Adventures with the Refractor

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In the continuing saga of one person's attempts at the perfect telescope, I offer the following. Having gone on at length about the Newtonian in part 1, I now go to the Refractor. This story is a bit circuitous, as this telescope evolved over several incarnations, starting with a small lens, then to a Schmidt Cass, from which the mount was born, finally to the acquisition of a really fine 5-inch lens, and the fabrication of the 5-inch tube assembly. This whole process was spread over about 10 years, as opposed to the 6 or 7 months for the 12.5-inch.

I had always wanted a refractor of some size. I still had, and have to this day, the 60mm Polarex, and a couple of other 60mm 'scopes, but they are 60mm. A real refractor is a 4" or more. As I said earlier, except for the Knotts telescope, a Newtonian, I was raised on refractors. There was the 12" Zeiss at the Griffith Observatory, and a beautiful 6" Brashear/Warner & Swasey at Mt. Wilson, which I was privileged to look through early on, and finally gained the use of on a nearly unlimited basis. There was an identical 6" at the student's observatory at UCLA. Remember, from Part 1, my driving my parents batty about a bigger telescope, I kept howling about Unitron: "Look a 4"! and on an equatorial to boot!!" Never mind the equivalent price, in today's dollars, of something like $8,000! This all passed, sort of, with the completion of the 12.5", but, still, a 4- or so inch refractor would have been nice.

I had the delusion of trying to make a lens. This seemed, at the time, out of reach. For one thing the math involved looked formidable. Maybe after I had algebra... That came and went, maybe Trig... No, how about Calculus... By the time I bit the bullet, I discovered all the high powered math wasn't needed. A little algebra maybe, and a whole lot of arithmetic. The gory details of the design process really is beyond the scope of this discussion, however, these design methods are described in Amateur Telescope Making (ATM) II, by J. R. Haviland (pp 212--) and in ATM III by Alan E. Gee, (pp 208--), Charles L. Woodside (pp 565--) and James H. Wyld, (pp 581--). Then there was the problem of glass. Mirror blanks were plentiful and cheap, optical glass wasn't. Today none of it is. Cheap, that is!

Somewhere along the line, I think I was just finishing up at UCLA, we were rooting around at the venerable old C&H Sales in Pasadena when I came across what appeared to be 4" lens blanks. Fat biconvex and deep plano-concave pressings, which if made into lenses, would have been very short, maybe f/3 or f/3.5. I don't recall if the index and dispersion numbers were on these or if we just assumed they'd be "ordinary" crown and flint. I bought a couple of sets of these things, for a quarter each, and thought seriously about making the long sought after 4" lens. Using the formulas for color correction and assuming the properties of these chunks of glass I set about to regrind the curves to make an f/15. It turned out these things weren't 4" but something less, leading to a 3.6" aperture. I thought if I make the crown equi-convex, and match the concave side of the flint, I could test the concave with the knife edge test, and match the convexes to that by interference fringes. If all looked good, I could then test the whole lens and, supposedly any error remaining would be on the back of the flint, which could then be dealt with accordingly. After polishing I was somewhat gratified that the focal length seemed close to the design, and with an eyepiece the color correction was reasonably good. I tried to figure these glasses with limited success, finally noting the lens was terribly astigmatic. A test with crossed polarizers showed the dreaded colored "Maltese Cross" in the crown element, indicating a large amount of strain in the glass. Amazingly enough, this was the crown element. The flint was fine. I checked the other blanks I had, and they too were strained. That put this telescope on the back burner.

