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# THE 120-INCH TELESCOPE

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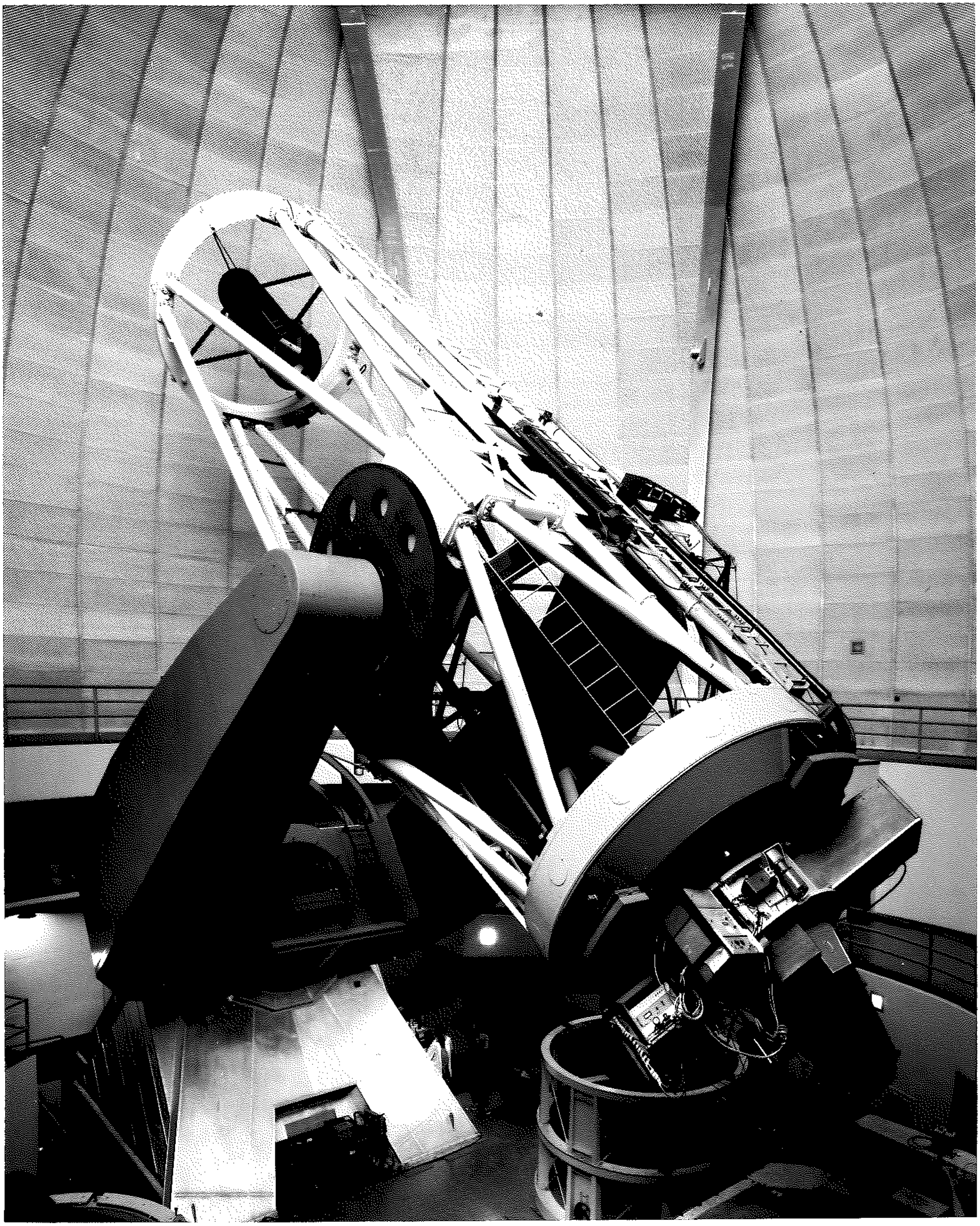


CONTENTS

## PREFACE

These notes were collected by the author to describe the functions of many of the operating systems of the 120-inch telescope. Certain functions had to be deduced from mechanical drawings, electronic schematics, and user's notes.

Much is included here for historical reasons and so that it will be recorded someplace. Reference can than be made to a publication instead of a memo in someone's file in someone's drawer somewhere. Certain items are for general interest only, while other items are intended to enlighten or even alarm some readers.

Several blank pages are included for reader's notes. I will publish an updated report in the future as the telescope grows and changes and I would appreciate reader feedback.

# CHAPTER I: TELESCOPE STRUCTURE

## General

The 120-inch telescope was built by Judson-Pacific Murphy. It is the largest fork-mounted telescope in the world. The moving weight is 160 tons.

The dome is 100 feet in diameter and the moving weight is 270 tons. The aperture is 20-feet wide. There is an up-and-over shutter. The lower portion of the aperture is covered with bi-parting doors. A windscreen is provided and its control is mentioned in the chapter on TELESCOPE CONTROL.

There are 3 foci: Prime, Coudé, and Cassegrain. The primary mirror is 120 inches in diameter with a 600-inch focal length, i.e., F/5. Cassegrain focal ratio is F/17. The 3-mirror Coudé system is F/36 and the 5-mirror Coudé system is F/38.6.

## Flexure Model

A mathematical model of the telescope flexure as a function of declination and hour angle was developed by Dave Rank and the author in 1976. The model also includes refraction and other non-flexure terms. Within a 60-degree cone of the sky, objects can be located within a 20-arc-second circle (at Cassegrain focus).

The main flexure term comes from the "droop" in the forks when the telescope is pointed at the zenith. When the telescope moves either East or West from the zenith, the "droop" goes away. The motion of the forks drives the tube in declination. The maximum error is 300 arc-seconds.

The correction formulae are included here:

120-inch telescope pointing corrections:

$$\Delta\delta_{\pi} = -1.65(\delta - 37.33°) + 150(1-\mathrm{COS\ H.A.}) + 60\left\{\frac{1-1.33\ \mathrm{TAN}\ \delta\ \mathrm{COS\ H.A.}}{\mathrm{TAN}\ \delta + 1.33\ \mathrm{COS\ H.A.}}\right\}$$

$$- 90(1-\mathrm{COS}(40° - \delta)) - 60\ \mathrm{SIN\ H.A.}$$

$$\Delta\alpha_{sec} = \frac{5.3}{\mathrm{COS}\ \delta}\left\{\frac{\mathrm{SIN\ H.A.}}{\mathrm{TAN}\ \delta + 1.33\ \mathrm{COS\ H.A.}}\right\} - 2\left\{\frac{\mathrm{SIN\ H.A.}}{\mathrm{COS}\ \delta}\right\} - .0167\left\{\frac{(\delta - 37.33°)}{\mathrm{COS}\ \delta}\right\}$$

$\delta$: Term 1 is declination scale factor

Term 2 is fork flexure in Hour Angle

Term 3 is refraction

Term 4 is declination encoder eccentricity

Term 5 is fork tine rotation

$\alpha$: Term 1 is refraction

Term 2 is fork twist about the polar axle

Term 3 is a fudge factor

# CHAPTER II - TELESCOPE BEARINGS

The polar axle is supported by 5 hydrostatic oil bearing pads. There are 2 bearing pads in the North separated by 60 degrees. The telescope center of gravity is North of these 2 pads so the South 2 bearing pads push down on the polar axle. Each of the North pads "sees" 96 tons because of this cantilever design. A single thrust pad in the South keeps the telescope from sliding downhill. The North pads are 24" in diameter and run on a journal which is 84" in diameter (Lick Drawing 8-OP-5).

The telescope floats on a thin film of oil about 0.003-inch thick. When not in use, the oil pumps are turned off and the telescope rests on the babbit linings of these 5 pads. There are 20 microswitches to monitor the oil film thickness and prevent the telescope from driving if there is no oil film. This sytem has been inoperative for some time (See TELESCOPE LIMITS).

Hydrostatic oil bearings are frictionless and very stiff. The stiffness is nearly 3 times the weight supported, divided by the oil film thickness. The 2 North bearings have the equivalent stiffness of a 10" x 10" x 10" solid cube of steel; much stiffer than the polar axle they support.

Oil supply pressure is 850 psi with a combined flow rate of about 5 gallons per minute. See Figure 1 on hydrostatic bearing systems (from Rippel).

