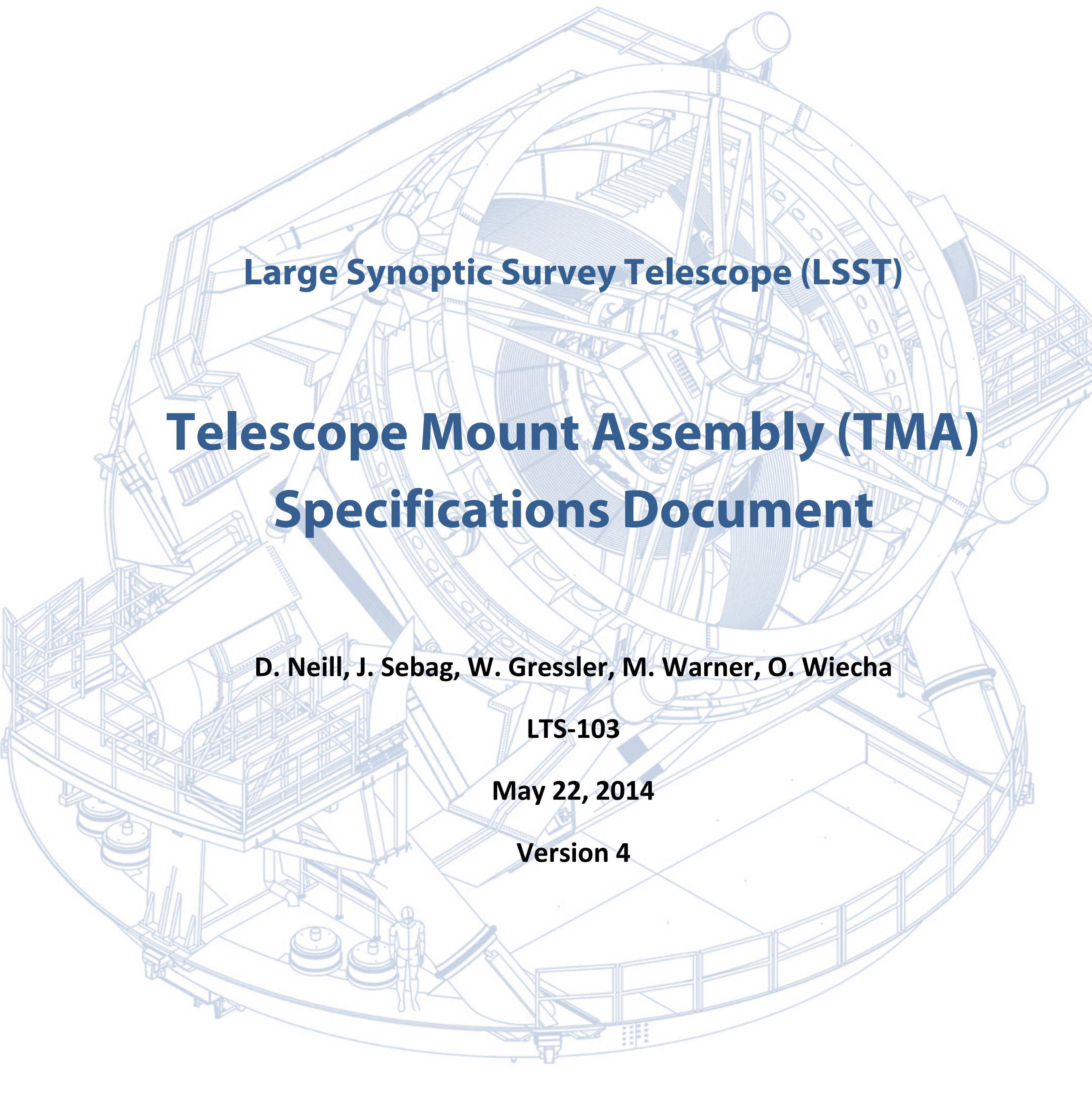
LARGE SYNOPTIC SURVEY TELESCOPE



Large Synoptic Survey Telescope (LSST)

Telescope Mount Assembly (TMA) Specifications Document

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CHANGE RECORD

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3	07/08/2013	Version for RFP Release	D. R. NEILL
4	05/22/2014	Version for TMA Contract	W. Gressler

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1 INTRODUCTION

This specification document contains the functional and performance requirements for the design, fabrication, assembly and testing of the Large Synoptic Survey Telescope (LSST) Telescope Mount Assembly (TMA). The purpose of the TMA is to acquire and track fields on the sky by providing motions about the azimuth and elevation axes. The TMA includes all the moving mass excluding the payloads which includes three optical systems: 1) primary/tertiary (M1M3) mirror cell assembly, 2) secondary (M2) mirror cell assembly 3) camera, their positioning systems (M2 hexapod and camera hexapod and rotator) and the M2 light baffle. The TMA also includes all the components attached to the telescope pier that are required to operate the mount. This specifically includes the bearing tracks, limit switches, hard stops, azimuth encoder system, cable drape, etc.

