Slip Ring-Brush Fabrication for Bicycle Headtube/Steerer

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Introduction

Fork rotation related to steering presents a challenge to routing power from a front wheel mounted generator to the tail light. The simplest method of tail light power delivery requires the conductor to be external to the frame at the fork/head tube interface and with enough slack to accommodate fork rotation. That's a perfectly serviceable solution but it requires exposed wiring at the lower portion of the head tube which can be snagged and damaged. Alternatively an electrical slip-ring can be mounted internally to the head tube/steerer tube assembly. That approach is far more difficult but it allows electrical power to traverse the rotating steerer and then travel to the tail light internally to the frame.

I wanted to create a head tube slip-ring brush assembly that could be fabricated by framebuilders having minimal tooling at their disposal. This article documents my efforts so that others won't have to re-plow the same field, or at least as much of it. A slip-ring brush ensemble seemed like a tricky project under any circumstances but the lack of a lathe would have to make it significantly more difficult. A robust brush assembly seemed like the stickiest wicket but I felt that suitable commercially available components would be available and make the project feasible.

Ignoring fabrication of the components for the time being, there are two fundamental approaches, each functionally a mirror of the other.

The first, developed by Herse, places the brush assembly inside the steerer and the slip ring on the ID of the head tube, just above the pressed-in spigot of the lower bearing cup. I posted a request for information on Dale Brown's Classic Rendezvous site and a number of folks replied. Jim Langely's web page provided information and photos that shed some light on the fundamentals of the design as found in one of his bicycles. Dirk Feeken provided a pdf of what looked like an original detailed drawing of the design (Photo 1); that was a real eye opener. It revealed that the brush assembly utilizes a wooden plug bored both for the brush and for insertion of a spoke as a brush retention device; the plug is pressed into the steerer ID. The brush bore is perpendicular to the steering axis and aligns with a hole drilled in the steerer. The brush protrudes from the hole in the steerer and slides on the slip ring fitted to the head tube ID. The brush retention device bore intersects the brush bore at 90 degrees and is drilled parallel to the steering axis but is offset near the steerer ID. After depressing the brush adequately into it's bore, a spoke can be inserted from the underside of the fork crown and into the retention bore in order to keep the brush retracted and aid fork assembly. That's intended to prevent damage to the brush while inserting the fork into the head tube. The plug is bored for wire routing as well. I don't know the order in which the holes are best drilled but there are a couple of possibilities.