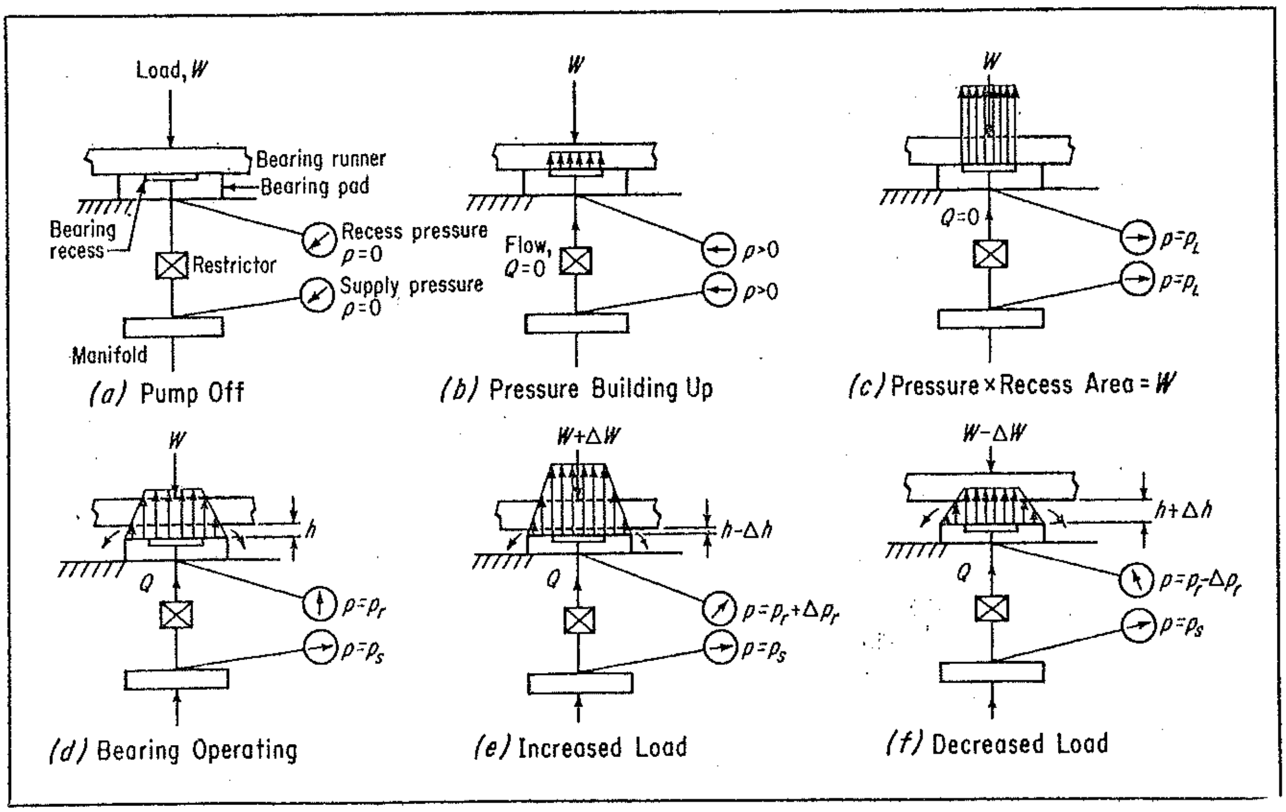



Figure 1. Formation of fluid film in a hydrostatic-bearing system.

Declination bearings are pairs of angular contact ball bearings mounted in gimbals. They are SKF #7070/G5. Their dimensions are 300-mm (11.81") inner diameter, 460-mm (18.11") outer diameter, and 74-mm (2.91") wide. Each single bearing has a thrust rating of 32,000 pounds at 1000 RPM.

## CHAPTER III: TELESCOPE DRIVES

The original drive systems for the 120-inch telescope were conceived when 1949 Fords and Chevrolets were new. Automatic control systems were cumbersome and expensive then. The telescope used 13 motors for driving. Today there are only 4 motors.

For right ascension there are 2 large steel worm wheels bolted to the polar axle. One worm is for tracking and one is for slewing. In declination there is 1 large spur gear with a small pinion gear mounted to a tangent arm. The pinion gear is driven by a large slew motor. For slow motions, the tangent arm is moved.

In 1974 a project was begun to enable the telescope to move quickly between slits spaced 36 arc-seconds apart at the Cassegrain focus. NSF financed the project (MPS 71-03146 A03) initially. One stepping motor replaced 6 motors in declination and a very messy differential summing gearbox. A stepping motor was installed in place of the "set" motor in R.A. Later (1980), a different stepping was added to replace all R.A. slow drive motors and gearboxes.

### Tracking Worm

The tracking worm wheel is steel with 720 teeth (1 tooth goes by every 2 minutes of time). The worm is bronze. There are 2 worms with a hydraulic clutch to allow only 1 to actually drive the telescope. It does this by anchoring either worm's thrust bearing. Both worms rotate during tracking and slewing, but only one will see any thrust load from its worm wheel. The use of a bronze worm driving a steel worm wheel is contrary to standard engineering practices. Steel worms driving steel worm wheels were tried with no success. Then, it was decided that a worn out bronze worm would be easier to replace than a worn out bronze worm wheel.

In June of 1980 it was discovered that the track worm was badly worn. About 0.010 inch was worn off the original drive surface. No one ever recalled having looked at the worm since the 1950's. We had a gear specialist from Western Gear inspect the worm and he made some suggestions about lubrication and periodic inspections. He also told us that this could be the result of 20 years' use as opposed to some sudden failure.

Periodic Error

A periodic error with a period of 2 minutes has been reported in the log books. December 21/22, 1976 M. Burbidge reported tracking "erratic," October 14-15, 1977 Sylvester reported "drive errors," June 8-9, 1980 Schmidt reported peak-to-peak drive error was less than 3 arc-seconds. August 4, 1981 Wampler reported about 2 arc-second peak-to-peak errors. All other reports have been verbal.

In December of 1982, the telescope was weighed and re-balanced. The amount of out-of-balance could explain some of the periodic error. The out-of-balance condition also overloads the worm gear while in the West, since a tail-heavy torque acts in the same direction as the hour angle preload counterweight. (See Chapter IV for more on telescope balance.)

Encoders

By 1974, Melsheimer et al. installed precision incremental shaft encoders with 1 arc-second resolution. The declination encoder is mounted independent of the declination drive system. The hour angle encoder is mounted "upstream" from the polar axle in the R.A. drive system. It will not measure or indicate any errors in the primary drive worm. The original encoding systems remain and are used for absolute position. This is done with pairs of SelSyn synchro transmitter/receivers. Two high speed and 2 slow speed pairs are used on each axis. We are currently (June 1983) mounting a friction-driven encoder to the polar axle directly to try to correct for the existing drive errors.

# CHAPTER IV: TELESCOPE BALANCE

The telescope must be balanced about the 3 principal axes: Polar axis, declination axis, and optical axis. The R.A. and declination drives each have preloading counterweight systems to eliminate drive gear backlash. Right Ascension preload is a constant 6500 ft-lbs. Declination preload is a constant 4000 ft-lbs.

The telescope has provisions for rebalancing the tube for different instruments and for focus changes. There are presently 15 different weight combinations which must be accommodated. All require rebalancing. There is a moveable weight, referred to as the "vertical counterweight." This is a weight which is driven along a screw inside one of the South truss tubes. Its readout is given in torque, e.g., 0 to 6000 ft-lbs. This range of adjustment is not enough to balance all instrument combinations, so a set of lead weights was designed to be added at 4 locations on the mirror cell. There are 48 weights, each is 32 pounds and the distance to the declination axis is 15 feet. Total balancing torque with all weights on board is 48 x 32 x 15 = 23,000 ft-lbs. Total range of adjustment is then 29,000 ft-lbs (23,000 + 6,000). There is a posted list of weight combinations for balancing the telescope in all instrument combinations (see Figure 2).

On December 15, 1982 the author helped balance the telescope tube and learned that the tube was "tail-heavy" by 4750 ft-lbs when the ITS was installed at the Cassegrain focus. This was using the posted balance weights for different instrument set-ups.

