Spring “Counter Weight” for a Dobsonian Telescope

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Abstract

This is a *How-To* for constructing a spring system to balance a dobsonian telescope while using heavier eye pieces, barlows, a Paracorr, etc. It covers how to calculate the torques, demonstrates a simple numerical model and shows how I modified my telescope.

1 Introduction

Figure 1: Spring counter weight on the Discovery.

When I started using a 40 mm wide-field with a 2 inch barrel along with my Paracorr^{TM} on my 12.5 inch Discovery^{TM} reflector, the views were spectacular. But the scope was unbalanced and tended to fall toward the ground at angles steeper than 20° from the zenith. Obviously, I never want to see my scope focuser box, new eyepieces or my Paracorr hit the ground! Also, steadying the scope by hand during viewing introduces vibrations and I occasionally host grade-school children and friends for star parties. A scope that falls to the ground when someone lets go of it to point in excitement at their first view of Saturn's rings won't work.

It was time to balance the scope. I started with a very simple solution. I hung some weight off the far-side handle of the mirror box. But this was a clumsy solution. I decided to build a spring mechanism to counter balance the scope. I searched the Web and found Field's [1] description of a spring "counter weight" system. A short look at the photos told me I could do this for my scope in a few minutes with parts I had in my shop.

If you decide to do this project, you may want to spend some time with the calculations to get your design optimized, but it is okay to skip to construction and get the right spring strength with a little trial and error. Note that an under strength spring works best because you can rely on the bearing friction to hold the scope, while a "perfect" spring ,i.e., one that exactly cancels the maximum torque due to the eyepiece, doesn't work so well because it may automatically right your telescope to the zenith at small angles.

Construction takes only 30 minutes to complete. Many of the parts are probably already in your shop. See below for a complete parts list.

2 Calculations

2.1 Geometry and Physics

Before I modified my scope, to torque due to the mirror box, which is heavy and close to the center of rotation was greater than that due to the focuser and diagonal mirror box. But the heavy eyepieces etc. topped the balance. To calculate the net torque on the scope before adding the springs we need to know the basic geometry of the scope. In particular, we need to know the weight of the mirror box, the weight of the focuser box and the distance of each from the center of rotation, l and L respectively. nearly.

The sum of torques on the unmodified scope as a function of the angle from the zenith, ϕ, is,

$$\tau = -L(W_{upper\ box} + W_{eyepiece}) \sin\phi + lW_{mirror\ box} \sin\phi. \tag{1}$$

In this equation, clock-wise (CW) is the positive direction. As the angle increases, the long lever arm, L, of the eye box and eye pieces causes the first term to dominate the torque equation. For lighter eyepieces, the friction of the bearings holds the scope in any position, but when I use my heaviest eye pieces (nearly 2.5 *lbs.*), the friction of the bearing system is no longer sufficient to hold the scope.

If we layout the spring as shown in Fig. 1, can we get enough torque to balance the scope? What size of a spring is required? Will it work at all angles and with various eyepieces?

To answer these questions, I wanted to build a model. What are the geometric constraints on the system? In order to get enough space for the spring to stretch, we need to layout the spring kitty-corner across the bearing box as shown in the Fig. 1. Doing this means we need a pulley in the corner so the cable will pull as nearly 90° to our lever arm, the attachment point to the mirror box bearing, as possible.

Now refer to Fig. 2. In this figure, the enter of rotation is the origin of the axes. the point where r and R intersect is the cable attachment point to the upper bearing on the mirror box and the point at the end of R is where the pulley is mounted. When my scope is pointed at the zenith, $\phi = 0$, the attachment point of the cable to the upper bearing is at an angle of $\psi = 51^\circ$ from vertical. This angle is a geometric property of the scope and remains constant in all the calculations that follow. As ϕ increases, the attachment point at radius, r makes an arc up and around the center of rotation. This motion pulls the cable over the pulley and stretches the spring.

