides of the block; note that the "stopped" hole has just the 1/8" pilot hole going through.



A 3/16" steel rod is then threaded about 1" on one end, and then bent back on itself. The length of the rod is chosen so the bent rod will fit into the slot routed into the neck; the rod should go about to the end of that slot. I usually find the slot is about 13" long, so I use a rod about 26" long. When doubled-over, the unthreaded end of the rod should be about 3/8" or 1/2" shorter than the threaded end.



The rod is then wrapped diagonally with fiberglass-reinforced packing tape to hold the two rods together when tension is applied to the nut.



The doubled-over rod is then inserted into the brass end block, with the threaded end going through the "through" hole and the unthreaded end going into the "stopped" hole. The threaded portion is longer, and

should stick out about 1/4". A small flat is then filed onto the brass end block so it won't stick up above the angled peghead surface when it is installed (see following photo).



The completed rod can then be inserted into the truss rod slot in the neck. The friction of the tape should keep it from falling out before the nut is tightened; once the nut is tightened to counteract the string force the rod will wedge itself tightly against the neck slot as it tries to bend itself backwards. Note the small angled flat on the end block that keeps the block from protruding above the surface of the peghead.



Tuning Machines

The installation of the tuning machines is straightforward; the only trick is that the shaft diameter is usually 10mm, and so will require a little reaming of the holes drilled in the peghead (which will also remove any finish that has gotten into the hole during the finishing process).

Bridge Pin Fitting

The pins used to secure the string ball-ends to the bridge need to be fitted to the string holes in the bridge. Since each pin will vary slightly in diameter, particularly ebony or other wood pins, it is necessary to ream each hole to fit its specific pin and then keep each pin associated with its hole until the strings are installed. The holes are reamed with a tapered reamer whose taper matches that of the pins. Each hole is reamed until its associated pin seats tightly with a firm push.

The front edge of each hole can then be relieved with a knife to break the hard edge where the string will pass over. The front side of the hole will also need to be notched to allow the string to pass between the pin and the hole - while the pin has a notch cut along its length for this purpose, it's usually not sufficiently deep to allow the pin to be pushed all the way down when the string is installed. The notch will naturally be bigger in the holes for the larger (lower-pitched) strings.



Nut

The nut and saddle are the pieces that support the strings at the end of the fretboard and the bridge, respectively. The nut in particular is notched to hold the strings at the appropriate spacing from one another. The saddle is usually not notched as the pegs holding the strings to the bridge provide the spacing. However, the height at which the strings are supported is important at both the nut and saddle; for the nut it's the depth

of the string slots that determines this height.

The nut and saddle are generally made of very hard material to resist the tendency of the steel strings to dig in. The traditional material is bone, but ebony, brass and even some plastics like Corian are also used. Bone nuts can be fabricated from inexpensive raw materials available at the grocer's - they usually have chunks of leg bone that they sell for soup or dogs. A section from the middle of the leg works best, as it tends to flare less at the ends. In addition, the bone tends to get "spongy" towards the ends where the joints are. The bone should be cleaned of as much extraneous material as possible, including the marrow, and then boiled for a couple of hours, changing the water occasionally, to remove any oils. After drying for a couple of days, the bone can be sawn into rectangular blanks using a metal cutting blade on the bandsaw. This is a little tricky as the bone is essentially a hollow cylinder and the desired chunks are rectangular "planks". Imagine trying to get useful rectangular boards from a hollow tree - not especially easy. To make matters worse, bone dust is quite toxic and shouldn't be inhaled. Fortunately, rectangular bone blanks are available from lutherie suppliers that eliminate a lot of the fuss of starting with an irregular hunk of bone.

To make the nut, a rectangular blank approximately 2" long by 1/4" wide by 1/2" high is used. (The one shown is from a raw piece of bone and shows a "divot" at one end where the inside surface of the bone is.)



The peghead veneer needs to be trimmed so the nut will fit between it and the end of the fretboard while sitting flat on the neck surface. This trimming is done using an angled block to guide the saw and keep it perfectly vertical while cutting. The block is positioned by placing the nut blank between the block and the end of the fretboard.