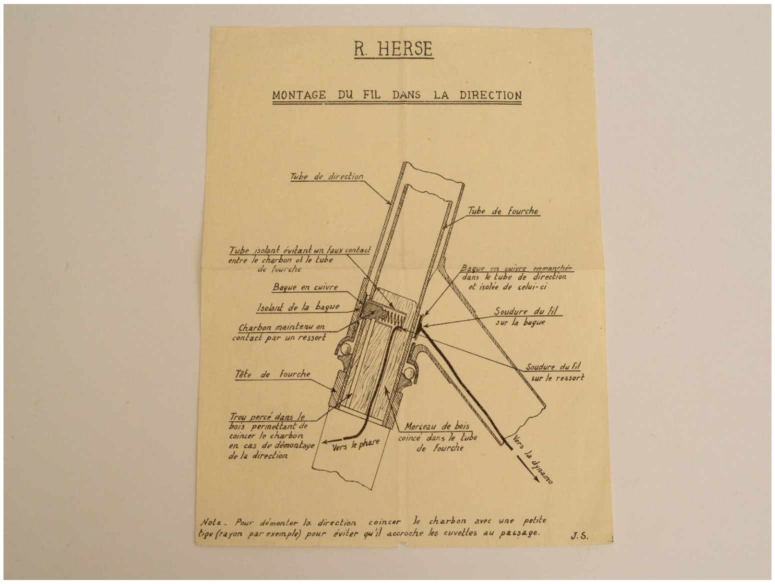


Photo 1: Drawing of the Herse slip-ring/carbon brush assembly

It's a very clever design and one of the things that occurred to me was the use of “appropriate technology”. A wooden plug sounds very low tech in this day and age but it was inexpensive, possessed the requisite insulation properties, would have been easy to produce with limited tooling, reasonably easy install, and could be removed if necessary. Because the carbon brush, instead of a wire, passes through the wall of the steerer, that hole is of significantly larger diameter than required by the method that follows. Additionally, any steerer ID mounted fender boss design must provide access for insertion of the brush retention device (the spoke) and removal or positioning of the wooden plug. The slip ring on Jim Langely's Herse appears to be made of a strip of copper formed into a short cylinder. If it is made from a strip, as opposed to a continuous bushing, I don't know whether or not it has a gap or discontinuity where the ends meet; that might damage a carbon brush if rotated 360 degrees. I also don't know what Herse used to insulate and secure it to the frame but based on the information at Jim's site it appears to be some sort of adhesive. The section of tail light wire thats inside the frame is soldered to the copper ring, routed into the downtube and thence to the rear end of the frame, which is used as the other conductor. I assume that the ID of the copper ring is the same as the ID of the headset cup and that the gap between them is minimal, in order to make disassembly possible and be less likely to damage the brush.

As an aside: With a suitable subcontractor, or perhaps only a lathe it might be feasible to make a bushing with a hard, non-conductive coating on the OD and end; I'm thinking you'd rough the bushing OD to somewhat undersize, cast it's OD somewhat oversize in an epoxy that would cure with adequate hardness and then turn to final OD/ID and pare to finished length.

The second approach, used by Hirose and I think Toei, places the brush assembly in the down tube/down lug cavity; the slip ring is on the steerer. I know little of the Toei details but a You-Tube video I found revealed some of the details of Mr. Hirose's approach to design and fabrication. He builds a brush capsule, containing the brush and spring, that fits into a cylindrical receptacle brazed to the OD of the head tube in the area that's concealed by the down tube. It appears that the down lug and receptacle are brazed to the head tube at the same time, or at least without the downtube which is brazed into the assembly later. Aside from that particular order of assembly the trick is sizing and placing the components so that everything fits within the downtube. It's conceptually simple but requires much attention to detail.

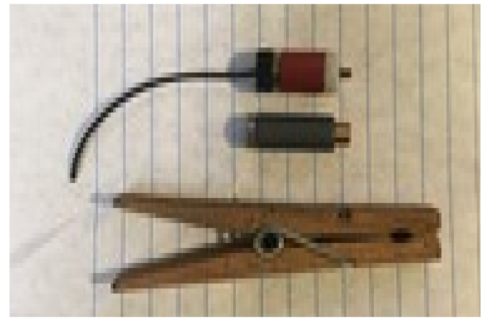
In the You-Tube video Mr. Hirose has the steerer chucked into a lathe and, at slow speed, winds a single strand of copper wire around the it. I assume that the wire is bedded in epoxy or other adhesive material. He then uses his lathe to turn the wire wound assembly into, functionally, a smooth, seamless copper slip ring upon which the brush slides. Absent the discontinuity of a gap in the ring, the fork can spin 360 degrees without risk of damage to the brush. Since the hole in the steerer carries only an insulated wire conductor it can be quite a bit smaller than required by the Herse approach.

Photo 2: A fender mounting boss that would provide access, if a bit fiddly, for removal of the wooden plug used with the Herse method.

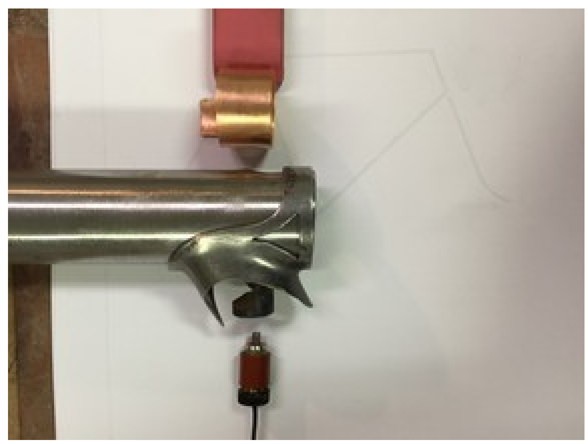
I decided to use Mr. Hirose's general approach though some of the details are slightly different. Getting ahead of the story for a moment, while I didn't accomplish the zero machining goal with this iteration I now see a way to do so; it's noted later in the article. I ended up needing a small amount of outside machine work. The brush and capsule had to be manufactured on a lathe, something Jamie Swan graciously produced to his high standards of craftsmanship.