1.1 BACKGROUND

The Large Synoptic Survey Telescope (LSST) is a large (8.4 meter) wide-field (3.5 degree) survey telescope, which will be located on the summit of Cerro Pachón in Chile. The survey mission requires a short slew, settling and active optics convergence time of 5 seconds for a 3.5 degree slew. One second is allocated to active optics convergence providing 4 seconds for the slewing and settling of the mount. This is significantly faster than similar aperture telescopes. Since the optical system does not include a fast steering mirror, the telescope has stringent vibration limitations during observation. Meeting these requirements will be facilitated by a compact mount riding on a robust pier, which produces high natural frequencies, an advanced telescope control system (TCS) to minimize vibration excitation and by reaction mass dampers. The dynamic characteristics of the steel reinforced concrete pier were enhanced by utilizing two different wall thicknesses, an unusually large diameter of 16 meters, a flared pier top and anchoring the foundation in unweathered bedrock. Optimum utilization of the advanced telescope control system (TCS) and reaction mass dampers requires a minimization of the variation in natural frequency as a function of azimuth angle and elevation angle. The minimization of natural frequency variation with azimuth angle will likely require mounting the azimuth drives on the azimuth assembly.

The telescope mount assembly design will be an altitude over azimuth welded and bolted assembly fabricated from mild steel. It will support the primary/tertiary (M1M3) mirror cell assembly, the secondary (M2) mirror cell assembly and the camera. The mount design must enable the on-telescope maintenance and the removal of these optical assemblies for servicing and recoating. Retractable / deployable platforms must also be provided for accessing the camera on telescope. As a result of the wide field of view, the optical system is unusually susceptible to stray light; consequently the mount must incorporate substantial light baffling.

1.2 OBJECTIVE

This document is intended to govern the design and fabrication of the LSST Telescope Mount Assembly (TMA). It provides the delivered system performance requirements needed for the LSST to fulfill its survey mission as described by the LSST Telescope and Site Requirements Document (LSE-60).

This document also provides the requirements for packing/shipping, site assembly and installation, testing and maintenance for the LSST TMA.

1.2.1 INCLUDED IN SCOPE

The following items are specifically included in the scope of the Telescope Mount Assembly (TMA).

- Telescope components fixed to pier
  - Azimuth bearing track and anchor bolts
  - Grout of azimuth bearing track
  - Azimuth drive magnets
  - Azimuth encoder tape and tape slot
  - Braking surfaces
  - Topple block and associated structure limiting azimuth rotation
  - Azimuth cable wrap / drape components attached to pier
- Telescope components in facility
  - Oil collection system
  - Oil Supply system including hydrostatic pump/cooler/tank
- Azimuth assembly
  - Main azimuth structure
  - Bearings
  - Removable shielding around bearings and tracks
  - Passive seismic restraints (retaining clips) at each bearing
  - Brakes
  - Azimuth encoder read heads and supports
  - Tachometer or other auxiliary device for independent velocity measurement
  - Glycol/water cooled drive system (motor coils)
  - Glycol/water cooled capacitor bank to supply electrical power to azimuth and elevation drive systems
  - Travel limiting shock absorbers interacting with topple block
  - Limit switches
  - Azimuth floor with removable section
  - Safety rails
  - 2x stairs to elevated access platforms
  - 2x elevated access platforms for accessing elevation cable wrap, elevation bearing, camera and elevation assembly center section
  - 2x deployable platforms for accessing camera

- 2x extensions off of each deployable platform (4 total) for accessing camera L1, hexapod and rotator
- 2x ladders with hatches to access telescope pier top floor from azimuth assembly
- Accommodations for LSST supplied rail in flooring for operating M1M3 removal cart
- Azimuth cable wrap dragging device. All cables/hoses/plumbing etc specified in this document from their stationary connections in the telescope pier to their terminations
- Elevation encoder read heads, motor coils, drives, hard stop, brake, Locking pins etc. attached to the azimuth assembly
- Seismic restraints

- Elevation assembly
  - Main elevation structure
  - Bearings
  - Removable shielding around bearings
  - Encoder tapes and tape slots
  - Elevation drive magnets
  - Brakes surfaces
  - Tachometer or other auxiliary device for producing independent velocity measurement
  - Travel limiting shock absorbers
  - Limit switches
  - Locking pins holes
  - Partial walk way around elevation assembly
  - 2x access ladders from elevated access platforms
  - Motor driven cover over primary / tertiary mirror (M1M3)
  - 2x motor driven and manually operated balancing units parallel to optical axis
  - 2x motor driven and manually operated balancing units perpendicular to optical axis and elevation axis
  - Light baffling vanes on all surfaces adjacent to the optical path.
  - 3x aperture light baffles (main elevation structure provides a forth baffle).
  - M2 baffle temporary support
  - Passive damping units
  - Top end assembly (excluding payloads)
    - Top end ring (fabricated from 2 of the 3 aperture light baffles)
    - Hollow spiders for supporting top end assembly payload
    - Fixed Structure (spider spindle)
    - Top end thermal control systems with plumbing, fans and ducts.
    - Camera cable wrap with specified lines
    - 2x removable Interior Structure (integrating structure)
    - 2x camera offset for attaching camera hexapod to integrating structure (note: only one integrating structure and camera offset can be installed)
  - Elevation cable wraps/drape

  - All cables/hoses/plumbing etc specified in this document through the elevation cable wrap /drape to their terminations
- Electronics, cabling, software and controls (note: some of these items are previously mentioned)
  - 6x top end electrical cabinets (for hexapods/rotator and M2 mirror cell assembly)
  - Capacitor bank for drives (attached to azimuth assembly)
  - Mount Control System (including simulator)
  - Safety interlock system
  - All cabling specified in this document
- Maintenance, testing and integration equipment
  - All the equipment required to test and operate the TMA are included in the scope
  - Guide rods for M2 temporary relocation
  - Guide rods for camera removal or similar
  - Camera assembly lifting fixture
  - Surrogate masses for balancing the elevation assembly
  - TMA assembly jigs

1.2.2 NOT INCLUDED IN SCOPE

The following items are specifically NOT included in the scope of the Telescope Mount Assembly.

