REPLACING WHEEL TEETH…
Files & Their Uses

This article is written without any assumptions. All clockmakers had to experience replacing wheel teeth for the first time and this article seeks to deliver from that perspective. It is not quite teeth replacement for dummies, but perhaps close. The repair techniques draw from our contemporary masters such as David J. LaBounty, CMC and his DVD "Replacing Wheel Teeth", Laurie Penman, and J. M. Huckabee, CMC along with the masters of old such as Henry Fried, CMW, CMC (Fried's Bench Practices Clock and Watchmakers) and Albert Osborne (NAWCC Article) along with my learning experiences while practicing.

Featured alongside this learning journey on replacing teeth is a tutorial on the use of files. If you have chosen to replace teeth by hand instead of by machine (lathe or mill), files are the tools of choice. This article illustrates the use of several uncommon files along with a few of the common to replace wheel teeth. It is not exactly a throwback to the yesteryears of clockmaking but it does bring to mind the value of one of the oldest clockmakers tool. My primary reference for learning about files was a chapter from Archie Perkins, CMW "The Modern Watchmakers Lathe And How To Use It". This would be an excellent reference book to add to your library. Thanks also to Grobet USA.

Reading doesn't quite get it done, one has to do. After you've read this article a couple of times, you'll need to practice and practice some more. To start with, here are some perspectives and overarching comments:

1. If damage is confined to only a few teeth, then it may be worthwhile to try and save the wheel by replacing these teeth.

2. Teeth replacement is nicely summarized by Mr. Henry Fried…a dovetail is cut out of the rim and a sheet of brass is cut to fit the dovetail. The teeth are then cut and filed to shape.

3. As this article is about wheel teeth, it will use the horological terms to describe the parts of the tooth being worked on such as addendum (upper part of the tooth), dedendum (lower part of the tooth), root (base of the tooth

4. Different authors use the terms work piece or plug to refer to that new material being shaped for insertion into the wheel rim. Additionally, some authors use the term dovetail while others use the term keystone for the shape. In this article, I'll be using the terms plug and keystone.

5. Teeth replacement, as Laurie Penman says, is essentially cutting spaces between the teeth.

6. There are a variety of clock wheels of different diameters with teeth spaces of various size widths. In wheel cutting terms, different diametrical pitches or as the English would say "different size modules". One will need to develop successful methods/techniques and possess the right means/tools to contend with this. This article lays out my means and methods.

7. The plug takes on the shape of the file. The file acts as an abrasive "die" to remove material and leave the desired shape.

8. Some words about files.
    a. It might as well be said up front that replacing wheel teeth requires an investment in files. So visit your marts and peruse your supply catalogs as you'll need to acquire certain special files. Along with your regular size hand files (6", 8") you'll need both needle and escapement files with at least #4 and #6 cuts. Each task in the article discusses the specific files to use for that task. I ended up purchasing a full set of joint files for filing the various size spaces between the teeth. That is just me☺. Joint files come in eleven different thicknesses and with their safe sides and cutting edges are excellent for filing tooth spaces, particularly those with round bottoms. I also like to draw their edges through some beeswax before filing. It is almost like cutting through butter. Select a joint file that mimics as close as possible the distance between the good teeth to file the tooth spaces. Use this as both a file and as a measurement guide.

       Remembering that one's work needs to mimic the original (David J. LaBounty, CMC), square bottom spaces need to be approached with equal attention. However, file choices with safe sides and square bottoms are quite limited. The square edge joint files have not been manufactured for 25+ years according to Tom at Grobet – July 13, 2010. What to do? Never fear, clockmaker ingenuity to the rescue. Typically, clockmakers will create this tool by taking a hand file with its square edge and sanding/grinding off one side until smooth. Being careful, of course, not to overheat the file and reduce its hardness. Or as Laurie Penman says (Clockmakers Newsletter Aug 1991), "do not allow file to color during grinding". So I purchased several hand and needle equaling files of different thicknesses and ground smooth one side on my 8" disc sander. This gave me several different thicknesses with a safe side and allowed me to file a square bottom and avoid damage to the adjacent teeth.
    b. An important reference to have on hand is Archie Perkins "The Modern Watchmakers Lathe and How to Use It". The "Files and Filing" chapter is an excellent resource for the beginner.
    c. Description of recommended files. Unless otherwise noted each of these files types are available in full size hand files, needle and escapement files.
    d. Oftentimes filing works best to use a # 6 cut file to create a file start point (a starting slot/file ledge) using very short strokes if necessary, then change to a # 2 or #4 cut as necessary to do the major removal of material

e. Finally, when using the joint files to file the outside and inside tooth spaces, it helps to draw the file edges through some beeswax prior to filing. The beeswax acts as a lubricant and it cleans off nicely.

9. Types of files
    a. Full size hand files (6" or 8") in cuts #2 and #4. Both sides have cutting surfaces; one edge is safe (non-cutting smooth surface); one edge has a cutting surface.
    b. Joint needle file – both sides are safe; both edges have cutting surfaces; These come in eleven different thicknesses and their edges are rounded. Insert them into the Lutz # 1 wooden file handle and place all of them in a tool roll and you are good to go.
    c. Equaling hand and needle files – both sides and both edges have cutting surfaces. These come in different thicknesses and their edges are square.
    d. Barrette needle file and hand file– with a pointed end; only bottom side has a cutting surface; top has a beveled surface that is safe; both edges are safe.
    e. Parallel barrette file – escapement file with parallel sides and a squared off end; top has a beveled surface that is safe; both edges are safe; only bottom side has a cutting surface. Excellent for filing the keystone angle in the wheel rim.
    f. Rounding off file – escapement file with parallel sides and a squared off end; top has a rounded surface that is safe; both edges are safe. only bottom side has a cutting surface and could be used in place of the barrette files.
    g. Square file – four equal sides; all sides cutting
    h. Three corner (triangular) file – three equal sides; all sides cutting.
    i. Needle files
        1. Barrett, square, triangular, slitting in cuts #2, #4 and #6. The most economical way is to buy full sets. When I'm having trouble getting my file ledge started, I find the #6 cut files to be the most reliable. Once I get the ledge started I can then reach for the # 4 or # 2 to remove the bulk of the material.

j. Escapement files. Again full sets are the most economical in cuts #2, # 4 and #6. I know they are expensive, but they really help you in a pinch and tight spot!