The tension in the cable attached to the spring will pull at an angle θ from the zenith θ given by

$$\tan\theta = \frac{a - r\sin(\phi+\psi)}{d - r\cos(\phi+\psi)} \tag{2}$$

The torque due to the spring depends on how far it is stretched as well as the angle at which it pulls relative to the lever arm. This part get's a little bit tricky so I will break the problem into two parts. First, the stretch of the spring, δR, is,

$$\delta R = R(\phi) - R(0), \tag{3}$$

where,

$$R(\phi) = \sqrt{(a - r\sin(\phi+\psi))^2 + (d - r\cos(\phi+\psi))^2}. \tag{4}$$

From the equation above,

$$R_0 = R(0) = \sqrt{(a - r\sin(\psi))^2 + (d - r\cos(\psi))^2}, \tag{5}$$

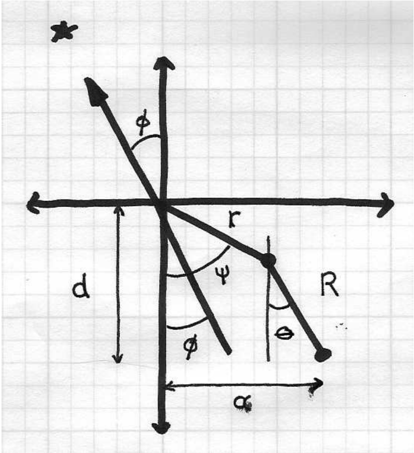


Figure 2: ϕ is the angle of the scope measured from the zenith, ψ is the angle of the moment arm at $\phi = 0$ and θ is the angle the spring pulls on the moment arm measured from vertical. a and d locate the pulley relative to the axis of rotation of the telescope. R measures the stretch of the spring. See text.

It may be the case the spring might work better if we make the cables short enough that the spring is under tension when the scope is pointed at the zenith–pre-load the spring. Because I designed the system with a cable around a pulley to connect the spring, it is okay to set $R_0 < R(0)$ if we need some extra tension.

Secondly, the angle to consider in order to calculate the contribution to the torque due to the spring is the difference between the angle of the cable attachment point on the upper mirror box bearing of the scope, $\phi + \psi$, and the angle the spring is pulling, θ.

Now we can calculate the torque due to the spring,

$$\tau_{spring} = \kappa r \delta R \sin(\phi + \psi - \theta) \tag{6}$$

This torque is positive since in tends to rotate the scope back toward vertical, in the CCW direction. I decided to put a spring system on either side of the scope so that I could disconnect one for half the balancing torque. In my calculations, I have to multiply this torque by 2 to account for both spring systems.

Putting it all together, the expression for the torque on the spring-balanced scope is,

$$\begin{aligned}\tau &= -L(W_{upper\ box} + W_{eyepiece})\sin\phi + lW_{mirror\ box}\sin\phi + \qquad (7)\\ &\quad 2\kappa r\delta R\sin(\phi + \psi - \theta). \qquad (8)\end{aligned}$$

We are nearly drowning in math at this point, so it might be useful to remember why we started doing this. We want to *balance* the scope with a heavy eyepiece on it. *Balanced* means we want the net torque on the scope to be zero at any angle.

If you think about the equations we have so far, this isn't going to happen. The spring force is linearly dependant on how far it is stretched while the angle the spring pulls is some cock-eyed angle that varies with the angle of the scope.

That's okay though. In this case we are saved by the friction in the scope mount. All we need to do is cancel out enough of the excess torque caused by the heavy eyepiece to let friction hold the scope. I'm not going the put the term in Eq. 8 to deal with the holding torque do to friction. Instead, I am going to run a quick model to how close I am, then wing it. After all, the point here is the actually build something. In fact, I am not even going to worry too much about optimizing my spring strength.

2.2 Plug In Some Numbers

A rigorous theoretical strategy would be to chose some angle ϕ at which I want to cancel the torques and then calculate the required spring constant κ in Eq.8. This will give an upper limit on the strength of spring we should use. Inebriated with my theoretical successes above, I started doing this to find the exact spring I wanted to buy. But when I went to the local hardware store to get parts, I was sobered-up a bit by choosing among only 3 available springs. I could calculate all day long, but I didn't want to wait for mail-order springs of exactly the right constant. So I bought the ones that seemed close. Because none of these springs were marked with a spring constant in Nm, "seemed" means I stretched them a couple of times, shrugged and left.