- Steel reinforced concrete telescope pier
- Fixed platforms and stairs inside telescope pier
- Fixed platform (perimeter walkway) surrounding telescope at azimuth floor level
- Piping and cabling from the facility to the connections in the telescope pier
- Primary/tertiary (M1M3) mirror cell assembly or its handling equipment (mirror cart)
- Secondary (M2) mirror cell assembly, M2 hexapod and their handling equipment, except the temporary relocation guide rods
- Camera with hexapod and rotator
- M2 Baffle
- Glycol/water chiller, pumps and plumbing used to supply coolant to the azimuth cable wrap
- Cables used to power supply and signal to the azimuth cable wrap. The interface is at the power cabinet/panel located in the pier. Therefore TMA vendor will have to install some cables between the azimuth cable wrap and the power panel
- Power supply. LSST PO will supply power at the power cabinet located in the pier. TMA Vendor will distribute and feed all TMA equipment over the telescope structure
- Rails for M1M3 mirror cart (however, the azimuth assembly must accommodate these rails and the M1M3 mirror cell assembly cart that rides on them)

1.3 RELATED DOCUMENTS

1.3.1 COMPLIANCE DOCUMENTS

In addition to the requirements and specifications contained herein this document, Contractor shall also be required to comply with the requirements and specifications contained in the following documents as it pertains to the completion of the Work (LSST PO will include a separate list of the documents to include the revision or issue date).

- Summit Support Facility Electrical Requirements LTS-52
- LSST Summit Environmental Conditions LTS-54
- Telescope Mount Assembly to Pier Interface Drawing LTS-77
- LSST Summit Electrical and Control System Standards LTS-96
- LSST Summit Control Panel Manufacturing Guidelines LTS-98
- LSST Summit Safety Interlock System LTS-99
- Telescope Mount Assembly to Dome Interface Drawing LTS-105
- M2 Assembly Envelope Drawing LTS-127
- M2 Assembly to Telescope Mount Assembly Interface Drawing LTS-128
- Telescope Mount Assembly to M1M3 Mirror Cell Interface Drawing LTS-130
- Telescope Opto Mechanical Coordinate Systems LTS-136
- TCS to TMA Interface Control Document LTS-159
- TMA to M1M3 Mirror Cell Cart Interface Drawing LTS-169
- TMA to Interlock System Interface Control Document LTS-173
- TMA Deployable Platforms Envelope Drawing LTS-179
- TMA Capacitor Bank Design Requirements LTS-180
- Telescope Mount Assembly to M2 Hexapod Interface Drawing LTS-181
- Telescope Mount Assembly to Camera Hexapod Interface Drawing LTS-182
- Optical Assemblies and Light Baffles Mount Location Drawing LTS-213
- M1M3 Mirror Cell Assembly Envelope Drawing LTS-216
- TMA to Utilities and Services Interface Control Document LTS-217
- TMA Camera Cable Wrap Design Requirements LTS-218
- Camera Assembly Surrogate Envelope Drawing LTS-219
- M2 Assembly with Hexapod Surrogate Envelope Drawing LTS-220
- Telescope Mount Assembly Interface Control Document Overview LTS-221
- Telescope Mount Assembly Statement of Work LTS-222
- TMA Crane Access Drawing LTS-223
- Control Software Development Best Practices LTS-224
- LSST Seismic Design Accelerations Doc-13228

1.3.2 SUPPORTING DOCUMENTS

The LSST Project Office (LSST PO) has produced a number of documents that the Contractor may find informational and/or useful during the course of undertaking the Work. These documents include:

- Hydrostatic Bearing Arrangement (SPIE-7018) Doc-5643

- A Comparison of Vibration Damping Methods (SPIE-7012) Doc-5721
- Adaptive Periodic Error Correction for ... Encoders (SPIE-7012) Doc-5878
- Mount Servo Model Doc-8384
- LSST Mount Drive Pinions Doc-9485
- Mount Tracking Rates and Jitter Analysis Doc-12095
- M1M3 Thermal Control Doc-13322
- Seismic Analysis of the LSST Telescope (SPIE-13381) Doc-13381
- Telescope Mount Assembly Baseline Design Document Doc-14411
- TMA Safety Hazard Analysis Doc-14428
- Top End Thermal Control System Calculations Doc-14590

1.4 SPECIFICATION AND DISCUSSION

Listed in the following sections below are the requirements for the LSST Telescope Mount Assembly.

Specific requirements are listed in sections preceded by the heading “Specification”. Sections preceded by “Discussion” are not specific requirements. Rather, this information is included as supporting documentation to provide the Contractor with background information. Sections which contain neither a “Specification” nor “Discussion” are included for additional background information or completeness.

