DFM Engineering, Inc.
1035 Delaware Ave. Unit D
Longmont, CO 80501
Phone: 303-678-8143
Fax: 303-772-9411
sales@dfmengineering.com

Search

Home

Company Profile

Products

Professional Services

Newsworthy Articles

Related Sites

Image Gallery

Inquiries

TELESCOPE STRUCTURE - DEFLECTIONS

By Dr. Frank Melsheimer, President, DFM Engineering, Inc.

In the last Engineering News article, we discussed how the geometry or shape of a part effects the stiffness or the deflection of the part. We found that the proper choice of the cross section can greatly improve the stiffness to weight ratio. But deflections are unavoidable because we must support the weight of the telescope structure (static loads). There are also dynamic loads applied by wind and accelerations. Now we will discuss how we can minimize the effect of the static load deflections.

The polar axle of a fork mounted equatorial telescope is supported by two bearings, one at the south end and another at the north end. The fork is attached to the north end (for a telescope in the northern hemisphere) and applies a combination of bending, thrust (a load along the length of the polar axle directed towards the south bearing), and shear (a load perpendicular to the lengthwise axis of the polar axle). Generally, materials are very stiff in thrust (tension-compression) and in shear, but the bending load causes the polar axle to assume a curved shape. The amount of curvature (measured in degrees from one end to the other for example) causes the telescope to rotate about a point lower than the undeflected case resulting in a polar axle alignment error. This error may be removed by adjusting the elevation alignment of the telescope IF the polar axle has the same curvature at all hour angles. Axial symmetry will produce a structural element which has constant angular deflection as a function of rotation angle. This symmetry defines a surface of revolution such as a cylinder or a cone. DFM uses a conical polar axle for our 0.4 meter telescope and a cylindrical polar axle for the larger sizes.

The fork also needs to have the same angular deflection for all hour angles, but it doesn't have axial symmetry to simplify the design. We have developed the characteristic DFM Engineering fork shape to minimize the changes in angular deflection as a function of hour angle. Both the polar axle and the fork need to have high stiffness to minimize dynamic deflections due to wind loads and other dynamic loads. We will further explore these requirements in the next Engineering News article.

Engineering Articles Summary

Steel & Aluminum

Geometry

Deflections

Pointing

DFM Engineering, Inc.
1035 Delaware Ave. Unit D
Longmont, CO 80501
Phone: 303-678-8143
Fax: 303-772-9411
sales@dfmengineering.com

Search

Home

Company Profile

Products

Professional Services

Newsworthy Articles

Related Sites

Observatories

Organizations

Image Gallery

Inquiries

TELESCOPE STRUCTURE - POINTING

By Dr. Frank Melsheimer, President, DFM Engineering, Inc.

Introduction

Telescopes have used a variety of hardware to provide pointing position information. Some of the old refractors have beautifully engraved and filled setting circles and verniers allowing a position readout finer than 1 arc minute. Later telescopes have used syncro transmitters and receivers to increase the resolution and readability of the telescope position. All of these early systems have a fatal flaw however. The pointing accuracy of even a perfect telescope will always be limited by the earth's atmospheric refraction which amounts to about 1/2 degree at the horizon.

A modern telescope position readout system consists of electronic encoders read by a digital computer. Typically, incremental optical encoders are used with a resolution of 1 arc second. The incremental position is electronically counted within the computer and various corrections are made. Sometimes the encoders are gear driven and sometimes they are directly mounted on-axis. The on-axis encoders need to have very high resolution, but don't see the gear errors and backlash of the encoder drive gearing. The gear driven encoder can have considerably less resolution and cost less than the on-axis encoder.

Many corrections need to be applied to the telescope's raw axis position data. Primarily, the corrections are of two types-coordinate information corrections (or coordinate transforms), and telescope corrections. These corrections are mathematically calculation intensive and involve many transcendental floating point operations. A task that is performed by a modern personal computer very well and very quickly. The software program that performs these corrections is often referred to as the "pointing model". It is possible to model the pointing with a geometrical model, numerical model, or a combination of the two techniques.

Top

Coordinate Corrections

The positions of celestial objects are cataloged in "mean" coordinates for a specific date or "Epoch". However the telescope works in today's epoch coordinates. This means that the "mean" coordinates must be corrected or transformed from the given epoch to today's epoch. This involves calculating the effects of precession, mutation, and aberration. The effect of the earth's atmospheric refraction is usually lumped into the coordinate correction category.