10. When filing, the wheel and plug needs to be held securely.
    a. This can be accomplished in several ways. They can be secured in a vise, held by hand on a projection such as a drawer or in a v-notched board clamped to your bench. I use a v-notch board with a tenon attached to the underside that I clamp into a vice. Each end has a different size v-notch and is quite versatile.

    b. There will be times one will want to hold the wheel vertical in a vise and file horizontal and other times when one prefers to hold the wheel horizontal and file vertically. Filing vertically provides much more controlled filing in the instance of filing the wheel rim. One has better control over the file strokes and can better see where to place the file and how much material is being removed. Filing horizontally has its advantages as well. Again, trial and error will determine the best method for you.

c. When using your bench vise, consider turning it on its base to present the best angle for filing in a controlled, accurate manner.

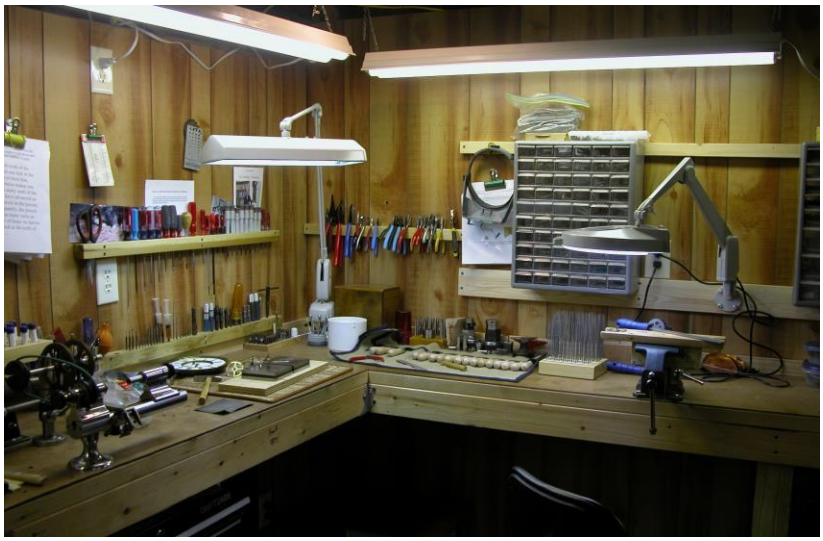
11. Scribing guidelines as a reference for filing. From my experience, one will need to at least scribe the shape of the keystone onto the plug. This will be discussed later on in the article.

    a. A very good scribe tool for this work is a needle scribe as it allows one to get into the most minute corners and produce a very clear outline (Osborne, P. 373). But I learned not just any needle will do. This needs to be a rigid, sharp sewing needle that is inserted into a pin vise or wood handle. You'll need one that will not bend when pressure is applied to scribe. I went to my local sewing machine store and bought a needle with a .092" body and inserted it into a wood handle. This allows me to maintain the necessary control and not bend while scribing.

    b. One can apply layout die to the wheel rim and/or plug and scribe onto this.

    c. One can scribe directly onto the brass with the needle scribe without any layout dye. Not using layout dye tends to speed up the process, as you don't have to wait for it to dry. I've also found that when scribing onto layout die it tends to curl up and blur the actual line to file up to or beyond. Remember you are working within very tight tolerances.

12. Lighting and magnification:
    You'll need bright light and magnification (3 X will do fine) to perform this task successfully. The paths one travels to attain this are ones own. Here is what finally worked for me. Two Dazor bench lamps…their three-bulb bench lamp and their inspection bench lamp with center magnifier (3x) along with my headband 3x magnifier. Turns out, I just couldn't achieve a good, repeatable outcome without the inspection bench lamp magnifying and lighting the needle scribe lines for the keystone plug.



13. An excellent tooth replacement job is one where the plug and replacement teeth are very hard, not possible to detect (Laurie Penman).

14. As with many clockmaking tasks, there are several different ways to accomplish the same result. You'll see clockmaker texts that use a keystone shape for slots, parallel shaped sides for slots, radial shaped sides for slots and even pie shaped. Certain of these approaches are keyed to the particular task at hand and certain of these are just clockmaker preferences. Each of these different approaches can achieve the same result and presumably have stood the test of time. This article uses the more traditional and commonly used keystone shape for multiple teeth and radial shaped sides for single teeth.

15. The approach to cutting slots in the wheel will likely vary depending on the number of teeth being replaced and the distance between teeth. When replacing only one or two teeth or if there is a short distance between teeth, using a square or flat file will most likely be adequate. However, when replacing three or four teeth or when teeth are farther apart using a jeweler's saw (preferably a thin # 2/0

or 3/0) to make the rough initial side cuts may be more appropriate. Note that when slots are started with a jeweler's saw, they are finished with files. This article primarily focuses on two teeth being replaced on an American time/strike 2nd wheel with teeth that are moderately spaced and files will be used. Secondarily, means and methods are referenced for replacing only one tooth and three teeth.

16. Soldering insight and tips:

    a. Solder is not a gap filling agent. Here is what happens when two pieces are soldered together. As the two pieces are heated the molecules of the two pieces expand to allow the solder molecules to flow among the metal pieces. When the pieces cool, the two pieces are fused together. This is why there needs to be a very good joint. Meaning most parts of the two metals need to be in contact with each other at the joint. This bit of knowledge will come in handy when you are soldering the plug into the wheel. If one or the other of the metal pieces does not come up to temperature for one reason or another, you'll likely end up with a cold joint as discussed in "c" below.

    b. Here is a solder technique commonly used by jewelers that doesn't really apply to teeth replacement but it surely could come in handy when doing clockmaking so I've included for reference. Heat a solder pick's tip to red. Touch the red hot tip to the small piece/crumb of solder and the solder should melt into a ball that sticks to the tip of the solder pick. Then place the ball of solder on the joint exactly where you want it. Apply indirect heat as normal to the joint area and the solder will flow exactly where you needed it.

    c. Use a "third hand" to hold the wheel and plug when soldering. I struggled a lot with my plug joint failing during filing until Dave LaBounty came to the rescue. Turns out I had a cold joint. I was laying the wheel and plug over an open vice to solder. The vice was acting as a heat sink, drawing heat away from the metal and leaving me with a cold joint. Using the "third hand" eliminated joint failure for me.