2 TELESCOPE MOUNT ASSEMBLY PERFORMANCE REQUIREMENTS

Although for maintenance purposes the Telescope Mount Assembly shall be able to point from horizon pointing to zenith pointing (elevation angles of 0 degrees to 90 degrees), all the performance requirements must only be met for observing angles which are elevation angles between 15 degrees to 86.5 degrees and for all azimuth angles.

2.1 POINTING REQUIREMENTS

The Telescope Mount Assembly shall be able to point at the different field positions on the sky. The requirements below define the pointing range and accuracy. The requirements are for simultaneous motions in both axes.

2.1.1 POINTING RANGE IN ELEVATION

Specification: The Telescope Mount Assembly shall be capable of pointing from zenith to horizon in elevation (from 0 degrees to 90 degrees in elevation angle). This range shall be reachable without overriding any limit switches, except the elevation axis operational directional limit switch. It may require overriding the adjustable software limits but not the fixed software limits.

Discussion: The pointing range of 0 degrees to 90 degrees in elevation is to accommodate maintenance procedures that require zenith pointing and horizon pointing. The performance requirements only apply to the observing angles of 15 to 86.5 degrees. The total elevation motion range must be larger than the pointing range to accommodate the limit switches and hard stops.

2.1.2 POINTING RANGE IN AZIMUTH

Specification: The Telescope Mount Assembly shall be capable of pointing in azimuth over the angular range of ±270 degrees. The azimuth angle of 0 degrees shall be located at the north direction. This range shall be reachable without overriding any limit switches or the fixed software limits. It may require overriding the adjustable software limits but not the fixed software limits.

Discussion: The azimuth cable wrap zero angle will also be located at the north direction. The total azimuth motion range must be larger than the pointing range to accommodate the limit switches and hard stops.

2.1.3 ABSOLUTE POINTING ACCURACY

Discussion: The absolute pointing accuracy of the telescope on the sky will be obtained after installation of the three major optical systems with their hexapods, and after applying the TCS mount model corrections. Consequently, there is no specific absolute pointing accuracy requirement of the Telescope Mount Assembly.

2.1.4 RELATIVE POINTING ACCURACY

Specification: The TMA shall achieve a pointing accuracy of 50 arcsec RMS relative to its own reference system for any motion within the pointing range. The origin of the reference system shall be chosen by the Contractor. The TMA optical axis defined in 3.2.2 shall be used as the pointing axis. The relative pointing accuracy shall be demonstrated using independently known references.

Discussion: LSST PO will produce a mount correction model to enable the telescope to point with an absolute accuracy of 2 arc seconds RMS. The correction for gravitational distortion is estimated at ~50 arc seconds RMS. This requirement ensures the accuracy of the TMA does not significantly burden the mount model. Consequently there is no need for the Contractor to apply additional mount model corrections.

2.1.5 POINTING REPEATABILITY

Specification: The Telescope Mount Assembly shall achieve a pointing repeatability within the value of 1arcsec RMS for any motion within the pointing range. The pointing repeatability shall be demonstrated using multiple different azimuth and elevation motion paths to include the effects of hysteresis. These demonstrations shall be determined in collaboration with the LSST PO.

2.1.6 RELATIVE OFFSET POINTING BETWEEN ADJACENT FIELDS

Specification: The Telescope Mount Assembly shall be capable of a 3.5 degree relative offset pointing on the sky within the pointing range with an accuracy equal or better than 0.2 arcsec RMS. Multiple references 3.5 degrees of each other shall be used to demonstrate this requirement.

2.2 SLEWING REQUIREMENTS

Specification: The Telescope Mount Assembly shall meet its slew and settling time requirements without exceeding the maximum jerk, accelerations and velocity requirements defined here. It must also be able to meet the minimum jerk, accelerations and velocity defined here.

Discussion: The total slew, settle and active optics convergence budget is 5.0 seconds. A 1.0 Second "buffer" has been allocated after the TMA has settled for the active optics to settle, leaving 4.0 seconds available for the TMA to slew and settle.

2.2.1 SLEW AND SETTLE TIME FOR AN OFFSET OF 3.5 DEGREES

Specification: For a 3.5 degree field of view change on the sky and for any zenith angle 30 degrees or larger, the telescope mount assembly shall slew and settle in less than 4.0 seconds. Settled is met when all the pointing and tracking requirements are met. This shall be measured during the 1.0 second buffer following the 4.0 second slew and settle allocation. The Contractor shall determine the motion profile utilized to verify this specification, however, the jerk, acceleration and velocities used must be consistent with the maximum and minimum slew rate limits. These slewing limits inherently limit the slewing time to no more than 3.0 seconds.

Discussion: The actual slew and settle motion profile used in operation will be determined by the LSST PO and implemented through the TCS. The Contractor is only required to provide the motion profile used for performance verification and to produce a Mount Control System that is compatible with the telescope's TCS. For azimuth motions, when the zenith angle is smaller than 30 degrees, the telescope mount will not be able to meet the 4 second slew and settling time allocation. Some deficit will result. For azimuth motions, when the zenith angle is larger than 30 degrees, the slew of the telescope mount will be less than the 4 second requirement. Since the mean viewing zenith angle is near 30 degrees, if the telescope meets the slew and settle specifications at this angle, it will approximately meet the motion specifications on average, see document 14411 for more details.

2.2.2 SLEWING RATE LIMITS

Discussion: The TMA must meet the slewing rates requirements in sections 2.2.2.1 and 2.2.2.2.