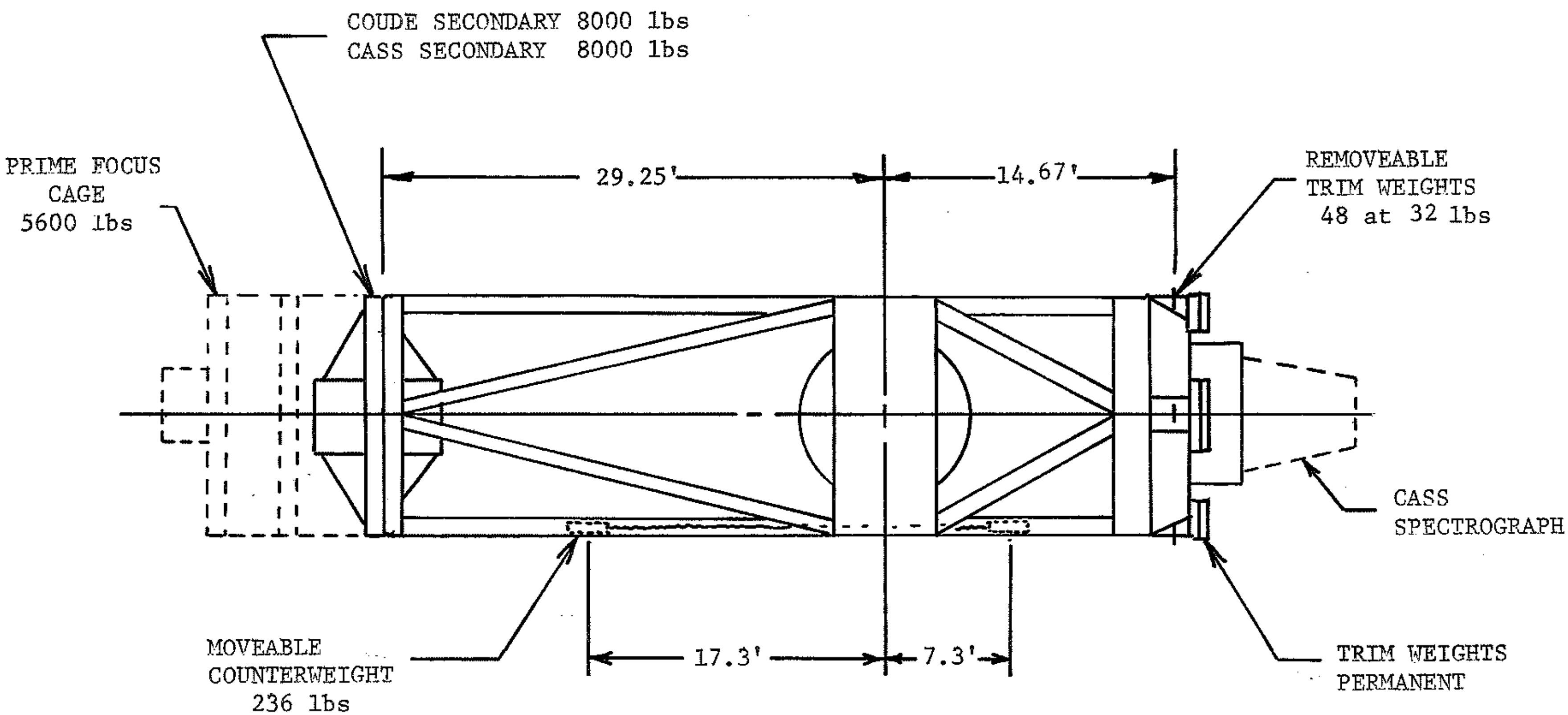



Figure 2. Tube balance

This much out-of-balance is alarming. In declination, the drive will be unpredictable when in the South. In Right Ascension, the worm preload will be increased when in the West, with possible worm damage. In the East, the drive preload will be reduced. This could affect the tracking performance.

Where did the 4,750 ft-lbs come from? The balance was checked in 1976 by the author. During the intervening 6 years, many things have been added to the TUB without regard to the effect on the telescope balance. The TUB is about 20 feet from the declination axis and 4750/20 is 240 lbs. This much weight could be new chassis racks, cables, power supplies and other hardware.

The TUB itself is horribly out of balance; enough so that the TUB backdrives the motor when the brake is released. This must be corrected or we might have to repair stretched or broken cables one day. There is no simple way to balance the TUB short of removing it from the telescope, but certainly it can be balanced enough to keep it from back-driving the motor.

# CHAPTER V: TELESCOPE CONTROL

A note from Bob Kibrick to all observers dated March 15, 1982 is included here. Prior to the installation of TELCO (Telescope Controller), I recorded all existing telescope limits and what happens when you get to one. This note dated September 14, 1981 is included here also. From September to the following March, we installed dual switches wherever possible so that TELCO had access to "mechanical" limits. The existing switches all had 110 volts AC and it was thought prudent to use separate switches for 5 volt logic signals for TELCO. The new limit switches were installed as close to the existing switches as possible but slightly ahead of them. Then, TELCO could decide what to do when the telescope got into a shutdown mode. TELCO at this point can only inhibit slewing functions.

During the process of recording all existing limits, we learned two startling things: The oil film thickness switches do not do anything, and after you dump the 7 degree horizon cone, all slew is inhibited but you can keep on tracking. After a while, you dump the 3 degree horizon cone and you can still keep on tracking. This last horizon limit switch only turns on a buzzer.

Since then, we have installed a pressure-sensing switch in the oil pressure line so that at least TELCO will be aware of an oil pumping failure.

The zenith distance computed by TELCO is used to set a "software" horizon limit within TELCO.

Future: The dome position and windscreen position will be read and controlled by TELCO.

To: All Observers at Shane Telescope

3/15/82

From: Robert Kibrick

Subject: Installation of Telescope Controller at Shane Telescope

A Telescope Controller (EL-741), identical to the controller at the Nickel telescope, has now been installed at the Shane Telescope. This memo describes the impact of this installation on the operation of the Shane telescope.

BACKGROUND

The original drive system for the Shane Telescope used 13 separate A.C. synchronous motors to perform the functions of slewing, setting, tracking, and guiding. These motors were connected via an elaborate system of gears and clutches, which were in turn operated by large banks of relay logic activated by pushbutton paddles used by the astronomer or assistant.

In 1975, the drive system was modified so that the functions of the set and guide synchronous motors were consolidated into a single stepping motor for each axis. A device known as the 120" Fast Precision Offset box (EL-547) was installed to generate the signals that drive these stepping motors. This modification enabled astronomers to use joysticks for controlling set and guide motions, as well as enabling the PDP-8/I computer to generate offset motions.

However, even with this modification, a number of limitations remained. In the right ascension axis, the motions of the A.C. synchronous motor used for tracking and the stepping motor used for setting and guiding needed to be added mechanically using a differential gear box. This gear box has been difficult to maintain. In addition, while the PDP-8/I computer could be used to move the telescope, it could not move in both axes at once, nor could it perform any other operations at the same time. Also, it could not adjust the track rates.

In an effort to overcome these limitations, the Telescope Controller (EL-741) was developed. Among other things, this device allows the functions of tracking, setting, and guiding to be consolidated into a single stepping motor, thus eliminating the need for the differential gear box. Also, the controller can offset the telescope in both axes at once, while allowing the PDP-8/I computer to overlap telescope offsets with other operations, as well as adjust track rates. In addition, the telescope controller will interface to the T.V. Autoguider system (EL-826), which is nearing completion.

INSTALLATION

The installation of the telescope controller at the Shane telescope has required a number of modifications to both the telescope drive hardware and the FOCAL data taking software. Every effort was made to keep these modifications as transparent and as easily reversible as possible. The hardware modifications have been made so that one can switch from the new configuration back to the old configuration simply by moving a few cables and throwing a switch. <u>The telescope assistants can make this change in about ten minutes!</u> The data taking systems have been modified so that they can run in either configuration.

HARDWARE CHANGES

In the new configuration, the A.C. synchronous motor that was previously used for tracking is disengaged. Accordingly, the Whitford oscillator, which provided the tracking rate for that motor, is no longer used, nor are any of the switches or potentiometers which were previously used to adjust the track rate. Also, the stepping motor that was previously used for setting and guiding motions is disconnected.

In place of these two motors, a new stepping motor is used. This new motor has a smaller step size (0.0508 arcseconds/step versus 0.093 arc-seconds/step, at the equator), as well as a faster top speed (1750 Hz. versus 500 Hz.) The tracking rate for this new motor is provided by the telescope controller, and it can be adjusted precisely by means of switches on the front panel of the controller, as well as on command from the PDP-8/I or the PET computer. A pushbutton paddle can be plugged into the PET to provide remote rate adjustment from the Coude' focus. A similar paddle will soon be available at the Prime focus, which will provide both rate adjustment and push button guiding.