Brush Capsule Assembly

Initially I decided to use a commercial carbon brush assembly. They're highly evolved products and I thought it made good sense to leverage mature technology for this purpose. I made a dimensioned sketch of the steering assembly, including the down lug and down tube, and found a brush assembly that I thought could be modified to work. Conveniently it's OD and base end were insulated but the side mount brush conductor attachment and tab were problematic; with a bit of clipping, filing, drilling and soldering I had the wire exiting through the capsule's aft end. I also reshaped the “business end” of the square cross-sectioned carbon brush to be round so as to produce a shoulder that could be used, by addition of a copper aperture plate that I soldered onto that end of the capsule, to limit travel and retain the brush when the fork was removed. The brush is installed into it's capsule from the threaded end. Initially this seemed like a good way to go, and I have no doubt it could work, but I was concerned about the ability of the brush to survive repeated assembly/disassembly cycles. At the end of the day my concern for the fragility of the carbon brush itself made me decide to abandon this approach and make a capsule with a brass brush, instead.



Photos 3 & 4: Commercial, but reworked, carbon brush unit above the Jamie Swan brass brush unit. The round aperture plate was soldered to the top of the commercial capsule and can be seen in the photo (round hole for the brush). The reshaped carbon brush can be seen as well. The nut on the Swan brush is for illustrative purposes and will be removed for use.



Photos 5 & 6: The partially reworked carbon brush and the finished brush, HT and slip ring laid out for visualization.

By this time I'd seen a photo of what was reported to be a Toei brush assembly which had a thin flange at the steerer end of the plastic capsule. Thinking that might eliminate the need for a capsule receptacle in the downtube, I sent a dimensioned sketch to Jamie. He produced the part but I found that between the OD of the slip ring on the steerer and the ID of the head tube there just wasn't quite enough room in the annulus to allow installing the unit. A flange and capsule end contoured to the ID of the head tube would solve that problem would but be significantly more difficult to produce. Aside from the lack of annular space, the flange was very thin and I didn't have much confidence as to it's longevity in use; as a result I cut off that end and shortened the entire capsule and brush a little. I also cut off the brush retention threads at the other end of the capsule, three things occurring to me, if a little late: 1) Shortening the overall length of the assembly a little would make installation in the head tube easier; 2) that being able to remove the brush while leaving the plastic capsule in place might be useful (a stuck capsule) and; 3) that there might not be enough room in the downtube to comfortably accommodate the retention nut on the threaded end of the brush; shorting against the tube might occur. Shorting against the end of the brush capsule receptacle would only occur with the fork removed and shouldn't matter (except, perhaps, from a standlight discharge perspective). I also discovered that a normal wooden clothes pin made an excellent capsule insertion tool! These are the results; the small nuts are simply to keep the parts in place for the photo.