2.2.2.1 MAXIMUM SLEWING RATE

Specification: The slew and settling time requirements shall be met without exceeding the maximum limits, if these values are exceeded the telescope mount assembly shall be automatically stopped per the requirements of section 3.7.7:

- Azimuth velocity: ±10.5 °/s
- Azimuth acceleration: ±10.5 $°/s^2$
- Azimuth jerk: ±42.0 $°/s^3$
- Elevation velocity: ±5.25 °/s
- Elevation acceleration: ±5.25 $°/s^2$
- Elevation jerk: ±21.0 $°/s^3$

2.2.2.2 MINIMUM SLEWING RATE

Specification: Meeting the cadence requirements for other than the baseline 3.5 degree slew requires the TMA be capable of meeting these minimum limits:

- Azimuth velocity: ±7 .0 °/s
- Azimuth acceleration: ±7.0 $°/s^2$
- Azimuth jerk: ±28.0 $°/s^2$
- Elevation velocity: ±3.5 °/s
- Elevation acceleration: ±3.5 $°/s^2$
- Elevation jerk: ±14.0 $°/s^3$

2.2.3 MOTION PROFILE

Specification: The TMA shall move directly and smoothly from its current position to its new position. The motion profile shall be a jerk-minimizing trajectory. The jerk shall be limited to values consistent with the slew and settling time requirement values.

2.2.4 DUTY CYCLE

Specification: The TMA shall be designed to be able to operate every night for the design life of the TMA. A typical TMA nightly survey operation consists of approximately 32 seconds of tracking followed by a 3.5 degree slew and settle over 4 seconds. On average, the TMA will operate 12 hours a night, every night. In general, the duty cycle during daytime maintenance will be negligible. However, any support equipment, such as the hydrostatic bearing pumps (if utilized), that are required to be operational during servicing shall be designed to operate continuously.

2.3 TRACKING REQUIREMENTS

2.3.1 TRACKING RANGE IN AZIMUTH

Specification: The Telescope Mount Assembly shall be able to track sidereal objects in azimuth over the angular range of ±270 degrees.

2.3.2 TRACKING RANGE IN ELEVATION

Specification: The Telescope Mount Assembly shall be able to track sidereal objects in elevation over the elevation angular range of 15 degrees to 86.5 degrees.

2.3.3 TRACKING VELOCITY RANGE

Specification: The Telescope Mount Assembly shall be able to track about the elevation axis at a velocity of between +13.0 and -13.0 arc sec/second. The TMA shall be able to track about the azimuth axis at a velocity of between +220 and -220 arc sec/second.

Discussion: The significantly greater velocity range in azimuth results from the Alt Az mount configuration and spherical geometry. For high elevation angles a much larger azimuth motion is required than the actual on the sky motion.

2.3.4 TRACKING DRIFT

Specification: The Telescope Mount Assembly tracking drift shall be less than 1arcsec RMS, unguided over a 10-minute interval within the tracking range. "Unguided" means without the aid of a guide star or other optical pointing aids, but with all feedback encoders and drive system controls operational.

2.3.5 TRACKING JITTER

Specification: The tracking jitter shall be determined over the tracking velocity ranges in 2.3.3. This requirement shall be met over 15 seconds which is the baseline exposure time and in the absence of external disturbances such as wind.

Discussion: Meeting this requirement necessitates designing the TMA to reduce periodic tracking jitter from the tape encoders. This can be accomplished by eliminating the low frequency (below the position loop control cut-off frequency) error signal from the tape encoders.

2.3.5.1 TRACKING JITTER ABOUT ELEVATION AXIS

Specification: About the elevation axis, the tracking jitter shall be less than 0.01 arcsec RMS.

2.3.5.2 TRACKING JITTER ABOUT AZIMUTH AXIS

Specification: About the azimuth axis, the tracking jitter shall be less than 0.01 arcsec RMS, for tracking velocities less than 25 arcsec / second. For larger tracking velocities, the tracking jitter shall be less than 0.01 + 0.00075 * (Az tracking velocity - 25.0) arcsec RMS.

3 TELESCOPE MOUNT ASSEMBLY DESIGN REQUIREMENTS

3.1 GENERAL REQUIREMENTS

Meeting the performance and functionality specifications will require fundamental elegance of design, exhibiting high efficiency usage of materials and components.

3.1.1 ALT-AZ TMA DESIGN

Specification: The telescope mount shall be an altitude over azimuth (alt-az) design. The Contractor shall use the coordinate systems defined in LTS-136.

3.1.2 TOTAL MOVING MASS REQUIREMENT

Specification: The total moving mass of the Telescope Mount Assembly (TMA) shall not exceed 290 metric tons. The TMA moving mass includes all items in section 1.2.1 "Included in scope," except those listed under "Telescope components fixed to pier," "Telescope component in facility" or "Maintenance and testing equipment." It does not include the three payloads. All items listed under 1.2.2 "Not included in scope" are not included in this mass budget.

