Fixpoint Secondary mount 2015 Aug 10 Tom Conlin

To achieve the best performance from your telescope it must be properly tuned before you begin observing. Telescopes need their optics to be collimated, the state where visual artifacts are minimized when the optical elements are aligned. When optics are aligned their optical axises intersect. In straight through telescopes the optical axises are coincident, when mirrors are used the optical axises may also intersect at points.

For a Newtonian telescope to be collimated it is necessary (but not sufficient) for the optical axis of the eyepiece to intersect the optical axis of the primary mirror. Collimating a Newtonian may involve manipulating the primary mirror, eyepiece holder, spider and secondary mirror. Often the eyepiece holder is held static and the primary mirror usually only tilts about two axises, so the secondary mirror and spider remain as the most active elements of adjustment. Adjusting secondaries can be an exercise in frustration. They have up to six degrees of freedom (translation and rotation over three axises) and are typically cantilevered off the spider which can result in problems with deflection and vibration. But more importantly, the traditional secondary adjustment scheme confounds rotation and translation. The rest of this paper describes the mechanics of secondary adjustments and introduces the FixPoint Secondary mount that isolates rotation from translation and can mitigate the issues of deflection and vibration as well.

The Problem

Translation is not the problem, the moving the of the entire secondary back/forth, left/right, up/down which does not in itself cause rotation. Translating the secondary might require a compensating rotation adjustment afterwards but does not induce a rotation while translating. The problem is in how secondaries are commonly rotated. Secondary mirrors have three axises of rotation. We can safely ignore rotation about the eyepiece's optical axis for now as it should be set once when the secondary mirror is attached to the secondary holder and turn our attention to the remaining two. The first is rotation is about the primary mirror's optical axis so that the secondary mirror is turned to face the eyepiece which I will call ***twisting***. The other rotation is about the secondary's minor axis to bisect the angle between the eyepiece's and primary mirror's optical axises which I will refer to as ***tilting.***

The first *twisting* rotation is relatively easy to get right because the mechanical axis of rotation runs through the surface of the mirror at or near the primary's optical axis. It is *tilting* that bears closer scrutiny. Solutions I am aware of rely on adjusting a tensioned “wobble plate” and vary in the details of how the plate is wobbled but are all fundamentally equivalent to having adjusting screws pushing mechanical axises around somewhere above and behind the surface of the secondary mirror. At issue is where the mechanical pivot point of the adjustment is relative to the logical/theoretical axis of rotation on the surface of the mirror.

There are various pivot mechanisms but in all cases, the adjusting screws define a control plane. When a screw is adjusted, the control plane rotates about a line through the remaining two points which means there are several non-parallel lines which the control plane will pivot about to effect the single *tilt* we need. Rotating about just two non-parallel lines on a plane can achieve every orientation, although it is best if they are orthogonal. When lines of rotation on a plane are not orthogonal, some of the rotation about one line leaks into the rotation about another line (a possible minor annoyance). The more serious issue is that the surface of the secondary mirror is a distance from its tilt pivot point.

The distance from the pivot point determines how much lateral displacement any point on the surface mirror experiences for a given tilt. Critically, when tilting, *every* point on the surface of the secondary experiences displacement since there is always a distance to the pivot.

Displacing the entire mirror is the job of translating the mirror. Complete displacement while tilting results in ambiguity, should I translate with the spider or tilt with the secondary? In practice, making one adjustment can adversely effect previous adjustments leading to a chase to minimize the error if you are good/lucky or cyclic behavior ending in "good enough" otherwise.

Some theory

In math there is the concept of a fixed point, aka "fixpoint". A function returns exactly what you give it, if what you give it is a fixed point for the function, otherwise it returns something else.

For example, a function to convert temperature between Fahrenheit and Celsius will return -40 degrees whenever it is given -40 degrees since that is where the two scales are equal. So -40 degrees is a fixed point for a temperature conversion function between Fahrenheit and Celsius.