In the declination axis, the same stepping motor is used in both configurations. It has a step size of 0.07108 arcseconds/step, and a top speed of 500 Hz. In the new configuration, its drive rate (if any), is provided by the telescope controller, and it can be adjusted similarly to the R.A. track rate.

The joysticks used by the telescope controller are different electrically from the joystick currently used, and must not be interchanged! The new joystick should, however, be functionally equivalent to the old.

Other hardware changes include the installation of a completely new set of telescope limit switches, and a special interface box (EL-892), that connects the controller to these limit switches, as well as to the slew contactor bays, and the telescope position synchros.

SOFTWARE CHANGES

All of the "public" 32K FOCAL data taking systems have been updated so that they will function in either configuration. These include:

- UCSC 32K 2-Slit Scanner Data Taking System
- UCLA 32K 2-Slit Scanner Data Taking System
- UCSD 32K 2-Slit Scanner Data Taking System
- 32K 4-Slit Area Scanner/Polarimeter Data Taking System
- 32K 8-Slit Area Scanner Data Taking System
- 32K Echelle Scanner Data Taking System
- CCD Data Taking System

During "INITIALIZE DATA TAKING", one specifies whether or not the telescope controller is available for use. If one indicates it is available, the data taking system assumes the telescope drive system is connected in the new configuration. If one specifies that the controller is not available, the data taking system assumes the old configuration.

In the case of the 8K FOCAL Scanner Data Taking System, it was not possible to produce a single version that would work in either configuration. Accordingly, there are now two versions of the 8K FOCAL S.D.T.S, one for use in each configuration. To facilitate changing between these two disks, an option has been added so that during "INITIALIZE DATA TAKING", one can copy sweeps, calibrations, and spectrograph setups between these two disks.

The changes to the data taking systems are all confined to the following areas:

- Initialize data taking
- Slit changing and telescope offsetting
- Reading of telescope position information
- Reading of time and date information

## OPERATIONAL CHANGES

Although every effort has been made to make the new configuration as similar in operation to the old, observers should take note of the following changes in the overall operation of the system.

### 1. JOYSTICKS

Since the step size of the new right ascension stepping motor is smaller by almost a factor of two than the step size of the motor it replaces, when guiding in R.A., each "beep" of the joystick will represent a smaller distance. The declination axis is not changed in this respect.

When switching joysticks between different locations, such as between the readout room and the Coude' focus, the controller may sense a slight offset between joystick zero levels, and this could generate a spurious guide rate. Once the appropriate joystick has been selected, zero the joystick by first centering the sliding trim potentiometers on the front of the joystick, then pressing the pushbutton labeled RESTART on the front of the telescope controller.

Observers may also notice that the new joystick is more "quantized" than the old joystick. Those who have observed at the Nickel telescope should already be adjusted to this difference.

### 2. THE PET COMPUTER

A Commodore PET "personal" computer is part of the new configuration, and it serves two functions. First, it relieves the PDP-8 computer of telescope-specific calculations and operations so that the PDP-8 need not be distracted from its primary job of instrument control. Second, it allows the telescope controller to be operated from a remote location, such as the Coude' focus, since the link between the PET computer and the telescope controller requires only a single coaxial cable.

The PET program currently is used mainly for "SET TELESCOPE" operations, for making rate adjustments remotely, and for offsetting the telescope. It also includes a feature called STAR LIST, which allows one to enter in advance the names and coordinates of the objects to be observed in order to simplify subsequent SET TELESCOPE operations during the night. In the future, the PET computer will be used in conjunction with the TV autoguider, as well as with a new tub controller.

## 3. THE TV DISPLAY

There is now a large television monitor that sits above the rack containing the telescope position display and the time standard. This monitor is used to display status information from the telescope controller. What information appears on the monitor is controlled by a 15-position "DISPLAY SELECT" switch on the front panel of the telescope controller. The first eight positions, numbered 0 through 7, are for maintenance purposes and allow inspection of the internal memory of the controller.

Position 8, which is labelled the CURRENT OBJECT display, shows the actual position of the telescope, as well as the date and time, the name of the object being observed, and which slit it is in. Also displayed are the zenith distance, azimuth, and air mass corresponding to the current telescope position.

Position 9, which is labelled the NEXT OBJECT display, shows the position of the next object to be observed, as well as the object's name, and which slit to begin observing it in. Also displayed are the current date and time, as well as the zenith distance, azimuth, and air mass corresponding to the next object position. Note that whenever a "SET TELESCOPE" operation is performed on the PDP-8 <u>or</u> the PET, the result is transmitted to the telescope controller so that it can appear on this display, thus relieving the observer of the need to read the results of the SET TELESCOPE calculation to the telescope assistant.

Positions 10 through 14 currently are not used, but in the future will be used to display information regarding track rates, dome and windscreen position, and so on.

Position 15 is the <u>normal setting</u> for the display select switch. In this position, the display can be remotely toggled between the CURRENT OBJECT and the NEXT OBJECT display. This toggling can be done either from the PET or from a PDP-8 which is running a 32K FOCAL data taking system. Whenever a SET TELESCOPE operation is performed, from either the PET <u>or</u> a PDP-8, the NEXT OBJECT display will appear. Whenever the first scan of a new object is begun by the PDP-8, or the SET CURRENT ID command is given by the PET, the CURRENT OBJECT display will appear. Unfortunately, the Echelle and CCD data taking systems do not yet provide this toggling from the PDP-8.

Note that the television monitor is also used to display error messages, such as the telescope encountering a limit. <u>If an error condition exists, and the display select switch is set to a position between 8 and 15, the monitor will switch to the CURRENT OBJECT display so that the error message will appear in the proper context.</u> Such error messages, as well as any warning messages, will blink between normal and inverted video at a rate of approximately 1 Hz.

## 4. RATE ADJUSTMENT

Both the right ascension and declination rates can be adjusted either from the front panel of the telescope controller, or from the PET. The rates can be adjusted in increments of .001 arcseconds per second. The range of adjustment with the front panel switches is plus or minus .999 arcseconds per second, and the range from the PET is plus or minus 1.023 arcseconds per second. The overall rate adjustment is simply the sum of these two different adjustments, so that the total range of adjustment is plus or minus 2.022 arcseconds per second.

In the case of the declination axis, there is a third source of rate adjustment, internal to the controller, which is used for telescope flexure compensation. Accordingly, even if the declination rate switches on the front panel are at zero, and the declination rate set by the PET is zero, there still may be a small DEC rate present due to flexure compensation.

CAUTION: Note that the TRACK ON/OFF switch on the front panel of the controller only affects the R.A. axis; it does not turn off any declination rate that might be present. However, if the telescope itself is powered down, then any DEC. rate emitted by the controller has no effect.

5. LIMITS

As mentioned earlier, a new set of telescope position limit switches has been installed on the telescope for use by the telescope controller. These "hardware" limit switches are located in the same positions as the previous set of limit switches. In addition, a set of "software" limits have been added, based on the telescope position as read from the incremental position encoders. There are two lights on the front panel of the controller, labelled respectively "HARDWARE LIMIT" and "SOFTWARE LIMIT", which can be used to determine which type of limit has been encountered. Note that when any limit is hit, all directions of telescope motion are disabled except for the direction which is the opposite of the limit. For example, if the North limit is hit, only motion to the South is enabled.

The software limits are listed below. Note the limits tagged as "5-Mirror" apply only when the five-mirror system is in use, and those tagged as "Normal" apply only when it is not.

| | Direction | Slewing | Tracking/Setting/Offsetting |
|---|---|---|---|
| Normal | NORTH | 7.5 degrees under pole | 10 degrees under pole |
| 5-Mirror | NORTH | 4.0 degrees under pole | 6.5 degrees under pole |
| Normal | SOUTH | -39.5 degrees | -39.5 degrees |
| 5-Mirror | SOUTH | -14.0 degrees | -14.0 degrees |
| | WEST | +5 hours 40 minutes | +5 hours 40 minutes |
| | EAST | -5 hours 40 minutes | -5 hours 40 minutes |
| | Horizon | 10 degrees above Horiz. | 10 degrees above Horizon |

In extreme cases, the software limits can be overridden using a key switch on the front panel of the controller. The key for this switch is kept by Ron Laub. However, except for the normal North limit, the hardware limits are located only slightly beyond the software limits. Thus, overriding the software limits should not be needed unless one wants to observe more than 10 degrees under the pole.