17. Centering is being radial and filing freehand:
    a. Centering is being radial: throughout this article references will be made to centering, being radial to the arbor, to the need to be centered, to enter with the file on center, etc. This is referring to the need to consciously keep the result radial or to the center of the arbor. This not only results in good workmanship, it is critical so as to maintain the geometry of the wheel.
    b. Filing Freehand: centering can be achieved relatively easily by using a method I've coined as "the freehand filing method" and this will be referred to frequently in this article as "freehand filing method" or "file it

freehand". While I doubt I invented this method, I have yet to read about it in any of the dozens and dozens of articles and books that fill my library. It probably is just a natural approach to successful filing. Anyhow, it involves eyeballing the arbor center when filing. Place the file at an angle and use it as a pointer to aim at the arbor center. At the start of filing and while filing, keep checking to ensure your file is pointed towards the arbor center and by doing so you will end up being radial to the arbor. There are other benefits to placing the file at an angle as well. One not only is more assured of landing on center, filing at an angle is a much easier approach to getting the filing started, much easier to file once started and places less stress on the plug and wheel rim. You can file at an angle all the way up to the point where one reaches the depth of the good teeth. Then you will need to resort to filing straight up (full vertical). But, by this time the rigorous filing is over, the file guide has been very well established and one can finish off the cut in a much less rigorous manner. In the end, this method worked very well for me. Not too shabby for a person not born of natural artisan or machinist tendencies.

18. Developing the skills necessary to replace teeth will only be achieved with practice. Thus, obtain several old $2^{nd}/3^{rd}$ wheels and mainspring wheels along with the 2^{nd} modern wheels and begin practicing. Merritt's usually has a supply of old wheels one can purchase. Worn out Hermle movements are also a great source for wheels to practice on. The 2^{nd} and 3^{rd} wheels along with the mainspring wheels tend to be those wheels that end up with mangled, broken teeth caused by, you guessed it, a mainspring breakage. Practicing with the different wheel diameters having different numbers of teeth will leave you amazed at how the different distances between teeth and lengths of the teeth raise the level of difficulty of replacing wheel teeth. The goal is to practice until one can repeat a satisfactory outcome otherwise known as "achieving repeatability". In the instance of replacing wheel teeth, a satisfactory outcome is when the new teeth are radial to the center of the arbor and the repair is not noticeable or detectable.

19. As one practices and gains skill and judgment, certain of the detailed steps can be eliminated. Which ones will become apparent in good time. However, the major tasks and their respective sequences will stay intact.

20. Summary of the major tasks for replacing wheel teeth. These major tasks with their detailed steps follow:
    Task 1: File keystone slot into wheel needing teeth replacement
    Task 2: File plug to the wheel rim's keystone shape
    Task 3: Secure plug into the keystone slot in the wheel
    Task 4: File the outside teeth spaces
    Task 5: File the inside teeth spaces
    Task 6: Reduce tops of teeth to the circumference of the wheel
    Task 7: Shape the addendum of the teeth to the shape of the original teeth
    Task 8: Remove excess thickness from both sides of the wheel

Task 1: File keystone slot into wheel needing teeth replacement (see picture)

- Needles files are the files of choice – Three-corner a/k/a triangular, square, equaling both of which have cutting edges on all four sides and the Barrette needle file along with either of the barrette escapement files (parallel square end or pointed end).

- Actual file choice is driven by the width needed for the slot. Usually on a two or more teeth project one would use a square file. If a narrower slot is required, such as for a single tooth, then an equaling needle file may need to be used. Some clockmakers make a file with a safe side for this purpose by grinding the cutting surface off of one side of a flat hand file.

- For either situation, after the slot is filed, either the pointed barrette or parallel needle files is then placed at an angle on the sides and then filed to create the keystone shape. For those who may wonder, why the Barrette file…this file has a safe back and safe edges, therefore it only removes material that the bottom comes into contact with and really helps one make that slanted slot needed for the keystone shape without the edge digging down deeper into the rim than desired. Remember one does not want the bottom of the keystone to be deeper than half the distance of the rim. Going further can weaken the wheel rim.

- Amount of material to remove:
    - Width - One must remove only the width of the teeth being replaced
        - Broken teeth leave scars behind and these scars are the best indication as to how much material to remove so as to make ready for the plug (L. Penman)
    - Depth - maximum depth is the center of the wheel rim (about half the depth of the wheel's rim (Fried).
    - Bottom corners (bottom part of the slant) of the keystone must not intrude on the adjacent tooth's radial line (Fried).

- Centering the slot. While not critical, it is good workmanship to enter the slot at center regardless of the number of teeth being replaced. I say not critical as there is time to correct if off center. This opportunity will come when it is time to file the angled sides. Now back to centering. Using the freehand filing method, eyeball the center of the slot and using the file as a pointer, place the file at an angle, aim at the arbor center and proceed to file. I'd suggest starting off with the #6 three-corner file or the #6 square file. Switch over to the #4 square file to speed up the removal of material once the file start/ledge has been created. Once that part of the slot is complete, then proceed to file the edges at an angle correcting one side or the other as necessary to achieve a centered result with the barrette # 4 and #6 needle files and escapement files.

Step 1:
Visualize the keystone shaped material to remove from the rim of the wheel. If you find it helpful, scribe the keystone shape onto the wheel rim with any of the above mentioned techniques. I started out using layout dye and then used the fine point Sharpie. After several practice sessions I found I could obtain the keystone shape by eye. So for first timers, go for it with the layout dye as after several practice attempts you'll gain the confidence you'll need to do by eye.

- If one wants to be more precise or wishes to train their eye, use the Vernier Calipers to check the depth of the keystone slot against the width of the wheel rim.

Step 2:
Securely place wheel as necessary to file the keystone slot. One could just fit it up into a vice or lay it firmly on a projection such as a drawer or my favorite is the v-notched board with tenon fitted up into a vise.

Step 3:
File a slot entering on center using square file or equaling needle file depending on the slot width desired and then file the angles using the barrette file. If you have scribed the lines, file up to the scribed lines i.e. save the scribed lines. For reference, an equaling file would likely be used when replacing only one tooth whereas if you were replacing two or more teeth a square file to achieve a wider slot would be the file of choice.