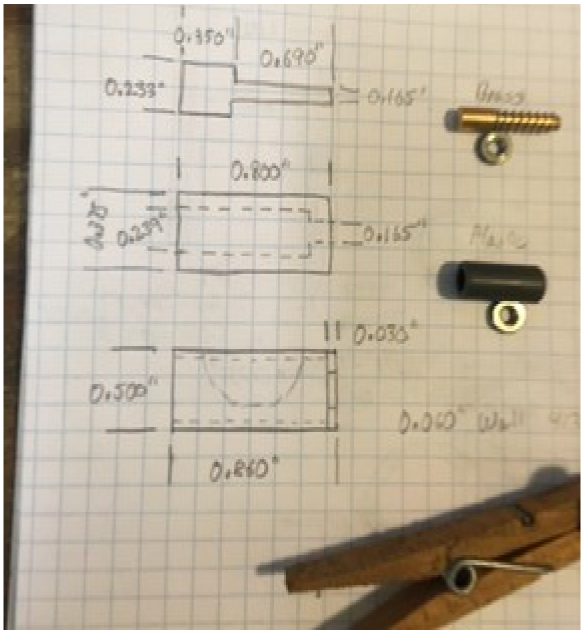


Photo 7: Dimensions of the brush, capsule and receptacle, from top to bottom.

Brush Capsule Receptacle

Since I wasn't going to braze the down lug and receptacle to the head tube at the same time the trick was shaping a receptacle that, once brazed to the head tube, would allow later assembly and disassembly of the head tube, down lug and down tube for final frame fit-up and brazing. If I'd thought about it ahead of time I'd have specified a brush capsule OD that could fit inside a receptacle made of a common *(*read less expensive and lighter) size of much thinner wall steel tubing; the smaller the OD the less room is required in the DT cavity. This part doesn't need to be heavy and robust. In any event I got some suitable tubing, fabricated a receptacle, brazed it to the headtube and carved it up so that the down lug could be installed and removed. Taking a cue from Peter Weigle I drilled it, if crudely, to reduce weight.

Long Shen 102 series lugs were used for the frame with pressed lugs for some of the prototyping. Rotating the lug so that it's upper point nestled in the sculpted area of the receptacle allowed the lug reinforcing ring to align with and slip onto the head tube; the lug could then be rotated into final position. It was it necessary to cut the bottom of the head tube to be essentially flush with the final location of the bottom of the lug reinforcing ring before assembly was possible. I'd imagine that this technique won't work for all lugs. Slicing a truculent down lug in half, in a transverse horizontal plane, and then brazing the two pieces together as part of the larger frame brazing job, or removing the upper point and brazing/welding it back on later, might be reasonable ways to get around that problem but I didn't need to do so.

Vertical placement of the receptacle in the head tube was driven by both the need to install and remove the lug and to ensure adequate room and orientation for operation of the brush; and all of that governs the vertical location of the slip ring, later. The receptacle ended up being as close to the bottom of the down tube/head tube intersection ID as I dared, consistent with being able to fully insert a coped, conventionally sized down tube. Oversize tubes would provide a little more latitude on this count. Once brazed to the head tube it's vital to smooth all brush receptacle edges and clean up the ID with abrasive roll material to ensure a reliable drop in fit/drop out removal of the plastic capsule. With the head tube/receptacle subassembly complete the entire frame was brazed and prepped, and the headset cups and lower bearing baseplate were installed. The fork was installed on the frame and an accurate determination of the brush track location on the steerer was made. With that information the location of the slip ring on the steerer could be determined.

Photo 8: Lug being installed by nesting the upper point in the sculpted portion of the capsule receptacle. The lug reinforcing ring is about to be pushed to the left of the photo and onto the head tube. That will allow the lug to be slid up to the proper height and rotated into it's final and pre-pinned position.

Photo 9: Checking the fit of the down lug, head tube and brush capsule receptacle prior to brazing.

Steerer Preparation

Approximately 5” of steerer was insulated, starting at the top of the fork crown bearing boss, with a couple coats of epoxy paint primer. It offers adequate insulation, is durable and adheres well to the epoxy adhesive used to secure the slip ring. The slip ring solder tab and hole in the steerer for the tail light supply wire need to be on the right or left side of the steerer because that's the neutral axis relative to the normal fore/aft loads on the fork. I suggest waiting to drill and dress the hole until later when you have a slip ring fitted and it's position and footprint are confidently determined. Once the steerer insulation has cured you can measure the OD and calculate the circumference for slip ring fabrication. I made two diameter measurements, 90 degrees apart, and used the average value to which I added 0.004” to account for a 0.002” epoxy adhesive annulus. That dimension was used to calculate the circumference of the ID of the slip ring and therefor the length of the copper strip. Jumping ahead of the story a little, the photo below shows an initial version of a nearly completed steerer assembly. The tailight wire coming out of the hole in the steerer will be soldered to the tab before the ring is permanently affixed to the steerer; the ring will be removed from the steerer for that job. Ring orientation will be such that it's seam will be at the front of the bicycle and the wire will be routed through the hole in the steerer and strain relieved with a small dab of epoxy.