6. POSITION DISPLAY AGREEMENT

The telescope controller is able to read the telescope position from the incremental encoders as well as from the synchro encoders. The controller checks that these two sources of position information are in rough agreement. IF THEY DIFFER IN EITHER AXIS BY MORE THAN TWO DEGREES, SLEWING IS INHIBITED and an error message is flashed on the television monitor. If this occurs, the offending source of position information should be corrected. In case of an encoder failure that cannot be rapidly corrected, slewing can be reenabled with the override key switch described above.

The controller also checks that the readings for hour angle, right ascension, and sidereal time are in agreement, according to the equality:

Right ascension = sidereal time - hour angle.

If they disagree by more than two seconds of time, a warning message is flashed on the television monitor, along with what the hour angle setting should be if the right ascension setting is correct, or what the right ascension setting should be if the hour angle is correct. These suggested settings both assume that the sidereal time has been set correctly. Note that the telescope operation is not in any way restricted if these settings are out of agreement.

Although the correctness of the hour angle display might not seem that important, the correct hour angle is needed for calculation of atmospheric extinction and refraction. Furthermore, it will be very important when the dome of the Shane telescope is brought under the control of the telescope controller.

POSITION DISPLAY INITIAL SETUP: The following procedure should be used when initially calibrating the position display. At the start of the evening, the observer should verify that the telescope controller has the correct sidereal time displayed on the television monitor. If not, the date and time should be reset using the PET computer. A bright star should then be acquired, and the right ascension setting of the position display should be set to match the position given by the SET TELESCOPE program for that bright star. Finally, the hour angle setting should be adjusted to match the hour angle setting prompted by the warning message of the television monitor.

## 7. TELESCOPE OFFSETTING AND SLIT CHANGING

The telescope can be offset using either a PDP-8 computer or the PET. Either PDP-8 can send its offset requests to the telescope controller using the serial multiplexer (MUX). However, the controller will only accept offset requests from whichever PDP-8 is in control of the telescope, as indicated by the Cass/Coude' switch located in the readout room. Although the PDP-8 need not wait for the offset to complete, all of the data taking systems are currently set up so that the PDP-8 waits for offset completion in order that data taking does not begin prematurely.

The PET computer sends its offset requests to the telescope controller over a single coaxial cable using a device called an A.C.I.A. Although there will be a PET at both the Cassegrain and Coude' foci, only one of them will be attached to the controller at any given time, so no Cass/Coude' switch is needed to arbitrate between PETs. Offsets initiated from the PET are asynchronous; neither the PET nor the PDP-8 waits for them to complete. The same considerations apply to slit changing, which is simply a special case of offsetting. Note that slit changing automatically updates the slit code that is displayed in the CURRENT OBJECT display.

The telescope controller makes a number of checks prior to initiating an offset, and will reject an offset request in any of the following situations:

1) The telescope is slewing.
2) A previous offset is still in progress.
3) A joystick is deflected from its null position.
4) The computer disable switch is thrown.
5) A rate change is in progress.
6) The telescope is at a limit.
7) The request came from a PDP-8 not currently in control of the telescope, such as from the Echelle computer during a Cassegrain run.

Conditions 1,4,5, and 6 are also sufficient to interrupt an offset once it has been initiated.

## 8. DOME, WINDSCREEN, AND SLEW CONTROL

Both on the front panel of the telescope controller and on the television monitor, references to DOME and SLEW control appear. Since neither control of the dome nor of slewing has been implemented at the Shane telescope, most of these references currently have no meaning. In particular, the blinking question marks in the DOME field of the television display, and the lamp labelled "DOME IN WAY" on the front panel of the controller, should be ignored, as should the "DOME ENGAGED" and the "SLEW AUTO/MANUAL" switches.

While it is planned that the telescope controller will eventually control the dome and the windscreen, as well as provide some limited control of slewing, implementation of these features will wait until there is agreement that the controller is performing its current tasks as desired.

## CONCLUSION

A great deal of effort has been made to test all of the hardware and software involved in this changeover, both at the Nickel telescope, and on numerous "dry runs" at the Shane telescope. In addition, considerable hardware redundancy has been provided, since the telescope controllers at the Shane and Nickel telescopes are interchangeable with each other and with a third controller, which serves as a spare. Similarly, the three PET computers on the mountain are interchangeable. Further, the telescope controller can take over the functions of the time standard, in case it should fail. Finally, in case of multiple controller failures, one can always switch back to the existing drive system in about ten minutes.

While it is hoped that this new configuration will work smoothly for everyone, it is also true that any time one makes a change to an existing system, there may be unexpected side effects. If you have any problems with the new system, or have reasonable suggestions for its improvement, please contact me as soon as possible.

Sincerely,

Bob Kibrick

Bob Kibrick
Sr. Programmer

Sept 14, 1981

TO: L. Robinson
FROM: J. Osborne
SUBJECT: 120-inch telescope limits

Lloyd-

I had Mike Owens record the present limits and telescope status at each. Here is a summary...

1. West limit:
   Telescope coasts to 6h 4m (at dec 56°)    Elev = 26°
   Status: No west slew, set, or guide
   All other functions work, including track
2. East limit:
   Telescope coasts to 6h 1m (at dec 57°)
   Status: No East slew, set, or guide
   All other functions work, including track
3. South limit:
   None. Horizon limit hits first (see horizon limit and status)
4. North limit:
   Telescope coasts to 35° 23' below the pole (at HA -5 28m 25sec)
   Status: No North slew, set, or guide    Elev = 25°
   All other functions work, including track
5. Horizon limit:
   In South at 0 HA, dec is -46° 42' (6° from horizon)
   Status: Track motor only
6. Tangent arm:
   Travel limits are ± 2°
   Status: you can set out of a limit in the appropriate direction.
   Centering switches must be sensed before dec slew is allowed.

Sept 14, 1981

120" Telescope

7. South limit with 4th mirror in place.
   Telescope coasts to -15° 6'
   Status: No south set. All other functions operste. No slew south.
   Also, telescope tube (ladder) is 13" from the 4th mirror structure.

8. Horizon limit in the west.
   Telescope set at HA = 5h 24m 36s; slew south, coast to dec = -3° 52'
   Elevation is 4.7°
   Status: No slew, Set north works. No set south. No set west.
   Set east drives the motor but the slow drive clutch is disengaged.
   East guide motor works. Tracking motor works.

   We let the telescope track for 20 minutes. At HA = 5h 38m a buzzer sounded and the telescope still kept tracking.

   Elevation is 2.04°

   To get out of this buzzer situation and all other horizon limits, you press a "7° override" button under the main console and hold the appropriate slew button.

(We suspected that the buzzer is the so-called 3° limit. To check this, I had Mike return the telescope to the zenith and go up on the tube and move the limit cones. The 3° cone does make a buzzer sound, only if the 7° cone is also displaced.)

9. Horizon limit in the north.
   Telescope coasts to 31° 39' (58° 21' past the North Pole)
   HA is +1h 21m (Elev is 7.17°)

Sept 18, 1981

| | H.A. | DEC | ELEV. | TRACK | SLEW | SET | GUIDE (5) |
|---|---|---|---|---|---|---|---|
| WEST LIMIT | 5h 49m | 37° 20' | | Yes | NSE | NSE | NSE |
| | (6h 2m) (1) | 37° 20' | | " | " | " | " |
| | (6h 4m) | 56° | | Yes | NSE | NSE | NSE |
| EAST LIMIT | -5h 44m | 37° 20' | | Yes | NSW | NSW | NSW |
| | (-6h 4m) | 37° 20' | | " | " | " | " |
| | (-6h 1m) | 57° | | Yes | NSW | NSW | NSW |
| SOUTH LIMIT | 0h | -44° 40' (2) | 8° | Yes | | | |
| SOUTH LIMIT 5-mirror | 0h | -14° 2' | 39° | Yes | NEW | NEW | NEW |
| | 0h | (-15° 6') | 37° | " | " | " | " |
| NORTH LIMIT | -5h 28m | (35° 23') (3) | 25° | Yes | SEW | SEW | SEW |
| | 0h | 10° (3)(4) | 27° 20' | Yes | SEW | SEW | SEW |
| HORIZON #1 SOUTH | 0h | (-46° 42') (2) | 5° 58' | Yes | none | NE | NE |
| | 0h | -46° 16' (2) | 6° 24' | Yes | none | NE | NE |
| | 0h | (-48° 27') (2) | 4° 12' | " | " | " | " |
| EAST | -5h 21m | -2° 22' | 6° 10' | Yes | none | none | none |
| | (-5h 39m) | -2° 22' | 2° 36' | " | " | " | " |
| WEST | 5h 20m | -2° 22' | 6° 24' | Yes | none | N | (6) |
| | (5h 36m) | -2° 22' | 3° 29' | " | " | " | (6) |
| | 5h 24m | (-3° 52') | 4° 42' | Yes | none | N | (6) |
| NORTH | 1h 21m | (31° 39') (3) | 7° 12' | Yes | none | SW | SW |
| HORIZON #2 WEST | 5h 38m (tracking) | -3° 52' | 2° (buzzer) | Yes | none | N | none |

J.O.