Discussion: The Telescope Mount Assembly mass budget specifically includes:

- All structures
- All bolted joints
- All cabling / piping / ducting
- All drives / motors / brakes / locking pins / limit switches
- The damping system
- All flooring
- All safety rails
- Both deployable camera access platforms
- M1M3 mirror cover
- All light baffling except M2 baffle
- Top End Spiders
- All components of the bearings that move with the TMA
- All cable drapes / wraps
- Capacitor banks
- Paint

3.1.3 TOTAL FIXED MASS REQUIREMENT

Specification: The total fixed mass of the TMA shall not exceed 75 metric tons. The TMA fixed mass includes all items in section 1.2.1 "Included in scope" and listed under "Telescope components fixed to pier." All items listed under 1.2.2 "Not included in scope" are not included in this mass budget.

Mass may be freely redistributed from the moving mass to the fixed mass, but not vice versa.

Discussion: The fixed mass includes all stationary components of the azimuth drive and bearing system. This specifically includes the fixed drive gear, azimuth bearing track and the grout required to mount this track. The masses of remote equipment such as oil pumps, electrical cabinets, etc. which are not attached to the telescope or its pier are not included in this mass budget.

3.1.4 INTERFACE WITH PIER

Specification: The location of all stationary components shall be compatible with the Telescope to Pier interface drawing LTS-77.

3.1.5 MAXIMUM ALLOWABLE ENVELOPE

Specification: The maximum swept volume in both, elevation and azimuth, of the mount structure, including the payloads and ancillary equipment, shall not exceed those dimensions specified in the Telescope Mount to Dome Interface Drawing LTS-105.

3.1.6 ENVIRONMENTAL REQUIREMENTS

Specification: The Telescope Mount Assembly shall be designed to function properly under the environmental conditions defined in LTS-54.

Discussion: There are two separate conditions that the TMA shall be designed in compliance with:

- The Site Survival Conditions which represent the extreme environmental conditions that the TMA must be able to withstand. The TMA will not be required to operate in these Site Survival Conditions.

- The Site Operational Conditions which include the nominal and marginal conditions representing the range of environmental conditions expected during nighttime hours when the LSST Observatory will be in use. The TMA and all of its subsystems shall remain fully operational throughout the range of conditions indicated, and shall meet all technical specifications and requirements specified in this document.

3.1.7 RELIABILITY AND LIFETIME REQUIREMENTS

Specification: The TMA shall have a design lifetime of 30 years.

Discussion: The remote nature of the site puts a premium on having robust systems that are highly reliable, and that can be easily and quickly repaired and maintained. The design life is sufficient to support the initial 10 year survey, a second survey and the associated integration, maintenance, calibration and testing.

3.1.7.1 FATIGUE AND WEAR

Specification: Unless otherwise approved by the LSST PO, all assemblies, subassemblies, components, parts, and mechanical systems shall be designed to exceed the TMA lifetime. Contractor shall identify any and all items not likely to exceed the design lifetime, and their application and use shall be subject to approval by LSST PO.

Friction and wear components not expected to provide reliable performance over the design lifetime shall be easily replaceable, and the appropriate number of spares supplied by the Contractor.

3.1.8 COMMONALITY OF DESIGN

Specification: The Contractor shall utilize identical equipment and designs throughout the TMA. The purpose of doing this is to lower costs associated with design effort, consumables and maintenance.

3.1.9 COMMON COMPONENTS

Specification: To the extent possible, components and subsystems that are common off the shelf (COTS) or previously designed, built, and tested by Contractor or by the LSST PO shall be used to minimize cost and to optimize the ability to maintain and procure consumable parts.

3.1.10 OBSTRUCTION TO VENTILATION

Specification: Obstructions to natural air flow (wind) perpendicular to the optical axis and specifically across the M1M3, M2 and camera optical surfaces shall be minimized. This requires that if the LSST PO demonstrates that a design feature produces unnecessary wind obstruction, that the design be altered accordingly by the Contractor.

Discussion: Providing natural air flow over the optical surfaces and allowing for the rapid thermal equalization of the TMA with the ambient air temperature is essential for operation of the LSST telescope. Examples of design features to increase air flow are cutouts in the web of the top end ring/light baffle and cut outs in the elevation assembly drive wheels.

3.1.11 VENTING REQUIREMENTS

Specification: All assemblies, subassemblies, parts and components of the TMA shall be vented as needed so that changes in atmospheric pressure when transporting from sea level to the observatory site shall not cause damage or failure.

3.1.12 DE-RATING REQUIREMENTS

Specification: Any equipment designed to operate at normal atmospheric air pressures and incorporating air cooling shall be de-rated for the reduced air density at the Site. The derating shall be by the manufacturer's recommendation. If no manufacturer's recommendation is available, the derating shall be proportional to the air density which requires a derating to 74% of its normal value.

3.1.13 LIGHT SOURCES AVOIDANCE

Specification: No equipment shall be allowed anywhere on the TMA that emits optical or near infrared (300 nm to 1,500 nm) light. Any unavoidable sources shall incorporate appropriate metallic shielding. LEDs will only be allowed where they are an integral part of a necessary piece of equipment (as such any light emitted shall be contained).

3.1.14 COMPONENT LABELING

Specification: All components shall be clearly and permanently labeled with a unique name. This is in addition to transportation labeling requirements provided in section 5.2

Discussion: If a component is packaged for shipping its permanent label may be inaccessible.

3.2 OPTICAL REQUIREMENTS

3.2.1 OPTICAL LOCATIONS

Specification: The three optical payloads (M1M3 mirror cell assembly, M2 mirror cell assembly and camera), as well as the telescope mount light baffles, shall be positioned according to the Optical Assemblies and Light Baffles Locations drawing (LTS-213).