Photo 10: Checking the general arrangement of an early attempt.

Slip Ring Options

I have no intention of generally spinning the fork around and around but it seemed to me that being able to do so without damaging the brush would be a good idea; I wasn't sure how I could accomplish that goal. Mr. Hirose's approach seemed optimal but, lacking a lathe, manually wrapping the wire around the steerer and then finishing the surface of the ring with fine abrasive material wasn't very attractive. I thought that maybe I could shape a flat strip of copper into a slip ring and cut it to length accurately enough so that the gap would be so small as to not be a problem if the fork were inadvertently spun, assuming a brass brush. I think that nearly any gap would be rough on a carbon brush. Supporting that approach was the thought that once a front rack was fitted, or brakes for that matter, spinning the fork wouldn't be possible; only careful assembly would be required to prevent problems but that didn't settle comfortably with me; sooner or later any fork is going to get spun around. I didn't think that I could make a continuous slip ring from flat strip, with the ends silver brazed together, accurately enough to slide onto the insulated portion of the steerer and with the minimum of annular clearance necessary for the epoxy adhesive. That sounded like a lost cause and so the conundrum of how to make an uninterrupted slip ring with such minimal tooling kept bugging me until one day I simply decided to try it; I didn't expect success. In paper prototypes I'd previously determined that the slip ring would need an offset solder tab for tail light wire attachment so that the lower bearing could be slipped over the joint before having to center-up and straddle the entire circumference of the ring, for which there isn't a heck of a lot of room. Note that the lower baseplate and conventional lower bearing races won't fit over this particular assembly but since baseplates rarely wear out I decided not to address that issue. Thinner copper foil might resolve it but it didn't seem worth the trouble. I had a small sheet of 0.016” copper stock from which I carefully cut, longer than final, the shape I'd decided to use. With the target length of the copper strip known from the calculations I used the sharp ID measuring points of my calipers to mark the cut location and then lightly scored across the strip against a machinist's square using a sharp marking tool (a sharpened, 4” drywall screw). It turns out that one can be remarkably accurate with that approach! A large, high quality pair of metal snips made a true, square cut and a little work with the belt sander cleaned up the other edges, the seam edge pair being left alone; it's worth the trouble to make that cut as square as possible

Photo 11: Roughed-out copper strip

I aligned the strip perpendicularly to a 1” dowel (against a square) and then hand rolled it as firmly and round as possible; that operation was repeated over the 7/8” end of one of my Omar Khiel manufactured lug/chainstay-spigot bending bars. Again I used my fingers for most of this with a light taps from a small hammer to coerce the tab area. Getting the two cut ends to adopt the proper radius of curvature required a little extra metal forming via a pressing/rolling motion over the bar with the fat end of my smallest machinist's square; the strip now had the proper radius of curvature right up to the cut ends. It wasn't *perfectly* round but relative to this job, very close. I gently and lightly closed the vice on it just bringing the ends into contact and confirmed that they met in a circumferentially smooth seam with no discernible misalignment. I checked/tweaked that a couple of times, fluxed the joint and silver brazed it with a very low flame on my smallest tip (AW-201), below. After soaking the flux off the silvered joint was carefully dressed on the ID and OD with small, fine cut files (Nicholson's 6 pack of 6” files). The OD was then polished with wet or dry abrasive paper, starting with 600 and finishing with 2000.




Photos 12 – 15: Checking the alignment of the slip-ring prior to brazing (upper left); slip-ring after brazing (upper right); fit checking against the steerer (lower left) and final polishing of the seam area (lower right). The hole for the tail light wire hasn't been drilled.