1. Parentheses indicate slew coasting. 2. South limit set to -44° 40' on 9/16/81. No South limit previously. Horizon limit encountered first. 3. Degrees below North pole. 4. North limit re-set on 9/16/81. 5. "Guide" refers to old RA motor for East and West. "Guide" for North and South is same as Set. 6. RA guide motor runs but slow motion clutch disengages.

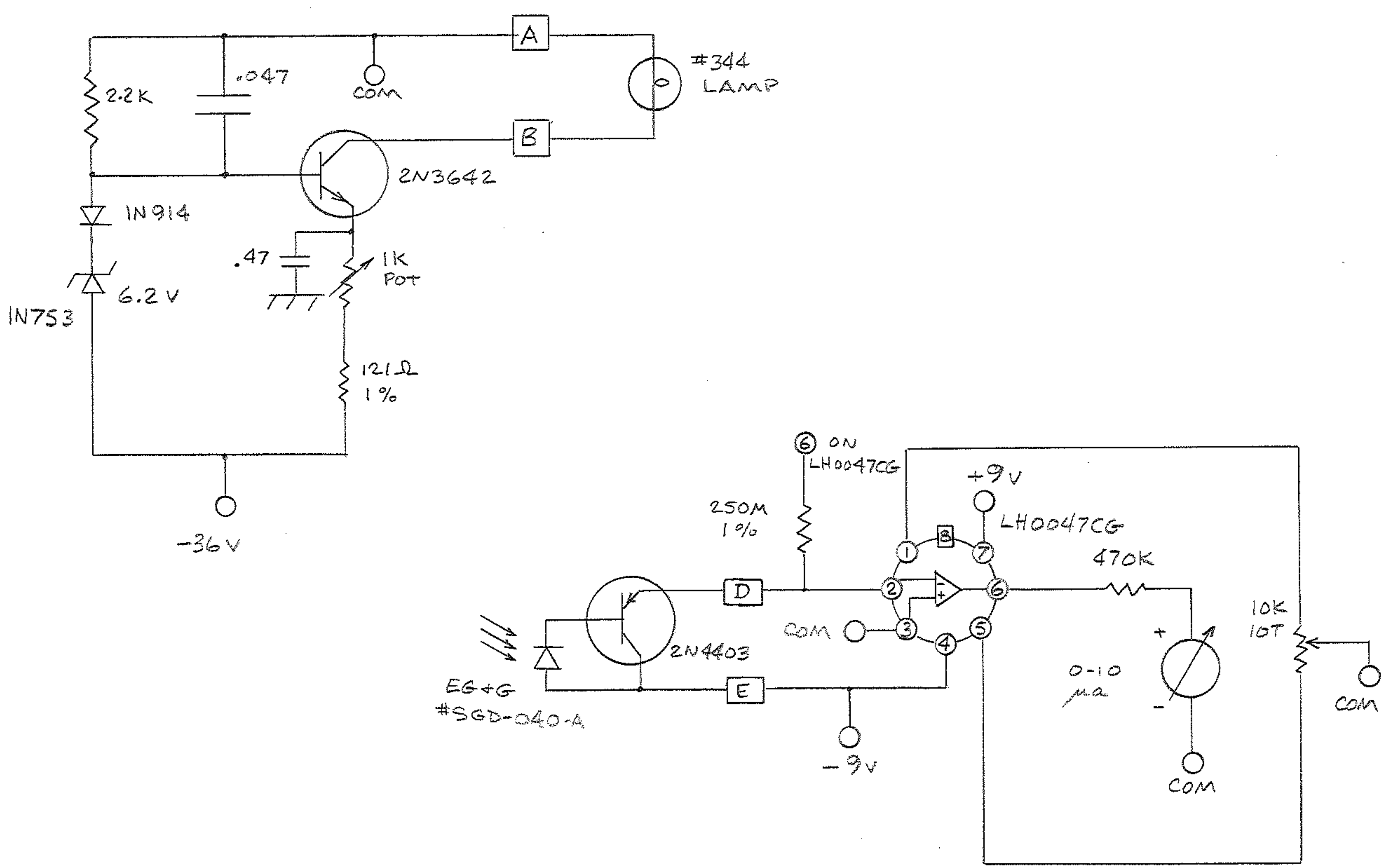
# CHAPTER VI: TELESCOPE ALUMINIZING

The primary mirror was aluminized in 1981 and is usually re-aluminized every 3 years. This procedure takes about 6 days. Ron Laub and Neal Jern have compiled a large notebook with lots of pictures of the entire process.

Two descriptions of the mirror cleaning process are included here.

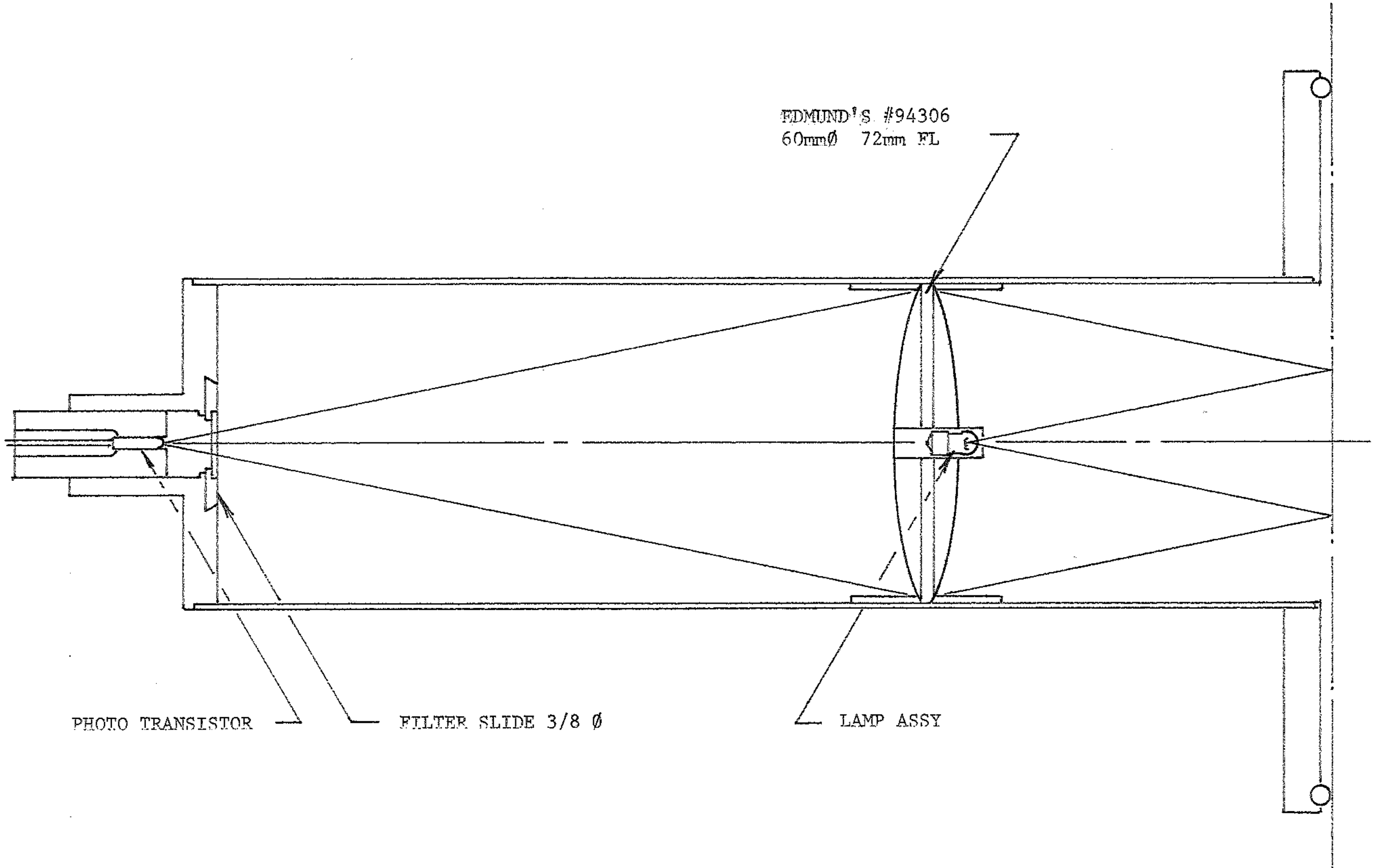
A reflectometer is used to help decide if a washing or a re-aluminizing is required. A schematic is included here with a drawing of the LOS 806 reflectometer (Figures 3 and 4).