Step 4:
File the sides at an angle using the barrette needle files correcting one side or the other to achieve a centered result. Remember that the old teeth leave scars and one is trying to file up to the point of the old teeth. Also, try to keep each of the angled sides the same size and shape. This will make it easier when filing the plug (Dave LaBounty, CMC)
Step 5:
Now that the angled sides are done, refile the bottom to ensure it is flat all the way across the joint.

Step 6:
Filing the keystone shape's angled sides into the wheel rim will throw up a slight burr at the top of the wheel rim, the root area of the tooth space. These burrs should be removed as they will interfere with the plug and prevent it from bottoming out in the keystone slot. This is easily accomplished with a stroke or two of the #6 barrette needle file.

Task 2: File plug to the wheel rim's keystone shape

- File of choice is the 6" or 8" hand file # 4 cut as it will give you plenty of control and will remove material at a more than adequate rate.
- This is perhaps one of the more difficult tasks. The good news is, if you over-file the plug and can't use it. Just cut it off from the long handle and start over again.
- File plug width first before filing keystone shape – so that it fits just within the wheel teeth.
- Leave the plug length a little long until it appears the keystone shape is about right. Among all of the great advice received from Dave LaBounty, CMC, the advice to leave the plug length a little long was one of his best tips.
- Use a clock hammer (flat-faced) when peening the plug to obtain a snug fit. Do not use ballpein/round faced hammer or round faced punches. Any of these may create an impression below the finished surface. A mark that you will be unable to file or sand away. I found a clock hammer from the supply houses with just the right size round flat face (3/8") that works fine in many instances and in other instances, I use the flat faced punches. When peening with this hammer, consciously hold it level so that it strikes squarely at contact and not at an angle.

- A final step when shaping the plug is to slightly round off the tips of the plug with a # 6 file or on a stone. Invariably, the keystone corner filed into the wheel rim is not as sharp as the plug's corner. Rounding off the plug corners allows the plug to bottom out nicely.

- Scribing preferences – after much trial and error, I found that my needle scribe worked best for me. Turns out I need a precise scribe line, bright light and magnification to be successful with filing the plug. Thus the needle scribe became the best tool for me.

- Soldering tips:
    - I'd recommend using a solder with a melting point between 400 and 430 degrees. 50/50 solder (400 degrees) will do as well as the Sta-Brite brand of solder (430 degrees) to secure plug into wheel. Though many clockmakers swear by Tix solder with its lower melting point and holding power, it didn't work for me. Tix left me with a weak joint. That may just be me☺.
    - Flux both sides of the plug joint in the wheel. Allow the flux to seep into the joint.
    - Use a "third hand" as the fixture to hold the wheel/plug. Using something like an open vice to lay the wheel/plug on likely will result in a cold joint as the vice acts like a heat sink and draws heat away from the wheel/plug joint. A weak joint a/k/a/ cold joint is likely to break during the filing process. To create a rigid fixture, I screwed my third hand and its base to my solder bench.

- "File the plug until it fits so tightly that no light can be seen thru the crevices" says Henry Fried (p. 252). That guidance from Mr. Fried's, while very good, required precise, expert filing. Probably beyond most of us. Certainly, after many practice runs, it continued to be beyond me. Don't fret, you can get close to that result and achieve the tight fit with peening or "swaging" as Mr. Fried says. I think the real moral to the story is not to have a really, really loose fit. Successful soldering needs tight joints.

Step 1: Choosing the plug

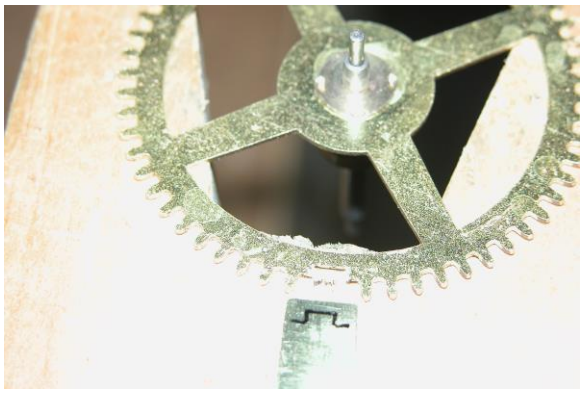
a. Thickness: Choose brass material for the plug that is thicker than the wheel. So that the brass stands proud on both sides of the wheel rim. When it comes to determining how much thicker, there is quite an acceptable range – some authors say use only a few thousandths thicker (those are the experienced masters who probably don't even need to use solder). Dave LaBounty, CMC recommends a thickness that is .020" thicker than the wheel's thickness. This leaves .010" excess for each side. I went with Dave's suggestion and it has worked well for me. However, this is an area where one can be flexible. Sometimes, the workshop supplies of such brass are limited and remember that ultimately this excess will be filed off. The idea here is to create a tolerance for error. If one needs additional length, height etc. one can use a flat face hammer or a flat punch & hammer to stretch the brass plug and gain back what was lost because of too much filing. Half hard brass sheet material in 12" x 12" sheets can be purchased from supply houses, "Speedy Metals" being one of those, in several thicknesses, .040"; .050"; 0625"; .080" & .090".

b. Width: The width of the plug addendum area should be just within the good teeth to ensure there is adequate material for coverage. For several reasons, I've found it helpful to first file back the sides of the plug so that it fits between the teeth. This creates the needed fit between the teeth (this is also a good time to break in a new file as the masters say never use a new file on steel – brass first). The less material on the side, the less that will have to be filed away to create the tooth space. Too much width and the plug sides will engage with the sides of the good teeth and prevent the plug from entering the keystone slot in the wheel rim. Having some distance between the sides of the plug and the good teeth helps when filing the outside teeth spaces as it tends to keep the file away from the good teeth.