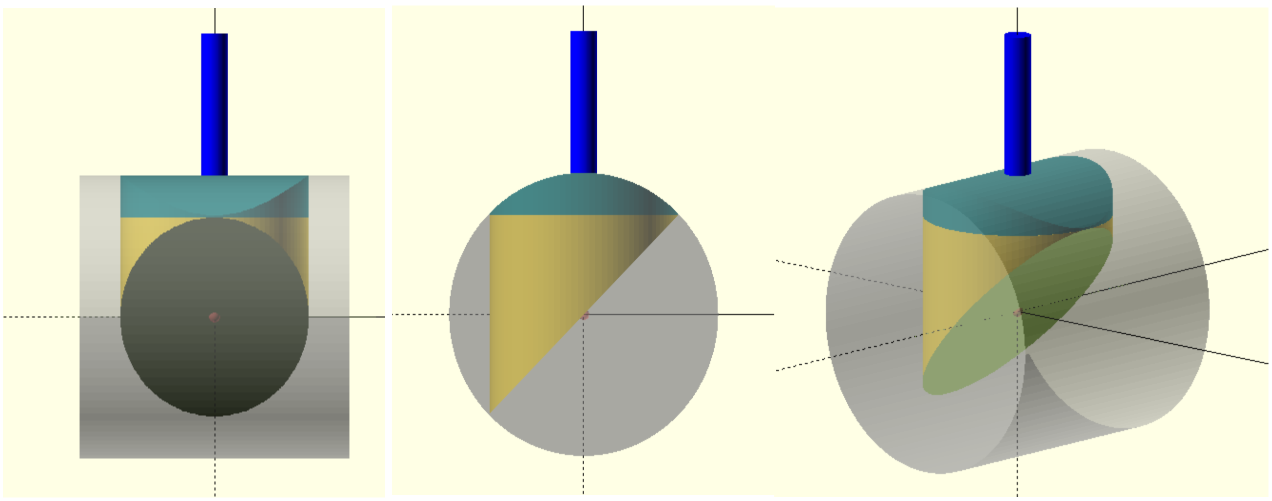
A geometric example is a function for the height of a point along a seesaw over time which changes as the kids go up and down. We can define the problem (or the seesaw) such that the point that identifies the middle of the seesaw is also the height of the middle which being the pivot point never changes. Likewise the line a plane rotates about is fixed for that rotation function.

We know that in order to achieve collimation, the optical axises of the eyepiece and the primary mirror must intersect and that the placement of the eyepiece holder is limiting where intersection occurs. Please note that the secondary is irrelevant in determining this intersection point. We use the secondary as a convenient way to find where these optical axises are, but the secondary in no way determines either of the optical axises nor their intersection. That is, the intersection of the optical axises is a fixed point with retrospect to anything the secondary does. Instead, the intersection point determines where the surface of the secondary mirror needs to be. In analogy, we may need a flashlight to find our lost keys but the flashlight has nothing to do with the keys or where they were lost.

Furthermore we know exactly where on the surface of the secondary mirror we want the intersection to occur. Naively we could aim for the geometric center of the secondary and not be far off. Or more accurately use the geometry of the light cone coming from the primary mirror to determine where the optical center of the secondary is. In any case, there is a point on the surface of the secondary mirror, which if aimed at optimizes for light collection by neither missing part of the light cone nor obstructing the primary unnecessarily. For a given telescope, the optical center of the secondary does not change. It is a fixed point. Bringing the optical center of the secondary mirror to the point of intersection of the optical axises only involves translating the secondary. As the determination of this point does not involve rotations of the secondary, rotation of the secondary can not change where it *should* be. That is our fixed point. If we were to point a laser at that point and rotate the mirror about it, the laser would *not* move across the surface of the mirror.