Future: Overcoating is being investigated. There are many reflections in some of the optical systems. If you lose only 10% of the photons entering the dome on the primary, and 10% of those left at the secondary, and 10% at the Coudé #3 mirror ... by the time you get to the detector you have only 39% of the light you started with (9 reflections to the 40" Reticon in 5-mirror configuration).




120" REFLECTOMETER
EL 589-2S 9-16-75 T.R.

Figure 3




L.O.S. 806 REFLECTOMETER Figure 4

F. MELSHEIMER 6-10-74

(Taken from FOCUS, August 1976...Sandy Faber)

## CONFESSIONS OF THE 120-INCH PRIMARY

Howard Cowan communicated the following details concerning the realuminizing of the 120-inch mirror, which took place in December 1975. The mirror periodically needs a fresh coating of aluminum because the reflectivity of the coat gradually declines with time as the aluminum ages and the mirror surface collects dirt and grime. A procedure to wash the mirror while still in the telescope was developed by Frank Melsheimer. Periodic washings are helpful in maintaining reflectivity, but eventually the time comes when a whole new coat must be put on. Dave Rank and Frank Melsheimer devised a simple instrument to monitor the mirror's reflectivity. When the reflectivity declined to only 70% of that of a fresh aluminum coating (as measured last Fall), the decision was made to apply a new coat during the poor-weather Winter observing season. A study of weather records over the past ten years, carried out for Dr. Osterbrock by graduate student Howard French, indicated that the December weather was likely to be the poorest and hence that realuminizing during that month would be least likely to interfere with observing. As it turned out, however, the 13 day period during the realuminizing was brilliantly clear. Oh well....

Howard Cowan says that this was only the fifth time that the primary has been realuminized since its initial installation in June of 1959. The most recent coat was applied in March of 1970. Realuminizing consumes roughly two weeks of valuable telescope time and also carries with it a considerable risk of damage to the mirror. The mirror and its cell together weigh 12 tons, which is not a trivial package to dangle at the end of a long cable. This time, the mirror was insured for $1.5 million, which was brokered by Lloyd's of London. Sudden last-minute doubts about whether the insurance could actually be purchased caused fears that the operation would have to be postponed, but the insurance was eventually purchased on time.

As the first step in realuminizing, the primary and its cell must be removed from the telescope. The telescope is tied down with three bars so that it cannot move (it becomes unbalanced when the mirror is removed), and the primary in its cell is placed on the mirror-handling carriage, a large platform which runs underneath the telescope along two rails. After being lowered by crane through a hatch in the dome floor to the optical shop in the basement of the 120-inch dome, the mirror is first cleaned with a solution of copper sulfate, hydrochloric acid, and distilled water to strip off the old aluminum coat. It then receives a second cleaning with photographic tray cleaner, a caustic grease-cutting solution. After the mirror is dried with lint-free bird's eye toweling (laundered at a special laundry in San Jose), it is covered with lint-free cellophane to keep dust off and then raised up by crane again to the mirror-handling carriage in the dome.

There the last and most mysterious cleaning operation begins. The secret here is Wildroot Cream Oil! No kidding. The hair oil is sprinkled on and is rubbed thoroughly on every inch of the surface with squares of hard felt. This rubbing takes four hours. Then powdered French chalk is scattered on, which absorbs much of the excess lanolin oil. When the chalk is rubbed off, the surface feels clean and dry but has a microscopically thin coating of lanolin still on it. This coating is later fired off with a high-voltage discharge in the aluminizing tank, carrying off the last traces of dust and dirt.

The trickiest part is yet to come. The mirror is tilted nearly vertical on the mirror-handling carriage (here everyone holds his breath), and is set in a sling, in which it is lowered through a second hatch in the floor to the aluminizing tank below. The tank and its associated vacuum pumps formerly housed a cyclotron accelerator on the Berkeley campus and were acquired by Lick as "surplus". After receiving a last-minute cleaning and air-dusting, the mirror is sealed in the air-tight tank, and the vacuum pumps are started. It takes nearly 24 hours to reduce the pressure to the proper level, only $2 \times 10^{-5}$ atmospheres.

To see why aluminizing requires a good vacuum, we must understand how the process takes place. Inside the tank close to the surface of the mirror there is an array of electrical wires, or filaments. When Howard pulls a switch, electricity flows through these wires and heats them to a high temperature. Before closing the tank, Howard hangs two hundred aluminum "hairpins" on these filaments in a pattern strategically designed to produce an even coating of aluminum on the mirror. When the filaments heat up, the aluminum hairpins vaporize, and the aluminum atoms fly off in a straight line, hit the mirror and stick. If too many air molecules are in the tank, the aluminum atoms will collide with them before hitting the mirror, and the process is ruined. This is the reason for having a good vacuum.

After the firing, when the tank is finally opened, Howard checks to see that the coat is uniform and that it has "taken" properly to the mirror's surface. Improper cleaning leads to a coat that isn't firmly bonded. To check this, Howard presses masking tape onto the coating in two or three places. If the tape comes away clean, the coat is O.K. A bad coat would mean cleaning the mirror over again from the start and repeating the whole process. Howard says he's never had a miss.

We're in business again for another five years or so!

# CHAPTER VII: AUXILIARY OPTICS CONTROL

## COUDÉ 3rd MIRROR:

The control of the 3rd mirror is described by Cal Delaney in a memo dated July 23, 1982. The present automatic control system relies on some very sensitive mechanical adjustments and doesn't operate reliably. The proposed modifications involve only a better means of determining the position error of the 3rd mirror. The existing motors will still be used.

2. When the difference in third mirror and dec exceed a certain amount the microprocessor system will energize the relay necessary to position the third mirror to agree with declination. Left in this mode the third mirror should track declination with an accuracy limited only by that of the synchros.

The above system can be constructed using existing standard Lick microprocessor cards. Cost of the hardware, parts and labor, should not exceed $3,500. Software development time is a little harder to guestimate but shouldn't exceed three man-months.

CRD

LICK OBSERVATORY
UNIVERSITY OF CALIFORNIA
SANTA CRUZ 95064
July 23, 1982

TO: DAVE RANK
STEVE VOGT

FROM: C. R. Delaney L.O.E.L.

RE: Third Mirror Drive 120" coude focus

On 7-21-82 Neal, Jack, and I traveled to Mt. Hamilton to investigate the operation and possible problems of the third mirror positioning system of the 120" coude focus. The two complaints most often received are third mirror pointing accuracy and an occasional apparent "run-away."

The pointing accuracy problem is inherent in the existing design. This design uses a two-speed synchro system to determine mirror position. These coarse-fine synchros, attached to the mirror cell drive gear box, are compared to the coarse-fine synchros on the telescope declination axis in a torque generating differential synchro. Mounted on a shaft of this differential synchro, is an arm on the end of which is a small bar magnet. As the shaft rotates this magnet comes into close proximity to one of two magnetically actuated reed switches. As a reed switch closes a relay energizes and applies power to a motor connected to the third mirror gear-box. This gear-box drives both the third mirror cell and the third mirror synchro. As the third mirror synchro signal approaches the same phase as that of the declination axis synchro, the magnet arm returns to the center position and the reed switch opens, removing power from the third mirror motor and the mirror is considered positioned.