The blank is then removed and the peghead veneer carefully cut away, using the block as a saw guide and being careful not to cut into the neck material.



The peghead veneer slot after cutting.



The nut blank is then placed into the slot between the end of the fretboard and the peghead veneer for marking. The ends are marked so they'll be flush with the sides of the fretboard. The top surface should be roughly parallel with the curved top of the fretboard, but above it to allow for the string grooves. This profile can be conveniently marked with a "half pencil" that's cut down the middle so that as the flat surface of the pencil rides on the frets the point will trace a line at exactly that height on the nut. A modified carpenter's pencil is shown below.



The line being marked is at the fret height, which is the reference mark for the bottom of the string slots. I put a thin piece of veneer or plastic on top of the frets to draw a second line parallel to and slightly above this to mark the curve for the top of the nut.



The nut is then cut and shaped using a hacksaw, files and sandpaper to the desired profile. When the shape is correct, the nut is glued into the slot in the neck using a couple of drops of cyanoacrylate glue. The shaped and installed nut is shown below.



At this point the string slots must be cut. The strings should be evenly spaced, with about a half-spacing at either side of the outer strings. These can be calculated and marked with a ruler; for convenience, I print out a set of lines with the desired spacing from a CAD program and glue a strip of paper with these spacing lines onto the nut top surface.



The string slots can then be cut with a series of fine saws and files. The depth of the slots should be just above the reference line traced with the flattened pencil riding on the fret surfaces. It's actually important not to cut them too deep, or the strings will buzz against the frets. The final depth adjustment can easily be done once the strings are installed, as described below, so at this point the slots are left a bit high, i.e., are not cut quite down to the pencil mark. The width of the slots should be equal to the width of the string that passes through it, which means the string slots get wider as you go from the treble to the bass strings. The slots should also be angled back at approximately the angle of the peghead.



Saddle

The saddle is fabricated from a bone blank 1/8" thick by approximately 1/2" wide and 3" long. The length of the blank is cut to fit into the slot routed into the bridge, including rounding the ends. The saddle is then placed in the slot, and the top profile is marked on the blank using a stick with a scribe at the end that acts like the flattened pencil used to mark the nut: the stick slides along the frets and the scribe marks the saddle blank top profile. The blank's top edge is then cut a little above this profile (to leave room for final adjustment, as described next) and rounded to ease the strings passing over.

To facilitate the saddle adjustment procedure described below, an initial saddle is made of inexpensive material (plexiglass or the like) and left a little overheight. This temporary saddle will be replaced by the final bone saddle when the appropriate height is determined.

String-up and Adjustment

The guitar is finally ready to be strung up. The strings can be installed with the bridge pins, attached to the tuning machines, and brought up to pitch. This is the point at which the instrument will finally play its first notes and chords. However, there will probably be a need for some adjustments. In particular, the action - the height of the strings above the frets - should be too high since we deliberately cut the saddle too high. The neck relief - the amount the neck deviates from a perfectly flat plane - will also likely be too great, since we haven't tightened the truss rod yet. Finally, the nut slots may not be the right depth, causing notes fretted near the nut (for "open" chords, for example) to be difficult to push against the frets. These parameters can be adjusted to provide an optimally playing instrument.

Nut Adjustment

The nut slot depths should really be such that the strings are supported at a height that exactly equals that of the nearest frets - i.e., the nut should be like just another fret, at least as far as the string height is concerned. In fact, some builders use a "zero fret", with the nut behind it; the nut provides the string spacing while the zero fret provides the correct string height. However, it's also common to make the string heights at the nut slightly higher than that of the nearest frets to allow a little more space to help prevent buzzing against the frets when open strings are played, as these tend to be strummed harder than fretted notes.

Checking the nut-slot depths is actually quite easy: just fret each string at the 3rd fret, and look "behind", between the 2nd fret and the nut. The string will be pressed against the 2nd fret and pass over the nut, with the 1st fret in between; the nut-slot depth is correct if the string just barely touches the 1st fret, or if there is a very small gap (say, .005" or less) between the string and the 1st fret.