A first approximation

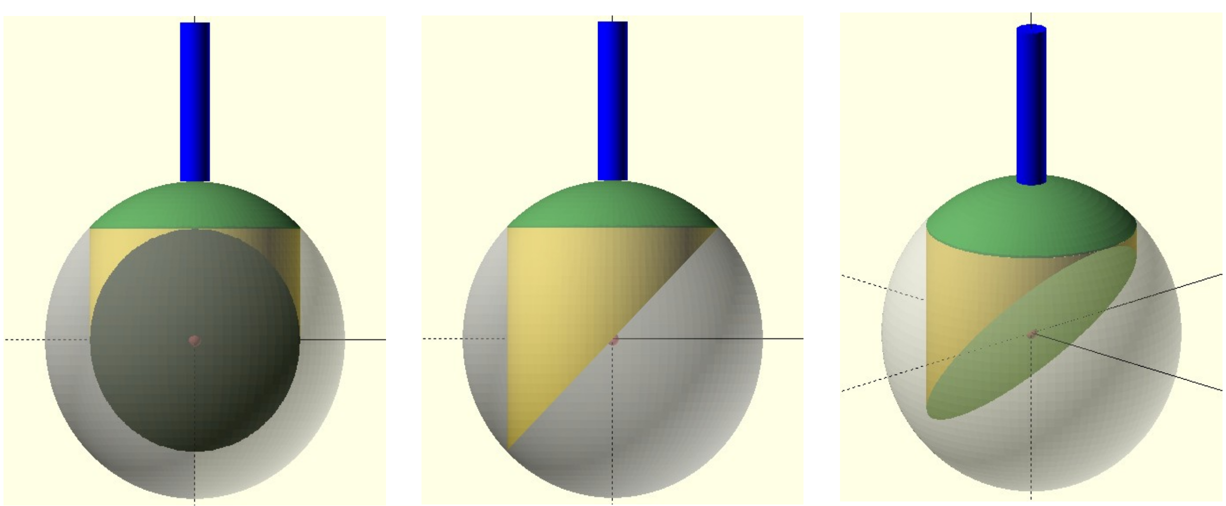
Since we know the fixed point we need, the question becomes; for what function(s) is this value a fixed point? Our existing *twist* function works pretty well because the axis we twist about does run through or near the fixed point. For similar results for *tilt* we would need an axis of rotation that ran across the face of the secondary mirror along its minor axis. This could be achieved by embedding the secondary halfway through a cylinder running perpendicular to both the primary's and eyepiece's optical axises. This cylinder need not be wider than the overall length of the mirror. Removing all parts of the cylinder that are not in the secondary's shadow would look something like this:



The top of the secondary holder would ride in a trough like a socket above it to tilt and the twist axis would need to pass through a slot. But do not worry about all the details to make this work because extending this concept to multiple axises allows us to simplify.

A Solution

The function for the location of the center of a sphere is fixed for both twist and tilt when several contacts with the surface of the sphere are maintained. Instead of different mechanisms for twist and tilt, use a single spherical control surface for all rotations, where the fixed point is the center of that sphere. For example:



Fixpoint Secondary mount 2015 Aug 10 Tom Conlin

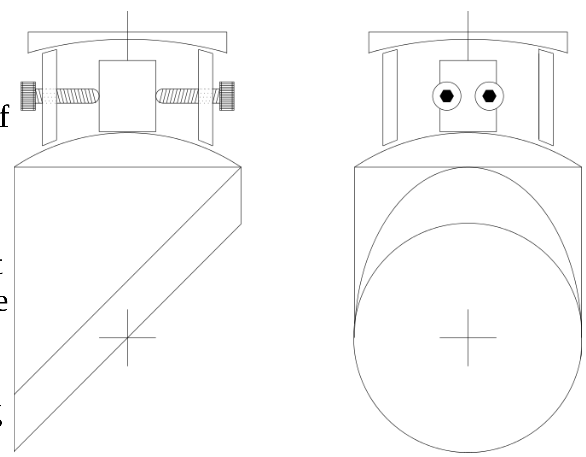
The rest of the secondary mount is any configuration for a socket attached to the spider which maintains several points of contact with the spherical control surface (green cap) and allows adequate range of adjustment.

The diameter of the sphere needs to be sized so that the mirror does not interfere with the active portion of the control surface. If the control surface is above the secondary a minimum radius may be found with $r=\sqrt{(t^2+(M+t)^2)}$ where **t** is the thickness of the mirror and **M** is the major radius which is ~1.414 times the secondary's minor radius.

Adjusting this secondary mount is done in discreet steps, translating the fixpoint to where it *needs* to be, and rotating the mirror so it is oriented correctly. Neither translation nor rotation have any simultaneous effect on the other and both may inform the subsequent adjustment of the other.