Discussion: Since it is attached to the M2 mirror cell and not the TMA, the location of the M2 baffle is located by properly positioning the M2 mirror cell assembly. Both the M2 mirror cell assembly and the camera are positioned by hexapods to facilitate the alignment and counteract the telescope mount flexure. The tolerance on the positioning of these items is determined by the motion budget of these hexapods.

3.2.2 OPTICAL AXIS DEFINITION

Specification: The optical axis shall be defined relative to the interface between the M1M3 mirror cell piers and the M1M3 mirror cell assembly, ICD-130.

Discussion**:** The clear aperture, light baffles and stray light vanes must all be positioned relative to the M1M3 optical surface/optical axis which is located relative to these interfaces. In operation the optical axis is defined by the orientation of the M1M3 mirror, consequently during TMA testing the optical axis is defined by the interface to the M1M3 mirror cell interface.

3.2.3 FIELD OF VIEW

Specification: The telescope mount assembly shall provide an unvignetted field of view from the sky to the primary mirror of at least 3.80 degrees (±1.90 degrees) as shown in the Optical Assemblies and Light Baffles Locations drawing (LTS-213).

Discussion: The telescope is required to have an unvignetted field of view of at least 3.50 degrees (±1.75 degrees). The ±1.9 degrees clear field of view requirement applies to both the inner and outer diameter of the optical path.

3.2.4 CLEAR OPTICAL PATH

Specification: The Telescope Mount Assembly shall provide a clear optical path aperture diameter consistent with the Optical Assemblies and Light Baffles Locations drawing (LTS-213) for all positions on the sky within the tracking range (excluding the spiders used to hold the Telescope Mount Assembly top end).

3.2.5 CLEAR APERTURE OBSCURATION

Specification: The on-axis clear aperture obscuration shall not exceed 2.5 percent. The spiders can only obscure the primary mirror. The off-axis clear aperture obscuration shall not exceed 3.5 percent.

Discussion: On-axis obscuration is the ratio of the area of the primary mirror (8.360-meter diameter) obscured by the spiders in the optical axis direction to the optical area of the primary mirror. Off-axis obscuration is the area obscured by the spiders at the limiting +/-1.75 degree field of view.

3.2.6 STRAY LIGHT ATTENUATION

Specification: The Telescope Mount Assembly shall take all actions necessary to reduce the stray light. This requirement shall be met by coating all light baffles, light vanes and potential stray light reflecting surfaces with a low reflectivity (low-emissivity) coating agreed upon by the Contractor and LSST. The exception is the top most surface of the top most baffle, which faces the sky, which shall be coated with a highly reflective (high-emissivity) coating approved by LSST.

Discussion: The Contractor baffle system will be reviewed by LSST to confirm performance.

3.2.6.1 STRAY LIGHT BAFFLES

Specification: The Telescope Mount Assembly shall include the four light baffles as specified in the Optical Assemblies and Light Baffles Locations drawing (LTS-213). This specifically requires that the inner top edge of the center section of the elevation assembly be designed to function as one of the four light baffles.

3.2.6.2 STRAY LIGHT VANES

Specification: The Telescope Mount Assembly shall include vanes on all vertical surfaces (when zenith pointing) that are adjacent to the light path, and face the light path, or produce a potential for reflecting light into the camera. This specifically requires that the inner diameter of the center section of the elevation assembly be designed with vanes. Unless approved by the LSST PO, the spacing between the vanes shall be less than the length of the vanes in the radial distance.

Discussion: Although matt black paint does significantly reduce glancing reflection for low incident angles it is inadequate for LSST stray light attenuation. Consequently, stay light vanes are required. The exact locations shall be agreed upon by the Contractor and the LSST PO.

3.2.7 AXES ALIGNMENT

3.2.7.1 PARALLELISM BETWEEN GRAVITATIONAL VECTOR AND AZIMUTH AXIS

Specification: The azimuth axis shall remain parallel to the gravitational vector to within 24 arc seconds over the entire azimuth axis operational range.

Discussion: This requirement principally affects the installation tolerances of the azimuth bearing track. This value was achieved by the Gemini telescope and was demonstrated to be adequate.

3.2.7.2 PERPENDICULARITY BETWEEN ELEVATION AND AZIMUTH AXES

Specification: The elevation and azimuth axes shall remain perpendicular to within 20 arc seconds over the entire operational range of both axes.

Discussion: This limits the cross coupling of the axes to acceptable levels.

3.2.7.3 PERPENDICULARITY BETWEEN ELEVATION AND OPTICAL AXES

Specification: The elevation and optical axes shall be perpendicular to within 60 arc seconds. This requirement is in addition to the tolerances provided on the related interface drawing.

Discussion: This requirement constrains the positioning tolerances requirements of the M1M3 piers to M1M3 mirror cell assembly interfaces.

3.3 STRUCTURAL REQUIREMENTS

3.3.1 BASIC REQUIREMENTS

3.3.1.1 STRUCTURAL INTERFACE REPEATABILITY

Specification: Interfaces shall utilize alignment pins or equivalent to provide repeatability of at least +/-1mm in all directions. Two pins shall be used to locate each interface. To prevent binding, one pin shall mate with a round hole and the other with an oblong hole. Alternative methods must be approved by the LSST PO.