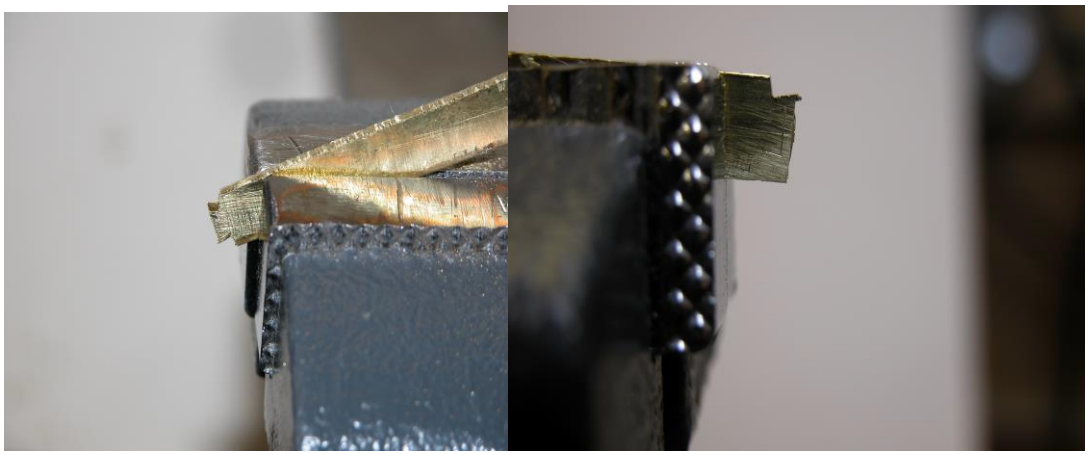
c. Length: Need to have at least approximately a 2" "handle". Short pieces are best maneuvered with a "handle". Refer to picture. (J.M. Huckabee, CMC, FAWI, FBHI). Choosing the right length is a bit of a balance between enough length to "handle" the short piece and being too long so as to act as a heat sink. Something around 2" probably strikes a good balance.

Step 2:

Overlay the wheel rim with its keystone shape onto the plug. Scribe the keystone shape filed into the wheel rim onto the brass plug with your choice of scribe. Include a scribe mark to indicate the top of the wheel rim. When filing, you will not want to remove much, if any, material above this point. Use it as you would any other "limiter" or "stop". For me, the right scribe ended up being the needle scribe. Turns out, that I need a precise point of reference to be successful in filing. I just could not achieve a good outcome with this particular task until I resorted to the preciseness of the needle scribe and as was mentioned above the inspection task lamp with magnifier. For the benefit of the reader, the below picture uses the fine point marker pen to better depict the necessary scribe marks.



Step 3:
Fit up plug into vice using vice as a guide as seen in below picture. Maintain only a very slight angle and file using the 6" or 8" hand file # 4 cut. This type of file will give you plenty of control and will remove material at a more than adequate rate. To keep your scribed area facing you, when filing the angled sides, you will need to transfer the plug from one side of the vice to the other.



Step 4:
Filing the keystone shape into the plug. File the plug using the scribed lines (this shape conforms to a keystone shape):

- The bottom of the plug needs to conform to the bottom of the keystone slot. This can be either filed square or one could just touch it on their belt/wheel sander.
    - TIP: Leave plug length a little long until it appears the keystone shape is about the right fit.
- Trial and error is the best approach. Keep filing and trying until the keystone shaped plug fits snugly into the keystone slot filed into the wheel.
- If using scribed lines as a guide. During this process continually compare the plug to the keystone slot for fit. Remember that the scribed lines are slightly smaller and "inside" the actual shape of the keystone slot. Therefore, file just up to the scribed lines so the plug will fit snugly (Fried, P. 252).

- If you have not filed the sides to fit, now is the time. File the sides of the handle and sides of the plug until there is a distinct space between the plug and the adjacent good teeth. This will provide you a “buffer zone” when filing the outside tooth space described below and has the added advantage of helping one to stay away from nearby teeth when filing. Good workmanship is not marring nearby teeth. Caution - don’t over-file into the space that will become the new teeth and leave sufficient material for the file ledge.

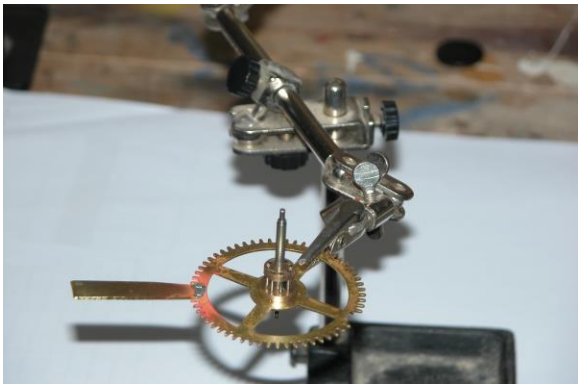
Step 5:
Insert finished plug into the keystone slot. A snug fit is critical. Most likely, with the first several practice plugs (and forever more), one will need to peen the plug to achieve a snug fit. When peening, use a flat faced hammer only on both sides being particularly careful to peen the plug only at the root and on the adjacent rim areas and not the surrounding teeth and not the addendum or dedendum parts of the plug. As much as possible, stay away from the tooth addendum part of the plug. A tight fit should require only minimal peening. Do not use round face punches as it most likely will leave an impression mark below the desired finished thickness and leave the job unprofessional and noticeable. Remember one is trying to achieve a result that is not noticeable. Remember also when peening with a flat faced hammer to consciously hold the hammer level so that it strikes the surface squarely and not at an angle.

The goal is to fit the plug tightly into the keystone slot but not so tight as to push nearby teeth out of their position. If one does slightly over-file, the plug can be peened (both sides) to tighten it in the keystone slot. When peening, caution must be used to only peen the plug area below the root of the teeth. One does not want to place a peen mark on the tooth areas. Peening is done only with a flat-faced hammer. Do not use a round face punch as it could result in deeply punching below the wheel surface and prevent one from filing out the mark. A reminder that an excellent job is when the plug and new teeth are not detectable.

Task 3: Secure the plug into the keystone slot in the wheel
Secure the plug with solder. There are masters who are so skilled at filing that a slight peening will permanently secure the plug. In most instances, however, both experienced and beginner clockmakers will need to solder the plug to ensure it is secure in the wheel rim.

Step 1:
Pound flat (tin foil thickness) a small piece of 50/50 or Stay Brite solder (400/430 degree melting point respectively) solder and cut off a crumb. A good tool for cutting off tiny pieces is a regular nail clipper.

Step 2:
Use a third hand to hold the wheel and plug for soldering.

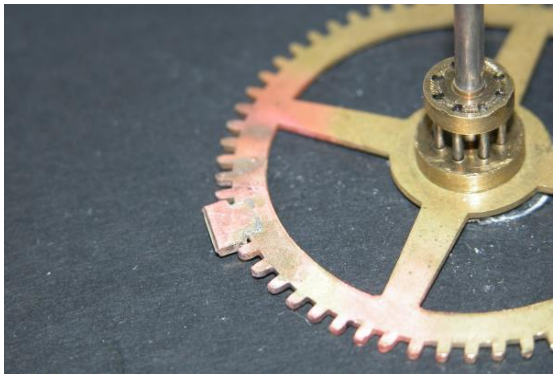


Step 3:
Place this crumb of solder at the bottom of the keystone joint. Amount of solder depends on the job. One tooth wheel takes one small crumb. A larger wheel of two teeth takes a larger crumb.