But I didn't want all my theory to go to waste, so I ran the calculations with the parameters of my scope through a Python (`http://www.python.org`) script to see how close I got. Python is free, available on many platforms and has good numerical capabilities. Alternatively, you could use a spreadsheet to do this calculation if you like that better.

Here is the Python script with comments describing the parameters. This script both calculates the spring constant, κ needed to cancel the torque at angle $\phi = 30^\circ$ ($\pi/6$) and then calculates a table of torque values for the spring I used.

```
#####################################################
# Dobsonian Mount Telescope Spring "Counter Weight"
# Calculation of spring constant and torque functions
#
# Scott Hendrickson
# 2007-02-15
#####################################################
from math import *
# All angles in radians
# Number of points on the curve
npts = 10
inc = (pi/2.) / (npts - 1)
#####################################################
# Scope parameters
W_E = 10.6     # Weight of heaviest
               # eyepiece/barlow combo, in newtons
W_M = 156.1    # Weight of mirror & box, in newtons
W_B = 44.6     # Weight of upper light box, in newtons
r = 0.142      # Radius of spring connection point
L = 1.2        # Distance to CM of light box, in meters
l = 0.15       # Distance to CM of mirror & box, in meters
d = 0.175      # meters, see diagram
a = 0.14       # meters, see diagram
R0 = 0.091     # meters, see notes, diagram
psi = 0.8901179# initial angle of lever arm
#####################################################
def deg( _rad ):
      return 180.*_rad/pi

def theta( _phi ):
      return atan( (a - r*sin( _phi + psi )) /\
           (d - r*cos( _phi + psi )) )

def T_Scope( _phi ):
      return - L * ( W_B + W_E ) * sin( _phi ) +\
           l * W_M * sin( _phi )

def T_Spring( _theta, _phi ):
      return k * r * sin( _phi - _theta + psi ) *\
           dR( _phi )
```

```
def k_Spring( _t_scope, _theta, _phi ):
      return -_t_scope/( r * sin( _phi -\
           _theta + psi ) * dR( _phi ) )

def dR( _phi ):
      return sqrt( (a - r*sin( _phi + psi ))**2 + \
            (d - r*cos( _phi + psi ))**2 ) - R0
####################################################
# Pick an angle, calculate spring constant
phi_0 = pi/6.
theta_0 = theta( phi_0 )
ts_0 = T_Scope( phi_0 )
k = k_Spring( ts_0, theta_0, phi_0 )
print '\nTwo springs with k = %1.3f N/m\n' % ( 0.5 * k )
###################################################
# Calculate torque as function of angle
k = 2 * 620.      # my 2 springs
tc = []
for i in range(npts):
      phi = i * inc
      t = theta( phi )
      tsp, tsc = T_Spring( t, phi ), T_Scope( phi )
      tc.append([phi, tsc + tsp, tsc, tsp, t, \
           ( phi + psi - t ), dR( phi )])
####################################################
# Formatted Output
# delimiters
# CSV
ds, eol = ',', ''
print '\nUsing spring constant k = %1.3f N/m\n' % ( 0.5 * k )
print 'phi\tnet tau\ttau sc\ttau sp\t'+\
'theta\tphi-theta+psi\tdeltaR'
for i in range(npts):
      print ('%1.1f'+ds+'%1.2f'+ds+'%1.2f'+ds+'%1.2f'+ds+ \
            '%1.3f'+ds+'%1.3f'+ds+'%1.3f'+eol) % \
            (deg(tc[i][0]),tc[i][1],tc[i][2],tc[i][3], \
            deg(tc[i][4]),deg(tc[i][5]),tc[i][6])
```

The bottom part commented *F*ormatted Output is overkill, but produces either CSV output or LaTeXtabular output for this document.