It is very convenient to be able to input coordinate data to the Telescope Control System (TCS) in any epoch, and it is likewise convenient to have the TCS display in any selected epoch. This means that the pointing model needs to be able to work the corrections forward and backward.

Top

Telescope Corrections

Even a "perfect" telescope will need error correction to achieve satisfactory pointing. This is because the telescope should be polar aligned on the "refracted" (by the earth's atmospheric refraction) celestial pole and not on the true celestial pole to minimize the field rotation introduced by the atmospheric refraction. Also, it is not practical to "perfectly" polar align the telescope in azimuth and in altitude.

The typical telescope pointing errors consist of the following items:

1. Azimuth and altitude misalignments to the celestial pole.
2. Mechanical and optical non-perpendicularities.
3. Encoder scale factors, offsets, and eccentricities.
4. Flexures of the telescope mechanical structure.
5. Flexures of the optical mounts.

The azimuth and altitude alignment accuracy will be set by the mechanisms provided to perform the adjustments and the time available to make these adjustments. The telescope should be aligned about 1 arc minute above the true celestial pole to be aligned on the refracted celestial pole. The alignment mechanisms need to be of sufficient quality to allow adjustments smaller than about 10 arc seconds for a professional telescope.

The mechanical non-perpendicularity between the declination axis and the polar axis is set by the machining and assembly tolerances of the various parts. Sometimes the flexure of the structure is the controlling factor. With some telescopes it is possible to measure the mechanical non-perpendicularity and shim or adjust the declination bearings to reduce the amplitude of this term.

The optical non-perpendicularity (sometimes called optical collimation error) is an error not really appreciated by many astronomers. This is an error where the optical axis of the primary mirror is not perpendicular to the declination rotational axis. It introduces large R.A. pointing errors. Sometimes the primary mirror tilt is changed when adjusting the collimation of the optics. This will change the correction coefficient and introduce large pointing errors. The primary mirror needs to carefully setup mechanically in its cell and then not adjusted in tilt (centering adjustments are OK) when the optics are collimated. If pointing measurements show that the collimation error is larger than desired, then the primary mirror needs to be adjusted to minimize the non-perpendicularity correction term.

The position encoder scale factors, offsets, and eccentricities may be corrected by introducing the proper values. The mounting of the encoders needs to be accurate enough to keep the eccentricity errors to less than 60 arc seconds.

The telescope structure is not infinitely rigid so there are always deflections. Typically the rotational deflections or translations causing rotations of the axes are the important flexures. Some of these flexures don't change with rotation of the polar axle. These symmetrical flexures typically do not introduce pointing errors. They may introduce image motions due to wind loading, however. The non symmetrical flexures can be large. For example, the Lick Observatory 3-meter telescope has 4 arc minutes of differential flexure in its fork structure.

Flexure and slop of the telescope optical mounts are problem areas that should be fixed rather than corrected by the pointing model. Slop (lost motion) is very difficult to predict so it does not model well.

Top

Telescope Pointing Accuracy

Performed correctly, the conversion between "mean" and "apparent" coordinates introduces no errors worth consideration. If these coordinate transforms are the only corrections applied, then the telescope pointing accuracy will be limited by atmospheric refraction.

The correction for atmospheric refraction is a function of zenith distance and atmospheric density (pressure, temperature and humidity). The correction amounts to about 30 arc minutes at the horizon at sea level conditions. An approximation of the atmospheric density can be made by correcting for altitude only. This will lead to an error in the refraction correction of about 1 to 2 arc seconds at a zenith distance of 70 degrees.

Polar misalignment errors can be minimized for pointing or for tracking, but not both. Normally the telescope is polar aligned on the refracted pole to minimize field rotation during tracking. The resulting altitude misalignment introduces pointing errors primarily in Declination as a function of hour angle. These errors can approach 1 arc minute in amplitude.

Optical and mechanical non-perpendicularity errors introduce large pointing errors in Right Ascension and may exceed 2 arc minutes in amplitude.

With a generalized and nonspecific site pointing model, a corrected telescope will have an RMS (root mean square or a form of average) pointing error in the 3 arc minute range. The RMS error can be reduced considerably with site and telescope specific pointing model coefficients. Many professional observatories quote a pointing error in the few arc second range. However, these values may be the best they have achieved and not necessarily what they achieve on a routine basis.