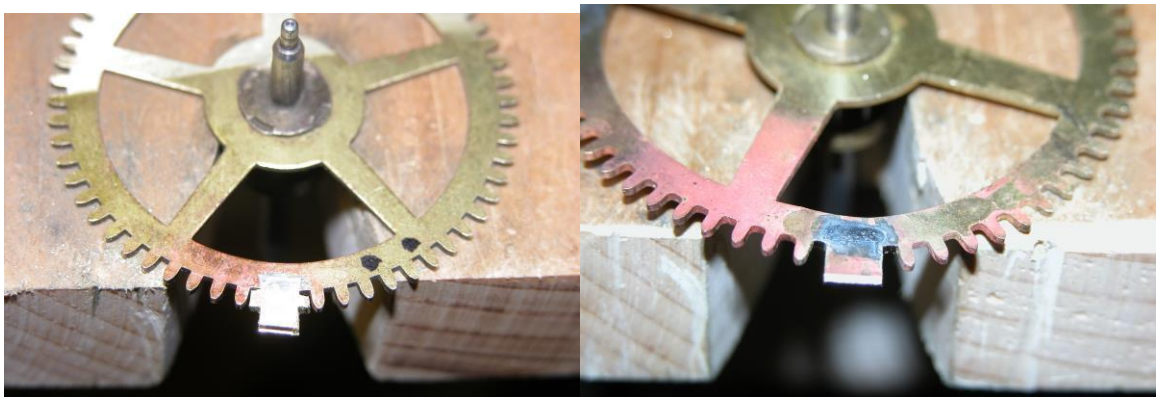
Step 4: Apply flux to all areas. Both the edges and bottom of the plug and to the edge surfaces of the wheel rim where the keystone slot has been filed.

Step 5: Using Blazer torch apply heat to the handle from beneath until solder melts and flows into the keystone joint. When the wheel and plug area is cool to the touch rinse it off with hot water. Remember that the metal and solder molecules need a chance to cool and fuse together.

Step 6: It is now time to cut off the excess material, handle of the plug. The place to make the separation is a point approximately one tooth height above the tops of the good teeth. A great tool to do this quickly and accurately are the diagonal cutters from either Knipex or Klein. The longer handle provides high leverage when cutting hardened steel as well.



Task 4: File the outside tooth space(s)
File the outside teeth spaces first. The inside teeth spaces will be shaped and filed in a separate task below. Let's build upon Dave LaBounty's guidance to first file the plug crosswise the width of the outside tooth space and then file down the outside of the plug to arrive at the proper sized space between the file (see picture). The idea here is to provide a starting file ledge of the correct width (correct tooth space) to file down to the bottom of the new tooth space. I've modified Dave's method by first filing the sides so there is a distinct space between the plug and the adjacent good teeth. Second, I file down using a joint file one to two sizes smaller than the right sized joint file. This helps me to avoid abrading the adjacent good teeth with the file.



- The barrette file with its safe back and edges will protect the nearby teeth from being damaged. Given the tight space one is working in and the tendency to over or under file in this tight space, one may also need to use a screw file, slitting file or similar file to accomplish this. Continually compare to the good teeth bottoms to determine when the correct depth has been achieved.
    - If one wants to be more precise or wishes to train their eye, use the Vernier calipers to compare the depth of the new root with the depth of an original root. File additional as necessary based on this measurement.

- A reminder to use the a joint file one size smaller than the proper width Joint file to file and measure which I'll refer to as the "right sized joint file". Ideally one will have a Joint file that is the same thickness as a good tooth space to use as both a file and a measurement guide. Once the file ledge has been created with the barrette needle file, use the freehand filing approach; file down with the joint file eyeballing the center of the arbor with the file at an angle pointed at the arbor center. Check periodically that the file is in line with the arbor center. This will result in the space being radial. Note – if you don't have the right sized file, you can use Jerry Faeir's suggestion of feeler gauges (HT, May 2009).

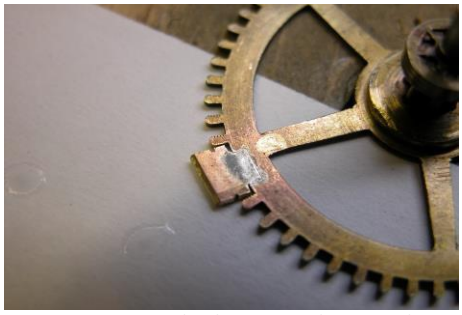
- Another tip is to have some beeswax handy to draw the edges of the joint file through. Using the beeswax as a lubricant when filing the brass plug is almost like cutting through butter.

- Exercise caution when filing to avoid contact with the top or sides of the adjacent good teeth. Use files with safe edges and safe backs so that the backs or sides of the files do not abrade or cut or mis-shape adjacent good teeth (Fried).

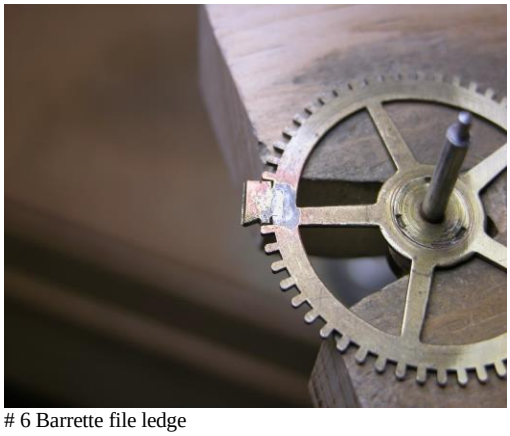
- Some of the masters recommend using a file guide. I've tried it and it is a lot of extra work and still does not assure the result is radial. Perhaps more practice might remedy this. When I was struggling to get this right, Dave LaBounty suggested making a reference line with the fine point Sharpie. This should be a reference line placed radial to the center of the arbor (see picture) and drawn down far enough to provide one a visual of the correct position of the file. The geometry experts among us might not need to do this, but for many it will translate the statement about the correct position of the file being radial to the arbor into a visual. In the end, I was able to repeatedly achieve a radial result using my freehand filing method.