Scorecard: In the final analysis I made four of these over a period of a week or two and was pleasantly surprised; all of them initially came out well and were a teeny bit too tight to slide onto the steerer. In spite of attempting to compensate for the annulus (on later versions) I didn't want to err overly large since I had no way to shrink the slip ring, short of cutting and rebrazing. I didn't quite know how I'd stretch the ring in a controlled fashion but I figured light hammering would be a reasonable start. That was a disaster so the first one got retired quickly. With the second one it occurred to me to use my 1" Omar Khiel lug vise. It's a simple "two finger" design that utilizes thick walled tubing driven by a relatively large bolt. That design stretches the copper ring to, approximately, the same diameter on each end.

Photo 16: Slip ring on lug vise: Go very easy and in very small increments with every stretching step! Pliers compress the vise immediately to the left of the backed-off bolt in order to ease installation and removal of the slip ring.

As an aside, I think a tapered plug, three, four or more-finger lug vise design is not as suitable for this job in that it would, I think, preferentially enlarge one end of the slip ring more than the other design. If that's what you have it's worth a try but if the resulting slip ring is much looser at one end than the other it's worth getting a lug vise designed like Omar's 1" model. Slip ring number two would have worked but was narrower than seemed prudent. Number three got botched via another "surely this method will work" go at hammer stretching. Number four, coaxed slowly and very incrementally on the lug vise came out perfectly. The seam required some extremely light forming with my small hammer to improve it's radius of curvature after brazing, not to stretch the metal. After 10 or 15 minutes of careful work with the lug vise, the result was precisely the right diameter. Also note that if you slightly over stretch the material, but the result has the same diameter at each end, along with true sides, it's possible to cut the brazed seam, trim a skosh off, and braze it up anew. My learning curve included doing that a few times on a couple of the rings.

Photo 17: The major tools I used, minus the machinist's square.

Some Fine Points:

1. Be certain to deflux and completely dress the ID and OD of the ring before any fitting or stretching operations.
2. It's extremely easy to go overboard with the stretching. After gently taking up the slack in the lug vise turn the bolt in increments of no more than 1 clock hour (Mickey's small hand). For example, if the slack takes up at 12 O'Clock, turn the wrench to 1 O'Clock and check the fit against the steerer. If it doesn't fit, go to 2 O'Clock and re-check, and so on. Going less is wise and may save some heartache. Leave the wrench on the bolt or mark it's location for consistency. Better to endure a large number of stretching steps than go one step too far! It's also a good idea to alternate the end of the ring that gets slipped onto the vise, to further minimize ID discrepancies between the two ends, at each stretching/checking step. And when you get close to a fit, reduce the magnitude of each step.
3. Rotate the ring so the two segments being stretched across the two gaps between the vise's fingers are different each time, until having to reset back to the first. You can only get four, maybe five different positions. You don't want to over thin and possibly rip one section while leaving the rest more or less as they started.
4. I didn't place the seam closer to the lug vise gaps than about 2 mm and I never put the seam over them. I don't know if it will fail but there's no need to find out.
5. After every stretching step, and before removing the ring from the vise for fit checking, rotate the ring to three or four different locations and lightly snug up the vise at each position. That improves the concentricity of the ring without stretching the material. You'll get a better fit and be less likely to find out that you over stretched the ring when a fitting problem was due to a lack of concentricity. Back the bolt off and squeeze the vise (large Channel Locs or similar) to ease removal/installation if the lug doesn't slide off easily so as to avoid having stiff lug fingers deform the ring.
6. Early in the stretching process you may need to use the pliers to install the ring on the vise. Be certain to keep the fingers depressed until the ring is completely installed, else you may get a bulge in the ring.