Table 1 shows the results of a sample run for my scope. The springs I used reduce the net torque to about 1/3 of what the original value. I used the other numbers to verify my model with a few quick measurements.

ϕ	τ_{net}	τ_{scope}	τ_{spring}	θ	$\phi-\theta+\psi$	δR
0.0	-0.04	0.00	-0.04	19.095	31.905	-0.000
10.0	-5.15	-7.44	2.28	8.468	52.532	0.016
20.0	-8.44	-14.65	6.21	2.551	68.449	0.038
30.0	-10.66	-21.41	10.75	-0.094	81.094	0.062
40.0	-12.30	-27.53	15.22	-0.639	91.639	0.086
50.0	-13.59	-32.81	19.21	0.173	100.827	0.111
60.0	-14.63	-37.09	22.46	1.884	109.116	0.135
70.0	-15.44	-40.24	24.81	4.214	116.786	0.158
80.0	-16.03	-42.17	26.15	6.980	124.020	0.179
90.0	-16.38	-42.82	26.45	10.062	130.938	0.199

Table 1: Torque Calculations. Angles are shown in degrees, torques in Nm, and δR in m.

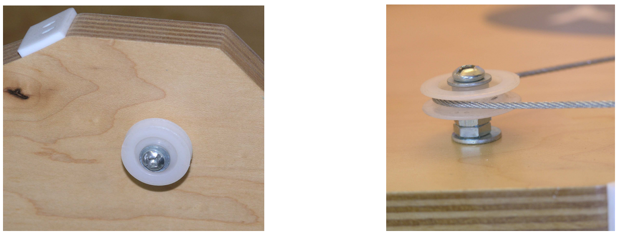
3 Construction

3.1 Parts List

I had machine screws, washers and nuts in the shop. In all, I spent under $10 for the springs, clamps and stainless steal cap screws.

3.2 Putting It Together

The bearing box of my scope already had 4 holes in it, 2 on each side. When facing the scope with it oriented so that it dips down to the left, I put a hex nut on the cap screw along with some washers as show in Fig. 4. I put the cap screw through the existing hole in the box and applied the T-nut as shown.



(a) Mounted pulley. (b) Washers and stand-off nuts.

Figure 3: Assembling and attaching the pulley.

#	Item	Description
2	Springs	5/16 diameter, about 14cm of coils
2	Cap Screws	1/4 – 20 1 3/8 inch
2	T-Nuts	1/4 – 20
2	Hex Nuts	1/4 – 20
		(The following need to have matching thread diameter and pitch)
4	Brass threaded inserts	
2	Screws	Machine 1 inch
2	Screws	Machine 3/4 inch
6	Hex Nuts	Machine
2	Nylon pulleys	1 inch, I got mine by disassembling 2 screen door runner replacements
-	Washers	Various flat washers
-	Cable	Steel cable and crimp-style cable clamps

Table 2: Spring "Counter Weight" Parts

Next, I drilled an appropriate sized hole in the upper right corner of the box for the threaded insert. Don't drill all the way through the side of the mirror box. Drill far enough so the insert goes in a little beyond flush.

(a) Cap screw at lower attachment point. (b) Mirror box attachment.

Figure 4: Spring end-point attachments.

I turned in the insert then assembled the pulley, washers and nuts on the screw as shown and fastened it in the insert.

Using about 10 inch pieces of cable I made harnesses for the springs as shown in the picture. I used crimp-style aluminum cable clamps to secure one loop through the spring and hook the other end to the mirror box attachment in Fig. 4 (b). I set the tension so that the spring was just starting to stretch when the scope is point at the zenith. You may want to pre-load your springs a little depending on your setup. My geometry does not allow the scope to travel all the way to horizontal, but there aren't any stars at low altitude in my city anyway. I left the upper loop in the cable large enough to go over the pulley for storing and carrying the scope when the mirror box is not in the bearing box.

I hope you find this useful [2]. Clear skies!

References

[1] Stuart Field, http://education.gsu.edu/spehar/FOCUS/Astronomy/krajci/krajci-2.htm

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