- Remember when creating wheel teeth, one is creating the spaces between the teeth.

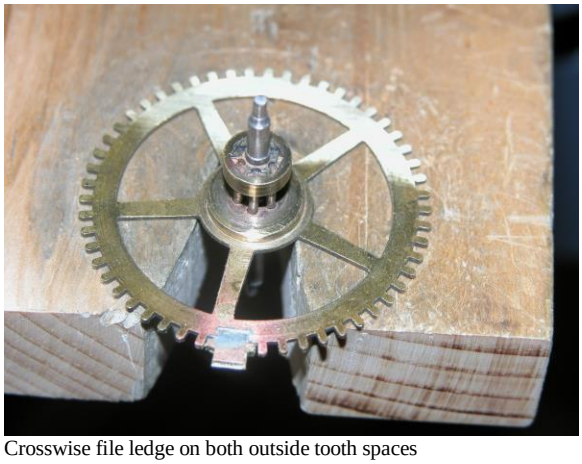
Step 1:
To achieve this, I started with my thin screwhead file to make a height reference point and a file start point on the plug just at the height of the good teeth.


Use thin screw head file for height reference & file start

Step 2:
Then I entered the file start with a #6 barrette needle file and filed crosswise. I switched to the #4 barrette needle file when the file ledge was well started to speed up the removal of material. It doesn't take very long to do this. Keep checking your progress until the right sized joint file matches up with the good teeth space. Do this for both outside teeth.


6 Barrette file ledge


4 Barrette file to finish crosswise file ledge


Crosswise file ledge on both outside tooth spaces

Step 3:
Tooth space width:

- File down with a joint file one or two sizes smaller than the right sized joint file using the freehand filing approach where the file is aimed at the arbor center. One is seeking to avoid abrading the adjacent teeth.

- Generally, after the initial filing, the tooth space won't be the correct width i.e. the right sized joint file won't fit in the just filed space. Here is where a right sized equaling file with a safe side comes in handy. Choose one that will fit into this space with room to spare and file the plug side until the right sized joint file fits into the space without removing any material. No need to be aggressive here. Make a few strokes with the equaling file and then check the width with the right sized joint file. Repeat as necessary. The idea here is avoid abrading adjacent teeth. If instead of removing more material with the equaling file, you were to squeeze the right sized joint file into this space, invariably you will remove material off the good adjacent teeth. Not the result you are looking for.
- As a final precaution, use a screw head file to file off the remnants of the plug in this outside tooth area. This is the time for careful filing as you want to leave the original root area intact. Stay mindful that this root area was never originally disturbed and does not need to filed, otherwise you'll quickly overfile the root.

Step 4:
Tooth space depth:
Check your progress periodically with the Vernier Calipers and stop when you've reached the depth of a good tooth. If you had a square bottomed tooth space, this is also the point where you would finish off the space with the equaling file or similar to achieve a square bottom.
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Outside teeth are finished

Task 5: File the inside tooth spaces
Now it is time to file the inside tooth spaces. Ideally one will have a file the same thickness as a good tooth space and of the shape of the bottom of the tooth space i.e. round or square. Joint files have a round edge and come in eleven thicknesses and thus are an ideal file to use for round bottoms. Remember the goal is always to match the original's shape. Using a Joint file of the correct thickness allows one to concentrate on the real task at hand and that is to ensure the teeth are radial and not tapered.

Filing the inside teeth spaces requires the result to be radial and for the tooth spaces to be equal widths. Let's discuss how to achieve an equal, radial result. Note also if you have a cold joint this is the step where it could show up. The filing process could break the joint.

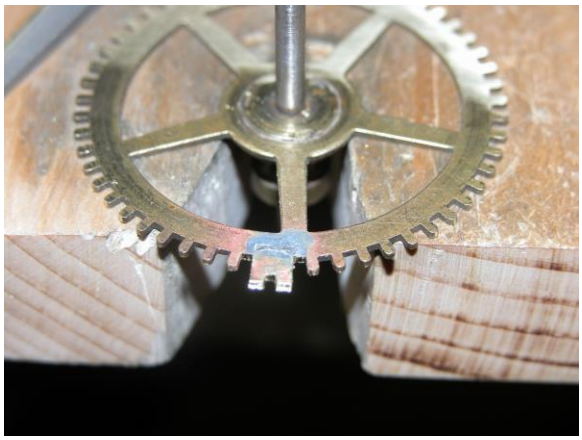
<u>Equal and Radial result a/k/a being on center:</u>
Again, here is where some of the masters recommend using a file guide. As mentioned previously, this is a lot of extra work that many customers are not willing to pay for and/or takes away from our profit. Furthermore, this approach does not assure one of a radial result. After much trial and error I finally achieved a repeatable outcome using my "freehand filing method" and an approach that I've coined "correct along the way". Here are the details.

Step 1:
I fit up my v-notched filing/saw board with its attached tenon into the vise and placed the wheel flat into the smaller v-notch.

Step 2:
I eyeballed the center point of the plug's tooth space and presented to that spot my #6 slitting file in an upright position. I again eyeballed center, made any minute adjustments that appeared necessary, and when I thought I had found center I proceeded to make a file entry mark and then filed a significant file entry point with the slitting file.


Eyeball center and use a # 6 slitting file
to make a centered file start

Step 3:
I stopped filing at this point and eyeballed center again. Usually one is still off a bit. No matter, switch to the #6 knife file with its three cutting surfaces and, while eyeballing center, proceed to file sideways one way or the other to create a center with two equal halves that the right sized joint file can fully enter. A Vernier Caliper is helpful at this point to measure and compare and contrast to a good tooth width. A Vernier Caliper is also helpful to check the progress when filing the depth by measuring the depth of a good tooth space and comparing.


Use a # 6 knife file to continue the file start and make equal teeth. Filing left or right to correct along the way

Note: If you were forming three teeth, at this point you would need to establish three equal teeth. This would require two file entry points that you would correct for equalness in the same manner as described in above Steps 3 & 4 using my "freehand filing" and "correcting along with way" methods. I would add the use of the vernier calipers to this step as well. Measure a good tooth and use that measurement to check the width of the file entry points and continue to "correct along the way".