Assembly

You need to determine the distance between the brush centerline and some convenient measuring point on the fork in order to position the slip ring. I installed the brush, without the lower headset cup, and measured from the brush centerline to the lower faced end of the HT. I then assembled the fork, frame and headset, and measured from the lower end of the HT to the milled, fork baseplate boss. Once done, and confirmed a time or two, position the ring accordingly on the steerer and mark the location of its lower edge on the steerer. Solder the wire to the ring tab; don't forget (as I did) to fan the multiconductor wire out flat so that the joint has minimum thickness. Once the ring is cool, scuff the ring ID (and steerer epoxy coating) with shop roll abrasive, mix the epoxy, apply a very thin smear to the ring ID to fill the scratches, a generous smear to the final location on the steerer and slide + rotate the ring into final position. Clean off the excess and tidy it up. Make sure to orient the ring so the silver brazed seam is at 12 O'Clock, the front of the fork; the solder tab should be at 3 or 9 O'Clock, the left or right side of the bicycle. The hole for the wire should be about 5 or 10mm from the end of the solder tab. I drilled and eased the edges of the hole after I had determined the location of the ring, but before I glued the it onto the steerer.

After the epoxy had cured I dry fit the fork to the frame without the brush. I found that I needed to enlarge the ID of the lower cup boss a little in order to slip the fork in; round and half round files were used and the swarf was vacuumed out. Once that was completed and I confirmed that there were no problems with installation or removal I installed the brush and eased the steerer into the fork. If it's a threaded steerer, and if a rinko or field operation, then a wrap of clear packing tape around the threads, or perhaps a piece of paper wrapped around them, will protect the polished contact surface of the brush against damage and might be worthwhile. Since my frame hadn't been assembled I just lightly pulled on the brush wire at the BB end to retract the brush during assembly. Electrical continuity and smooth 360 degree rotation of the fork were confirmed.

Photo 18 – 20: Finished components and final assembly for continuity testing

Brush Fabrication Without Machining

I haven't done it yet but it seems feasible to make the brush and plastic capsule without any machine tools using the following approach:

Brush: Brass rods of two different diameters. Use the large diameter for the contactor end, the smaller for the spring/guide end. Center drill one end of the larger diameter to accept the smaller diameter rod, silver braze together and dress as necessary for smooth surfaces. Err both pieces a little long and trim as necessary later. Make a gentle round chamfer on the perimeter of the contactor end of the brush and polish the surface starting with 600 and ending with 2000 wet or dry abrasive paper.

Plastic Brush Capsule: PVC round stock of suitable OD, center drilled to accept the brush while retaining a floor in the bottom end to be drilled for the spring-guide end of the brush. Creating a smooth bore with common drill bits, and good axial alignment might be the difficulty but absolute perfection shouldn't be required. I haven't looked for small bore PVC or other glue-able plastic pipe but if available in suitable sizes that might prove to be a good approach and would eliminate the drilling step. An end cap would have to be fashioned from scrap stock and glued to the capsule ID at one end.

Commercial Carbon Brush

Having abandoned it, and later discovering that making a continuous, gapless slip-ring cylinder from sheet stock is fairly easy, I may try using the commercial carbon brush in a future project. The brush itself isn't as overhung as I thought it would be. With the help of a thin piece of plastic rolled into the shape of a long cylinder slipped over the steerer and guiding it through the head tube (like a tube from a roll of paper towels), assembly of the fork without damaging the brush seems reasonably possible; care would certainly be required but once installed the superior lubricity and electrical conductivity of the brush material should make for optimal performance and, hopefully, long and trouble free operation; as I understand it the contact areas of the brass brushes sometimes need to be cleaned.

Materials and Some of the Tools

Carbon Brush: Arrowhead electric, BH11570S holder with brush and cap is what I tried.
Copper Sheet Stock: K&S Metals, Stock #277, your local Ace Hardware can get it for you, avoiding shipping costs from online sources. K&S offers small quantities of sheet and rod stock of copper, brass and other metals.
Bending Bars and Lug Vise: Omar Khiel, Oasis Cycles. I find them very handy for framebuilding.
Brush Spring: Ace Hardware. Rummage through their spring box and you should be able to find something that looks like the one in the photo.