The scene now switched to my first job, right out of school, with Valor Electronics. Tom Johnson, the owner, was fooling around a new type of telescope. My first encounter with Tom was at a star party, where he showed up with an 18" Cassegrain. (See cover, Sky & Telescope, March 1963) Remember, this was the mid '60s, and aperture fever stopped at 12.5", maybe a 16 or two. This 'scope didn't perform all that well, and Tom tried some redesign and, skipping over the details, his fiddling led to serious breakthroughs in the manufacturability of the 4th order aspheric plates for the Schmidt telescope. This fooling around led to what we know today as the Celestron Schmidt Cassegrain. I helped Tom develop this system and he was able to keep me out of the army. Clearly a fair trade! One optical system we did while I was there was an 8" f/12, using a very fast f/1.6 primary. I made an extra set of optics as a backup, and when the order was delivered I was able to keep the spare set.

In the first part I talked about the machine shop education. By now my dad and I had the lathe, drill press with X-Y and rotary table and all. Also, the L.A. area is a paradise for tinkerers, as there is a major scrap metal yard seemingly on every street corner! Also, even though this was California, USA people, back then, weren't as damned "sue-happy" as they are today, so the managers of these places let us go tramping around and pick up what we needed, weigh it, pay up and go. What came of all this was the fabrication of an equatorial mount, for the 8" SC, patterned, functionally, after the Warner & Swasey at Mt. Wilson. This one was all machined from aluminum with 1.25 thick walled tubing for the shafts, threaded and set up at 90 deg to the saddle plate and bearing housings. Again, ball bearings (some lessons never get learned!) but this time there was adequate damping in the design of the clamps and the bearings could be preloaded to some extent. The drive is a 6.25" 100 tooth brass worm gear, a 16:1 reduction and a 1 RPM motor. But wait! That's 1600:1! Thanks to the slot car hobby I obtained the gears for a 20:18 gear train, and voila! 1440:1. The motor is mounted on the baseplate, the power is transmitted to the gearbox by a short shaft and universal joints. This system allows a little flexibility as the latitude is changed. The slow motions are both tangent arms, the declination being the equivalent of a 691:1 gear reduction, the RA being 534:1. the Declination is clamped to the bearing housing, the R.A to the hub of the drive gear. This way, using the RA slow motion doesn't affect the drive rate, and therefore the RA circle carried on the gear doesn't get out of time. Since the lead screws on the tangent arms straight and the motion is along the arc of a circle, the screw mounts and the nuts they engage must be able to swivel to avoid jamming. The worm on the main gear is spring loaded to eliminate backlash, and allow for any "out-of-round" of the main gear. I was complemented on this design at one of the star parties and it was strongly suggested I get this patented. I said I really can't. I stole this entire concept from an 1880's vintage Warner & Swasey mount! The ball bearings are retained by threaded rings in the axes, which can be tightened to provide preload to the bearings. The cover over the lower polar axis bearing is also a 3.5-inch hour angle circle. Since the shafts and housings are both aluminum, there is no trouble with temperature changing this preload. This equatorial head is supported by a stout old transit tripod. The telescope this mount was built for was the 8" SC for which I subsequently completed the tube assembly. The details of this telescope will be told later.

While at Valor I remembered my failed 3.6" lens and asked our glass supplier if he had any suggestions. He said to bring the lens and maybe his place could reanneal it or something. When I got the lens back, it looked OK, but when I put it together the performance really stunk. Close examination showed a sort of "fire polished" appearance on one side. It needed to be reground. As I refine-ground the bad surface it ground in an hour-glass pattern. After this I again reassembled it and took a look. The astigmatism was much worse. Rats! I needed to regrind the other side as well. When the glass was reannealed it sprung into a potato-chip shape. After all this consternation I finally got the lens to a reasonable condition, but it never did work very well. A Clark or Zeiss this is not! This telescope is now serving as a guide telescope on a 4" astrograph made from one of the old f/6 Aero Tessars. This camera, with the 60mm Polarex as a guide 'scope, is pictured on the cover of the Griffith Observer for Feb. 1961.

It seems I have strayed, digressed and wandered from the purpose of this article, my 5" refractor, the one in the accompanying photo. Believe it or not all the previous baloney is leading up to this 5".