The accuracy of such a system is determined by how close together the two reed switches can be placed. If too close, the system will "hunt," the hysterisis of one reed switch driving the arm far enough to energize the opposite reed switch and vise versa. The precision of this system relies on the sensitivity and hysterisis of the reed switches remaining constant. These characteristics can, and do, change with temperature and age. It also relies on the flux density of the bar magnet remaining constant.

It is suggested that the above system be left intact but, by the use of a switch, be disabled and the following scheme be switched in:

The outputs of the four synchros be digitized and, via the shops standard port card, be compared by a microprocessor system. This system will display, digitally, the position of the third mirror. One of two modes of operation will now be switch-selectable.

1. If the difference in third mirror and declination exceed a certain amount, a warning light is turned on and, by using push-buttons, the telescope assistant can position the third mirror to agree with telescope declination.

MIRRORS AT MT. HAMILTON

1. 40-inch telescope

   Primary 39.4" x 7"; 670 lbs.

   Secondary 12.5" x 1.9"; 19 lbs.

2. 120-inch telescope

   Primary 120" x 16" (not solid); 7,740 lbs.

   Cass Secondary 34.55" x 5"; 360 lbs.

   Coudé Secondary 31" x 4"; 260 lbs.

   Coudé 3rd mirror 24" x 50" Ø x 9"; 1,000 lbs.

3. Coudé Spectrograph Camera

   20" fl camera: 29.5" x 7"

   40" fl camera: 31.5" x 5"

   80" fl camera: 36" x 8"

   160" fl camera: 50" x 9"

4. Crossley telescope

   36" x about 4"; about 450 lbs.

5. Coudé Auxiliary Telescope (CAT)

   #1 mirror (siderostat) 30" x 48" Ø x 9"; 970 lbs.

   #2 mirror 30.25" x 5"; 290 lbs.

   Primary 24.25" x 5.1"; 190 lbs.

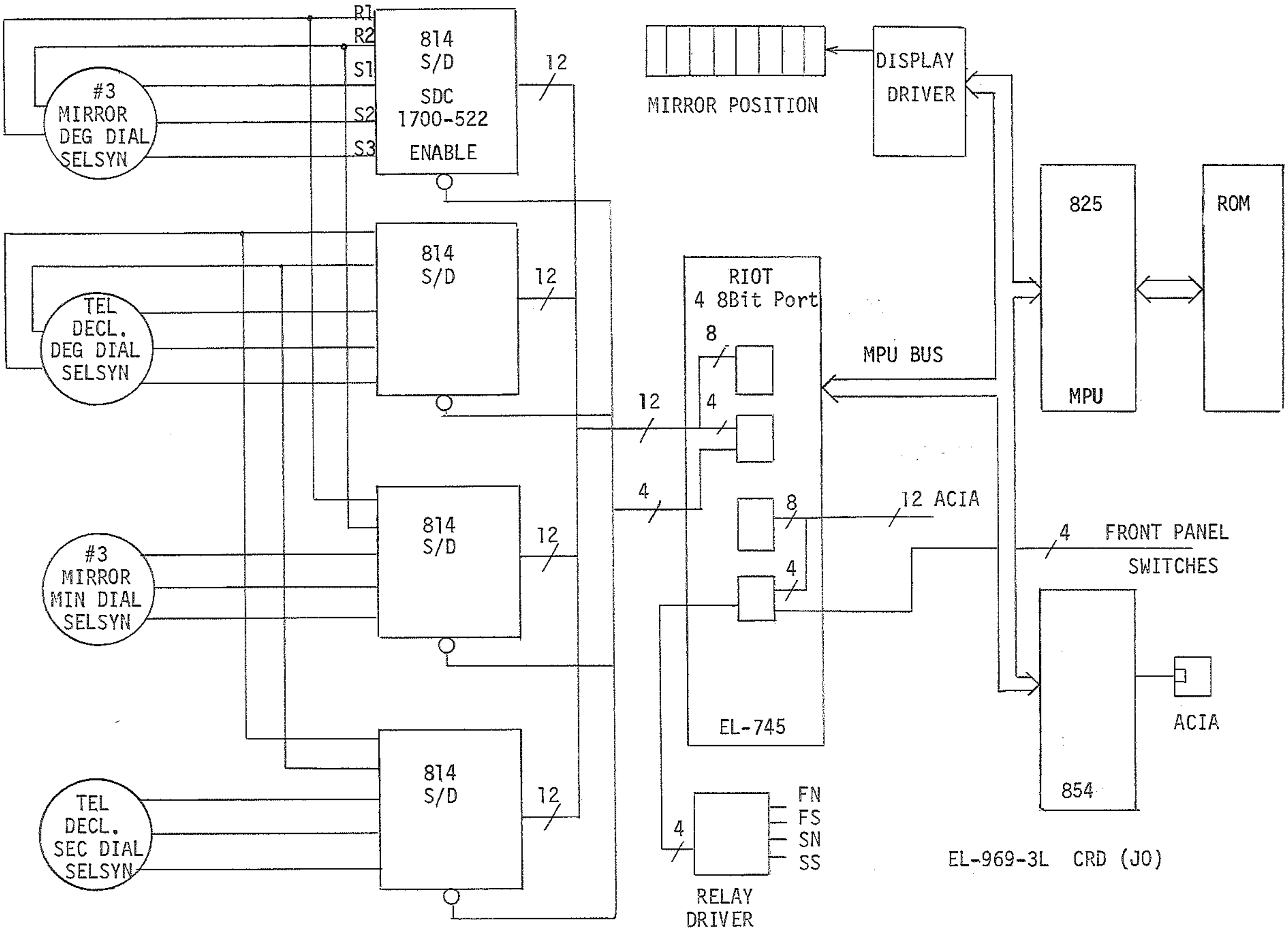
   Secondary 7.44" x 1.2"

   #5 mirror 4" x 8.5" Ø x 1.1"

6. 24-inch telescope

   Primary 24.7" x 4.25"

   Secondary 7" x 1.5"



R1
R2
S1
S2
S3
814
S/D
SDC
1700-522
ENABLE
12
#3
MIRROR
DEG DIAL
SELSYN
814
S/D
12
TEL
DECL.
DEG DIAL
SELSYN
814
S/D
12
#3
MIRROR
MIN DIAL
SELSYN
814
S/D
12
TEL
DECL.
SEC DIAL
SELSYN
MIRROR POSITION
DISPLAY
DRIVER
825
MPU
ROM
RIOT
4 8Bit Port
8
4
12
4
8
4
EL-745
MPU BUS
12 ACIA
4
FRONT PANEL
SWITCHES
854
ACIA
4
FN
FS
SN
SS
RELAY
DRIVER
EL-969-3L CRD (JO)

METHOD OF CLEANING MIRROR BEFORE ALUMINIZING

by

Don Hendrix

The Mirror is cleaned before aluminizing as follows:

1. Bathed with K.O.H. solution (ordinary tap water). Buy the K.O.H. in 1 lb. bottles only. It is best to have a generous supply on hand - say a 24 bottle carton.

2. Bathed with "Orvus" water. ORVUS is paste form of DREFT. It comes in 5 lb. jars and is a Procter-Gamble product.

3. Bathed with Photo tray cleaner - formula given in Kodak handbook. We make up in 5 gal. bottle.

The above solutions are applied with swabs made of the best grade of Carolina long-fibre cotton on plexiglass rods. Rubber gloves and aprons for this job.

4. Clean with <u>200</u> proof alcohol and distilled water - 50/50 solution. About one pint of solution required per clean job. Solution applied with lens tissue made by Scott Paper Co. We buy (when we can) the lens tissue from Government Surplus.

5. (Alternate) Sometimes step 4 is eliminated and the mirror is rubbed with lanolin solution (Wildroot Hair Oil) 1 large bottle required. The lanolin is then removed with precipitated chalk - 2 lbs. required. Buy the chalk in 1 lb. glass containers. The swabs used in this process are made of 1/2 inch hard white felt. Five square feet of felt should be purchased.

5. Put in pot and cook.

## REFERENCE


Mayall, N. V. and Vasilevskis, S., 1960, A.J., **65**, 304-317.

Rippel, H.C., 1963, Machine Design, p. 108, August 1.

NOTES