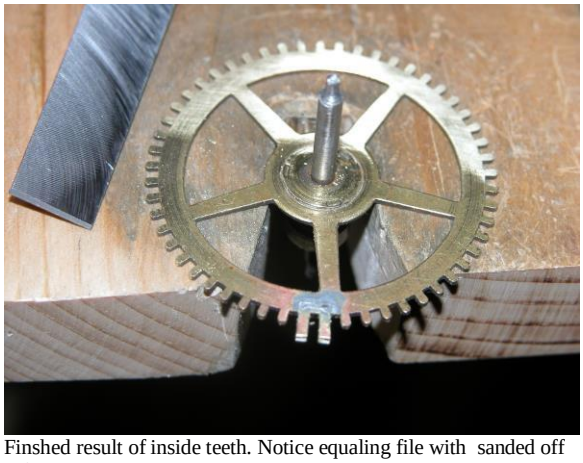
Step 4:
Open up this center equally using the knife file until it can receive the right sized joint files. Draw your joint file through the beeswax and proceed to file at an angle and radial until you reach near the root. Continue to use the arbor center as a reference point to ensure being radial and continue filing until the depth of a good tooth has been reached.

Note: If during all this filing, which is unavoidable no matter how you make the teeth, the plug may loosen up at its joint. Take the wheel and the plug to your smooth, flat staking block. Peen it a couple of times and then take it to your solder bench and resolder it judging whether or not you need a small, small additional crumb of solder to help it out. Most likely, you'll just need to reapply flux on both sides of the joint and reheat to remelt the solder and resecure the plug which by now is beginning to resemble two teeth.

Note: Also as part of all this filing of plug and securing of wheel, be open to using the v-notch filing board that is fitted up in your vice as a bench and look to swing the vise on

its base at whatever degree presents you with the best filing angle. One which will give you the best control over your filing

Step 6:
When near finished, if you have a square bottom, this is the time to switch to the equalizing files to stroke the bottom a few times to square up the root to the correct depth. To check the depth of the new root, use the Vernier calipers to measure an original root and compare to the new root. File additional as necessary based on this measurement.



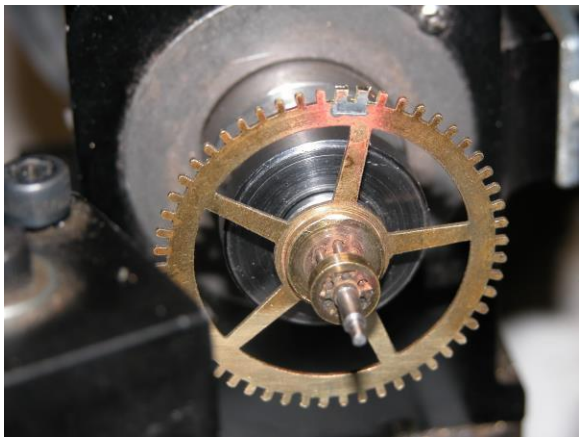
Finshed result of inside teeth. Notice equaling file with sanded off safe side and square edge.

Vulnerable Plug:
There is not much supporting the plug other than the compressed, peened metal and soldered joint. Filing the inside spaces places a lot of stress on the plug and can sometimes break the solder joint. Given this, here is what I did to ease this stress. I placed the wheel on my v-notched board and placed a fingertip on the plug to keep it from moving when filing and, in addition, used progressively wider joint files to create the space. This was based on the old clockmaker method of using progressively larger drills to drill holes. I started with a narrow width joint file to create the file guide and then moved up to wider and wider joint files until the end where I used the right sized joint file to finish the cut. This removes small amounts of material at a time and induced much less stress onto the plug. Using this approach plus the support of my fingertip enabled me to most times file the plug without breaking the joint. Despite these precautions, I would sometimes break a joint. In those instances, I peened it and resoldered it and it was good to go.

Task 6: Reduce tops of teeth to the circumference of the wheel a/k/a reduce the length of the teeth:

The preferred method is to use a lathe with its slide rest and cutting tool as you can arrive at the precise height quite easily. So, if you have a lathe, fit up the wheel into a lathe and turn the correct height with the cutting tool.

- This is called an interrupted cut and you will need to keep feeding the cross slide closer and closer, moving the cutting tool back and forth across the surface of the plug teeth until you have reached the tops of the good teeth.
    - Once the cutting tool is into the cut, continue to feed the cutting tool into the plug. You'll find this technique works better than removing the cutting tool from the plug and making progressively deeper passes.
- Stop the operation as soon as one begins to top the old teeth at any point (James L. Tigner, CMC; Replacing Wheel Teeth; AWCI's Questions and Answers of and for the Clockmaking Profession; p. 151-155).



Otherwise you'll need to file:

- Choice of file:
  6" or 8" # 4 hand file and Barrette hand file used to reduce top of plug to the circumference of the wheel.

Task 7: File Teeth Addendum to the Shape of the Original Teeth:

- Shape only the addendum of the teeth so that it matches the original good teeth. Stay away from the dedendum of the tooth/teeth being shaped. The dimension and shape of the dedendum and root was established in above Task # 4 and # 5 when the space between the teeth was filed to the correct distance, depth and shape i.e. square or round bottom.

- This task is the most critical and will require the most attention. If one overfiles and "wishes" they had more material to work with here is where the extra thickness comes into play. Using a flat punch and hammer, position punch in the area needing more material and hammer lightly until the material is stretched and then refile to the correct shape.

- File teeth addendum using Barrette needle and escapement files to finish file the arc to the shape of the original teeth. If you have a particularly tight tolerance to finish off, the rounding off and parallel barrette escapement file are very handy for this task.

Task 8: Remove excess thickness from both sides of the wheel

- Lay the wheel on your bench or the v-notched board, and sand it with the buff sticks. Because the plug and solder stand proud of the wheel rim, this will sand off rather quickly. Use different buff stick grits to finish the job so the repair is not detectable. Sand all evidence of the plug from both sides of the wheel while being cautious of removing too much material and thinning out the teeth.

EPILOGUE:
After many days and weeks of practicing, I was able to achieve repeatability, a repair that was barely detectable and successfully replaced two wheel teeth within two hours. This prepared me well for my AWCI Certification exam. I went through a significant learning curve. Proof once again, that one can learn if one practices long and hard enough ☺
Not bad for someone born without natural artisan and machinist skills ☺☺