Some years go by, I switched jobs to Fairchild Space and Defense Systems in El Segundo, where I was being taught lens design. I was called in by them to fill an optician's position, but I wasn't that interested at the time. The person I went to see said to see "Dick" on the way out. "Dick" was Dick Heimer, the director of optical design. "Do you know anything about optical design?" "A little-- telescope objective.. (the 3.6)" "Do you know anything about computers?" "No--Besides I'm not all that good at math" "Get your butt in here Monday-- You'll learn" So, for the next 2.5 years I learned optical design. After that (FS&DS was closed, all the managers went back to Long Island, the rest of 'em went to Hughes) I fulfilled my prime directive-- get out of LA. I found myself here in Colorado.

I still wanted a "big" refractor. Maybe I should try again with better glass. I was older, presumably wiser(?) and it would be interesting to go through the whole process, hopefully now knowing a little more about what I was doing. I had approached a very good friend in Tucson, asking if he knew where one could obtain blanks for a refractor objective. Given the choice, I decided to go for a 5", thinking that 4s are nice, but fairly common, while a 6 would be a monster, based on the experiences with the Mt. Wilson 'scope. Lynn said he'd sniff around and see what he could find. Tucson probably has more optical companies and telescope makers (really big telescopes) per acre than anywhere else on the planet. I had begun to calculate the curves for a 5" f/15 using Conrady's G-sum method described in Alan Gee's chapter in ATM III. Somewhat arduous but the curves supposedly lead to a lens corrected for secondary color, third order spherical and coma. This method is an algebraic technique, assumes thin lens approximations, and leads to a good starting point which should be "tweaked" by rigorous ray trace techniques. Here is where practicality steps in. One can tweak and tweak and tweak, but the moment of truth comes while producing those carefully calculated curves. As the lens progresses it will need to be tested and figured until all traces of aberration are gone. It is far less torturous to use the initial curves from Gee, and then polish until the lens looks good. Saves a whole lot of wear and tear on the calculator, (and the brain) besides the indices of the glass might not be exactly as given and the thicknesses and radii of the surfaces might be a little off, requiring even more "tweaking". Making a lens is quite different than a mirror. The mirror needs only one surface (good) but it must be paraboloidal, not spherical, and must be made roughly four times more accurately as the lens surface. (The error on the wavefront for reflection is twice the surface error, while for refraction it is roughly half the surface error.) The lens needs four surfaces, but these are spheres and usually with fairly steep radii on three of them so the figure is relatively easy to control. The back surface is generally of a long radius, nearly flat in some cases, and is a bit more of a problem. One usually figures this back surface last when finishing up the lens. Attention needs paid to wedge, the parallelism of the two sides of the lens element. This HAS to be carefully controlled. Element thicknesses are not all that critical. in fact these parameters are ignored in the G-sum calculation, as is the airspace. Once the lens is close to completion, one can vary the airspace slightly to try and improve the correction, or to "tweak" the color correction, then control the remaining spherical by a tad more polishing.

A large box appears on my doorstep from Tucson. Lynn's return address on it and "Fragile, Glass" written all over it. What-?? Then I remembered asking him some months earlier about telescope glass. I opened the box, dug through a zillion wads of paper and all and got to the first piece of glass. I unwrapped it and wow! a pristine, beautiful lens element! It was even AR coated, edged to 5" diameter and seemed to have a fairly long focal length, around 800mm or so. My initial figuring showed the crown element should have a focal length around 770mm or so. Mixed emotions!