Top

How good is "good enough"?

Even the "best" telescopes will need some form of guiding or correcting the telescope tracking using optical feedback from a star. If the telescope tracks perfectly, tracking corrections will still be needed to correct for small refraction effects (seeing for example).

Guiding may be performed with a reticle eyepiece or using some type of electronic detector. In any case, the guider optical system will have a finite field of view. The guider is used to acquire and center the object and then to provide tracking corrections.

The pointing accuracy should be sufficient to place the object within the field of view of the guider system open loop (without optical feedback). Small telescopes tend to have a relatively large field of view while large telescopes have a very small field of view so the pointing needs to be better for large telescopes. Typically, it is desirable to have a pointing accuracy (RMS) of about 1/4 of the field of view of the guider system. This level of pointing is considered "Good".

The guider system will often have a field of view of several arc minutes so the pointing needs to be a fraction of an arc minute. For moderate size telescopes (0.5 to 1.5 meters) a pointing accuracy of 30 arc seconds RMS or better is sufficient.

Top

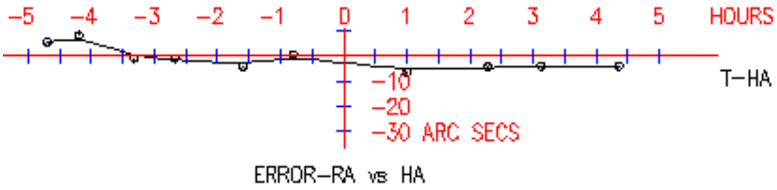
DFM's Telescope Pointing Accuracy

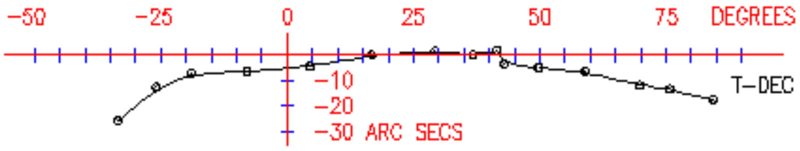
The DFM Engineering data sheets provide very conservative pointing accuracy with typical values of 30 arc seconds RMS or better stated. The following table shows actual values for a few of the DFM telescopes installed or serviced lately. The pointing model used by DFM is a geometric model. Typically, the DFM telescopes have little to no flexure to correct which demonstrates the high stiffness and symmetry of the structure. The control systems we have retrofitted to many telescopes (mostly Boller & Chivens telescopes) often correct flexural errors in the 2 arc minute range.

Size	Institute	Pointing RMS	Notes
16"	Macalester College	9.9 arc sec	
20"	Dr. Ron Kohl	13.5 arc sec	Serviced 8-00 / Installed 6-91
24"	Dickinson College	9.5 arc sec	
32"	U. Maryland, Baltimore	10.0 arc sec	
51"	USNO, Flagstaff	11.3 arc sec	
24"	U. North Carolina	11.5 arc sec	Boller & Chivens telescope with DFM Control System

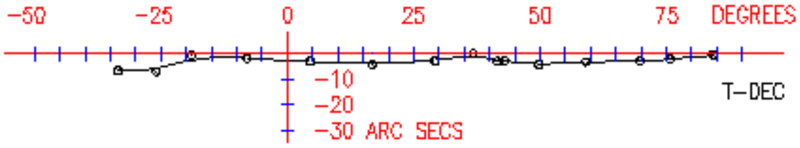
The following 4 graphs show the various pointing errors for the Dickinson College DFM 24-inch telescope.

Notice the largest error is less than 30 arc seconds and this error occurs at a zenith distance of 80 degrees where the refraction model is not very good. The smoothness of the data indicates that further modeling effort would improve the pointing slightly. The RMS value is less than 10 arc seconds and is considered to be "excellent".

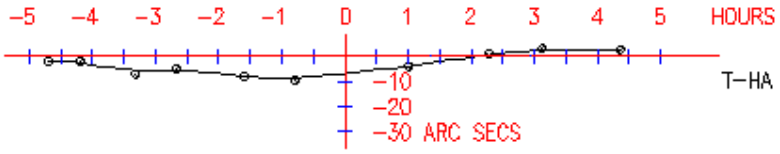




ERROR-DEC vs DEC



ERROR-RA vs DEC



ERROR-DEC vs HA

Top

Engineering Articles Summary

Steel & Aluminum

Geometry

Deflections

Pointing