If the distance is too great, the nut slot depth should be increased. If there's not enough space - i.e., the string presses down on the first fret - the nut slot needs to be filled to raise the slot depth. However, I've not found a completely satisfactory way to do this, so I will usually just make a new nut. Since this involves a fair amount of work, I'm generally careful not to cut the slot depths too deep, leaving them slightly high until this adjustment stage.

Truss Rod Adjustment

The truss rod is next adjusted to get the neck relief to the right state. As discussed above, it's desirable for the neck not to be perfectly flat, but instead to have a small amount of "bow" or relief. However, the tension of the strings generally puts a little too much relief into the neck - the strings will tend to bow the neck more than is desirable. The truss rod counteracts the pull of the strings to bring the relief back to the desired value.

The relief can be evaluated by using the straight string to measure the bow in the neck. The high E string is fretted at both the 1st fret and 12th fret; the relief can then be seen by the fact that the string doesn't touch each of the frets in between.



Because of the bow in the neck induced by the string pressure, the frets between the 1st and 12th will be seen to "curve away" from the straight string, with the largest space between the string and frets occurring about half way between, at the 5th or 6th fret. This maximum space gives a way to measure the amount of relief; I generally adjust the truss rod so the space between this "middle" fret and the string is about .010", or about the thickness of the high E string itself.



The relief can be varied (by adjusting the truss rod) to accommodate different playing styles. A lower relief will suit softer playing and fingerpicking, while a higher relief can better accommodate harder playing and strumming.

Saddle Adjustment and Action

The saddle height is the final element to be adjusted. Note that the saddle provides just the height adjustment for the strings; the positioning of the string holes in the bridge provides the spacing. Thus the saddle does not have slots like the nut does. When the nut slot depths and relief have been set as desired, the action is controlled entirely by the saddle height. The action is the height of the strings above the frets, and is typically measured at the 12th fret, halfway between the nut and saddle. The action can be measured using a calibrated wedge; the wedge sits on the 12th fret, and slid under the string as the string is gently plucked until the string contacts the wedge, at which point the action (the height of the string above the fret) can be read from the surface of the wedge. In the photo below, the high E string action reads .105".