Translating is usually done with the spider. Translating up/down (along the primary's optical axis) needs to occur between the socket and the spider and should be an initial/infrequent adjustment which persists. With spring tension pulling the sphere into the socket, rotating the secondary can be as simple as: reach in, push|pull|twist and let go.

For fine control of rotation, one approach includes an element with flat surfaces fixed atop of the sphere within the socket to act as a proxy for pushing directly on the mirror. Pairs of opposing adjusting screws on either side of the primary axis would adjust and lock the mirror's twist and tilt.



To date, I have only used a complete ring as the socket, but the full ring may be reduced to three points of contact if the materials allow it without deformation. Perhaps the most damning observation I can make about the three adjusting screw wobble plate technique to *tilt* the secondary is: using the ends of the same adjusting screws as our “socket” will be a superb way to *translate* where the center of sphere is located. This is interesting because it allows all secondary adjustment to occur between the socket and the spherical control surface leaving the spider free to be simplified as it is no longer responsible for lateral translations of the secondary.

I will note that the design shown so far does allow for a more compact and sturdy secondary holder than the “tuning fork” arrangement found in an average Newtonian. However, since we no longer have separate mechanisms for tilt and twist I think we can do much better.

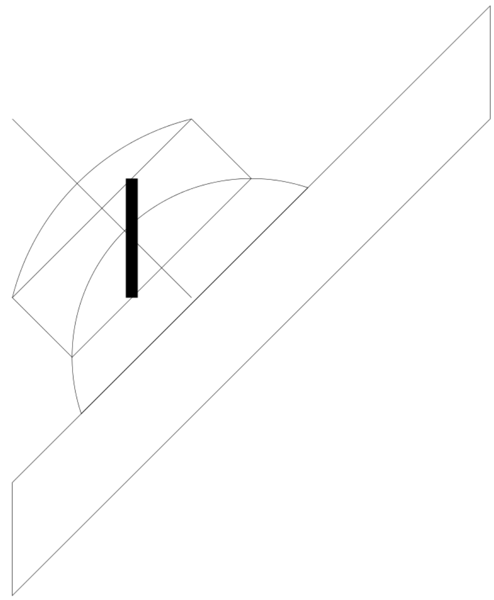
Less is more

Traditional secondary holders extend above the secondary mirror and attach to the spider at the top. The further the secondary mirror is from the spider the greater the lever arm and more deflection the secondary mirror is subject to. The closer the center of mass of the secondary is to the spider the shorter the lever arm available to deflect or vibrate.

Fixpoint Secondary mount 2015 Aug 10 Tom Conlin

If we attach an appropriately sized spherical control patch directly to the back of the mirror and orient the socket parallel to the surface of the mirror we have a secondary mirror holder that sits within the shadow *behind* the secondary instead of needing to extend above it which brings the spider vanes down to nearly the level of the focuser and the center of gravity of the secondary.

The vertical bar in the next diagram represents where the spider attaches on the outside of the socket. In this scenario the width of the area of support is greater than the distance between the spider and the secondary's center of gravity. You do not see a lot of deflection or oscillation in a beam that is taller and wider than it is long.



In addition to the simplified collimation, this configuration allows for a very compact and rigid secondary ring that includes all the necessary components in nearly the same plane. [truss/string connectors, ring, focuser, spider , secondary] Having the spider at the level of the eyepiece lends itself to using the front vanes as eyepiece light baffles. As gluing a dissimilar material to the back of the secondary could cause distortion, a section from a readily available glass ball may be a good choice for a control surface.

I expect this design will be found to be increasingly relevant as we move towards more portable, larger diameter, short focal length mirrors which require heavier secondaries and are much more sensitive to misalignment.

Although the large fast scopes in our near future will need these advantages, our typical telescopes and observers today will all benefit from adopting the FixPoint mirror adjusting scheme with tools not dropped, and short, deterministic collimation sessions in the dark.

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URL: http://ix.cs.uoregon.edu/~tomc/Hobbies/Astronomy/ATM/FixPoint_Secondary.pdf