I'd feel terrible grinding into this lens, but then again, hopefully, it'd be a nice lens after the surgery. Maybe I could leave this one alone and match the flint to it, using other glass tools to shape it. Further digging produced a weakly negative lens element (the flint) equally as pretty as the crown. Suddenly it hit me. There is some guy out there expecting the delivery of a lens and is highly disgruntled at receiving a couple of blanks! I called Lynn and told him I had what appeared to be a finished lens and that he'd goofed. When the customer for the lens called to give him hell, he can explain the mix-up, and in the mean time I'll get this in the return mail. Lynn said "no, no goof. You wanted a 5" crown and flint, that's what you got" "But this is a finished lens!" "So what, one crown, one flint..." 'but..." "Don't know if its any good or not. I found it in our scrap glass locker. I apologize as I don't know which flint it is, F2 or F4. The crown is BK7 for sure. Enjoy..." I took the elements outside and measured the combined focal length. 1800mm! Just what I was planning to make. Wow! No grinding, no G-sum process, but was this thing any good? Scrap glass? I taped them to the end of a long cardboard tube and looked at Jupiter and a few stars. It was good. Very good.

I obtained a 5" diameter 5 foot long aluminum tube and some other odds and ends from which to make the lens cell and rack and pinion focuser. The 5-inch tube was cut off at 90 degrees at both ends and a counter cell machined to fit on the end. I tested the lens by autocollimation, and determined the last couple of millimeters of its diameter showed some error, so the clear aperture was made to be 122mm. I had a 5-inch thin ring, threaded on the outside, so I threaded the back of the lens cell to match this ring. I cut a shallow groove in the countercell as clearance and when the lens is mounted on the tube, this groove prevents any possibility of the cell ring coming loose and the lens elements falling out. The lens cell is attached by three sets of push-pull screws to allow for collimation. The focuser has a brass tube 2.8" in diameter with a 7" travel and a 2.5 inch holder diameter. I hate refractor focusers with small travel! Once I got these components put together the balance point was only about a quarter of the way down the tube. It worked but looked sort of silly. This thing needed weight at the bottom end. I solved this by mounting my 60mm Polarex as a guide telescope, which served a useful purpose and placed the balance near the middle of the tube. Later I added a Unitron 10X40 finder, purchased from a friend, and a couple of sliding weights on the tube to rebalance for different eyepieces and accessories. The tube is fastened to a piece of 3" channel with stainless steel hose clamps. The channel is bolted to the saddle plate on the mount's Declination axis

Mount? You may have guessed. The 8" SC mount talked about earlier was used for the refractor by rotating the Dec. axis 180 degrees, to bring the slow motion knob closer to the eye end. The mount could then be used for either 'scope quite easily. With the design of this mount, with the refractor on it really looked like a telescope! A freak accident led to the loss of the 8" SC (a story in itself) after which the mount was dedicated to the 5" I added extension rods and a flex cable to the clamps and slow motions so they could be operated easily from the eyepiece.

Paul Thayer, a long time member of DAS handed me a big eyepiece one night at a Chamberlin star party. He said "this thing is a pig! If you think you can use it, it's yours" It was a 63mm Plossl, war surplus, probably the one described in MIL-STD 141, Optical Design. I tried it on my 12.5, and it didn't work well at all. Much too low a power, exit pupil too big and so on. But what about at f/15. More optical certified duct tape, and I tried it on the 5" Worked nicely! 28X, 1.8 degree field. Nice. I asked Paul if he really couldn't use it on his 4" f/10 refractor. He said "no. It's a pig" so I machined up an adapter for it. One night, New moon, I was in the middle of Nevada with this setup and was poking through the Southern Milky Way. Dark nebulae, little star clusters, black sky and subtle contrasts, needle sharp images all the way across the 1.8 degrees! This made a believer out of me and popped the myth that an f/15 can't be a richest field telescope! With other, more normal eyepieces this telescope is superb for double stars and the planets, especially when the seeing is marginal and the 12.5 would need to be stopped down. With a Herschel wedge and #10 welders filter the Sun can be spectacular with all the fine detail in sunspots and spot groups as well as the granular appearance of the photosphere. This telescope is primarily used on the Sun, Moon, planets and double stars, but is a capable richest field with the 63mm eyepiece. It has fulfilled the desire for a really nice refractor. It saw first light about 1973, and has been used continuously ever since. A medium sized refractor is a real pleasure to use, and a 5" seems just the right size, balancing performance and portability.

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