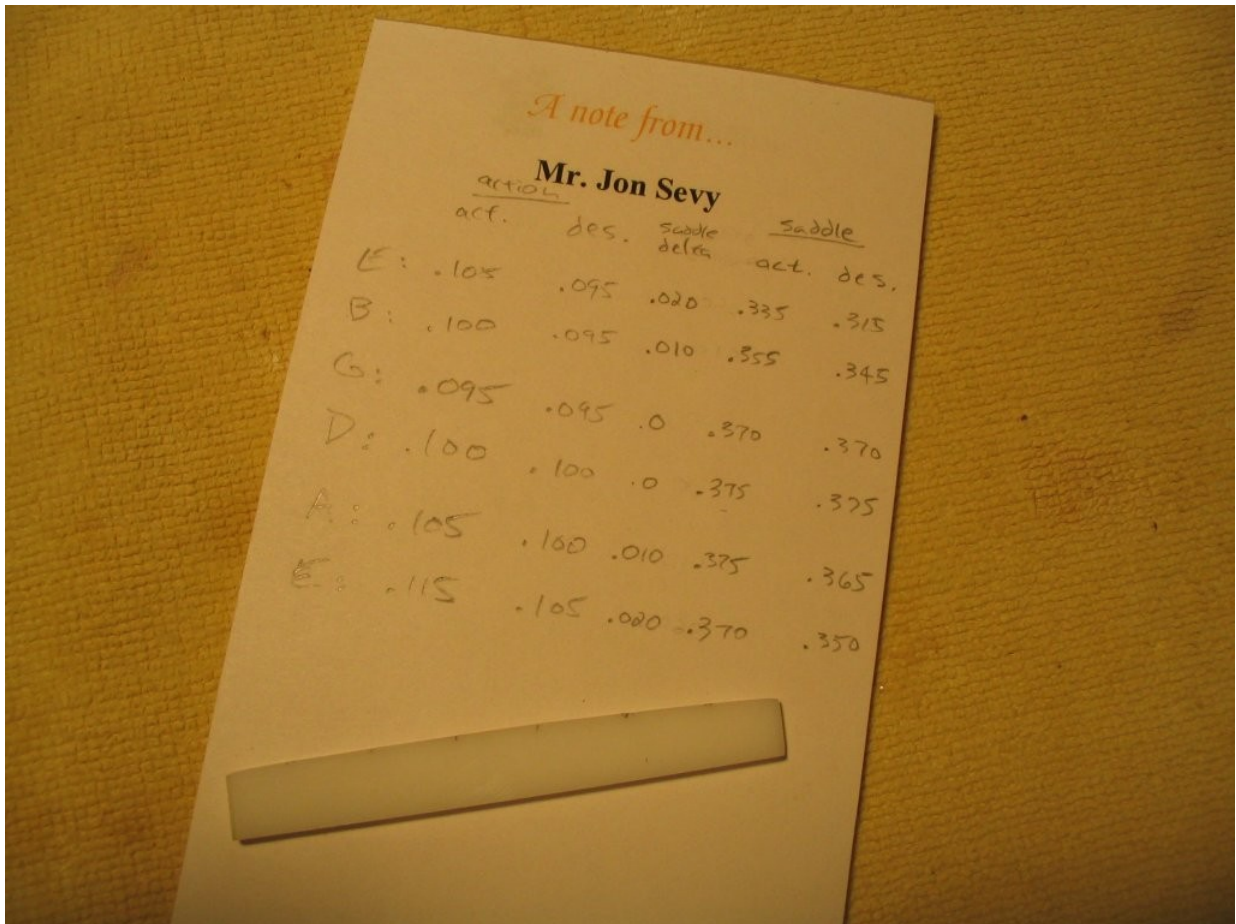


The action should be adjusted to accommodate the owner's playing style. As with relief, a lower action is best suited for softer playing and solo work, while a higher action can accommodate a harder playing style while avoiding string buzz. The action is usually set lower on the higher-pitched (smaller diameter) strings than on the lower-pitched strings to account for the lower strings' tendency to vibrate with greater amplitude. A general range of action settings at the 12th fret is

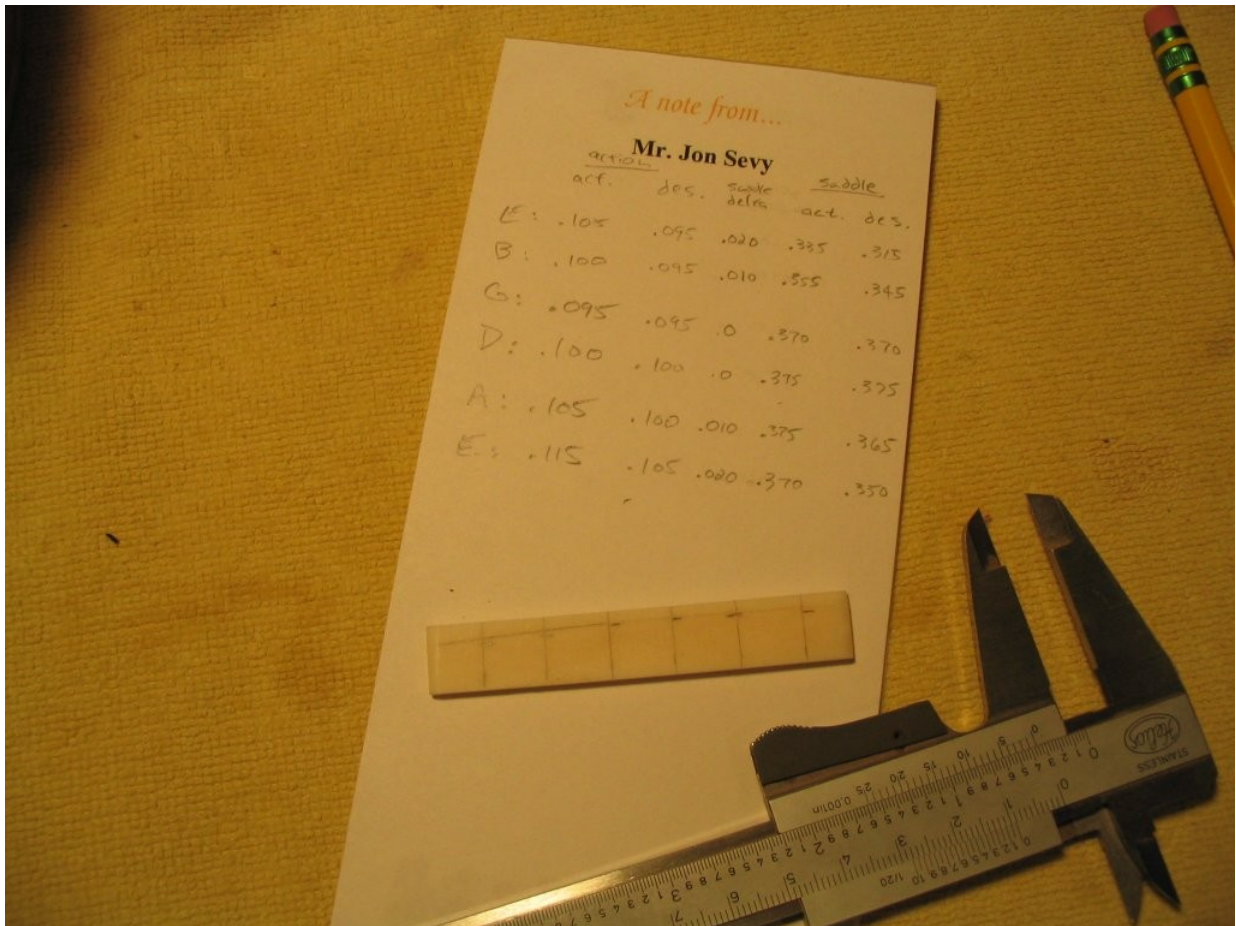
- High E: .085" - .095"
- Low E: .100" - .115"

with the strings in between having actions between those of the outer strings.

To lower the action, the saddle height is lowered. However, because the action is measured halfway between the nut and saddle, the reduction in action will be half the reduction in saddle height, or equivalently, the saddle height must be reduced by twice the amount it is desired to reduce the action. For example, suppose the action on the high E string is desired to be .085"; and that it initially measures .100". The action for this string is thus desired to be lowered by .015"; this then requires that the height of the saddle at the position of this string be lowered by twice this, or .030". The equivalent calculation is done for each string.



The strings are loosened and the saddle is removed from its slot in the bridge. The height of the saddle at each string position is measured, and the desired height is calculated from the action measurements. A bone saddle blank is then marked with the desired height at each string position.



The saddle is cut to the marked profiles, and then rounded on top. When the saddle is reinstalled, the strings should all have the correct action.

Interactions

The action and relief settings are not completely independent; adjusting either can affect the other. Tightening the truss rod to reduce the relief will also generally lower the action, because the force of the truss rod pulls the neck back and thus tends to make the strings lie closer to the fretboard. Conversely, if the action is lowered by lowering the saddle height, the strings will lie closer to the surface of the fretboard and thus have less leverage to put a bow into the neck, reducing the relief. Thus if either the action or relief is adjusted, the other should be checked to make sure it has not changed significantly.

Truss Rod Cover

When the neck relief is in adjustment, the cover for the truss rod adjustment nut can be fabricated and installed. The cover is secured with 3 small brass screws.



Pickguard

The final step in finishing the guitar is to fashion and affix a pickguard. The pickguard can be made of pretty much any thin hard material that will protect the soft spruce top from errant pick strokes. I use plastic of .025" thickness, attached with spray adhesive. The pickguard is cut to shape with an Xacto knife, the edges rounded and the surface polished. A template is cut in a piece of paper and taped to the guitar top to allow the adhesive to be sprayed onto the face of the guitar in exactly the shape of the pickguard. The pickguard is also sprayed, the paper template is removed, and when the adhesive has dried on both the guitar face and pickguard, the pickguard is placed onto the guitar and pressed to firmly attach it to the top.

Chapter 20 – The Result









Check website for more information:

http://gicl.cs.drexel.edu/people/sevy/luthierie/guitarmaking_guide/building_flattop.html

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