Discussion: The mount structure needs accurate, repeatable interfaces. Since they will be repeatedly reinstalled, the repeatability of the optical payloads is of extra importance and elaborated on elsewhere.

3.3.1.2 STRUCTURAL HYSTERESIS

Specification: Connections shall be designed and analyzed to prevent slippage and local yielding during operations. Multiple load paths shall not be used unless approved by the LSST PO.

Discussion: The mount structure needs to have minimal non-repeatable position errors and minimal structural hysteresis. Some multiple load paths are unavoidable. All multiple load paths utilized in the baseline design, document 14411, can be assumed to be approved. Some local yielding of joints during assembly is unavoidable and is not prohibited by this requirement.

3.3.2 PAYLOADS

Specification: The telescope mount assembly shall meet all its requirements while supporting the three principal payload items M1M3 Mirror Cell Assembly, Secondary Mirror Assembly (with hexapod and baffle) and Camera Assembly (with hexapod and rotator). The ICDs for these items are provided through LTS-221. The masses, CG locations and moments of inertia are provided in LTS-213. The TMA shall meet these requirements with either the actual payloads or surrogate masses representing them. It shall provide mounting surfaces and interfaces for these payloads.

These three payloads are not considered components of the Telescope Mount Assembly, the masses provided below are for reference only:

- M1M3 Mirror Cell Assembly 53.0 Metric Tons
- Secondary Mirror Assembly + hexapod + baffle 5.5 Metric Tons
- Camera + hexapod + rotator 4.0 Metric Tons

3.3.3 NATURAL FREQUENCIES

Specification: The TMA shall be designed to meet the natural frequency requirements of either section 3.3.3.1 or 3.3.3.2. For either case, the resonance frequencies shall be demonstrated analytically by Contractor via Finite Element Analysis (FEA). This FEA shall include valid bearing and drive stiffness values. The natural frequencies of the mount structure shall be determined with the payloads, ancillary equipment and all masses supported by the telescope mount assembly included. Output from the structural resonance frequency FEA shall include all natural frequencies under 20 Hz.

The M2 mirror cell assembly payload and camera payload shall be modeled as lumped masses representing the payload masses, per LTS-213, and supported by hexapods. In the FEA model, the stiffness of the camera and M2 hexapod actuators shall be 100,000 N/mm (570,000 lb/in).

Although these requirements must be met for all azimuth and elevation angles they must only be demonstrated at zenith pointing and horizon pointing. They must be met during telescope operations but not during maintenance or when the telescope is stowed.

Discussion: The TMA structure design must be optimized for high specific stiffness to meet the structural resonance requirements and the performance during slewing, settling, pointing, and tracking operations. It will likely be easier to demonstrate meeting these natural frequency requirements incorporating the LSST supplied FEA models of the M1M3 mirror cell assembly, mountain top and pier.

3.3.3.1 NATURAL FREQUENCIES INFINITE SUPPORT

Specification: The telescope mount shall be analyzed such that when supported on a theoretical infinitely rigid pier/earth and supporting an infinitely rigid M1M3 mirror cell assembly, the three principal natural frequencies are at least 8.4 Hz and both locked rotor frequencies are at least 9.2 Hz. All other secondary natural frequencies shall be at least 12.3 Hz. All three payloads shall be modeled as lumped masses according to LTS-213.

Discussion: This will ensure adequate dynamic characteristics of the telescope when the flexibility of the payloads, pier and mountain top are included.

3.3.3.2 NATURAL FREQUENCIES WITH LSST SUPPLIED FEA MODELS

Specification: The TMA shall be analyzed with the LSST PO supplied FEA models of the M1M3 mirror cell assembly, telescope pier and mountain top. For this case the three principal natural frequencies shall be at least 7.4 Hz and both locked rotor frequencies are at least 8.0 Hz. All other secondary natural frequencies shall be at least 11.0 Hz. For this case the M2 mirror cell assembly payload and camera payload shall be modeled as lumped masses representing the payload masses, per LTS-213.

3.3.4 VARIATION IN NATURAL FREQUENCIES WITH AZIMUTH ANGLE

Specification: There shall be no inherent design features in the azimuth assembly that produce variation in natural frequency with azimuth angle.

Discussion: Meeting this requirement mandates that drives, etc. be mounted on the azimuth assembly. The telescope mount assembly must exhibit negligible variation in natural frequency or vibration mode with azimuth angle. Some variation in natural frequency with elevation angle is unavoidable and not prohibited by this requirement.

3.3.5 VARIATION IN NATURAL FREQUENCIES WITH ELEVATION ANGLE

Specification: For all natural frequencies under 20 Hz, the variation in natural frequencies with elevation angle shall not change by more than +/-4% between horizon pointing and zenith pointing.

The structural resonance frequencies shall be demonstrated by FEA for the following three cases:

- Elevation assembly at 90 degree elevation angle (zenith pointing);
- Elevation assembly at 45 degree elevation angle;
- Elevation assembly at 0 degree elevation (horizon pointing).

3.3.6 VIBRATION COUPLING

Specification: The telescope mount assembly shall be designed to minimize coupling between vibration modes. This requires that the low frequency structural vibration ($f < 17$ Hz) modes that can sympathetically combine (are not orthogonal) are staggered in frequency. This requires that whenever practical the higher of two modes that can be sympathetically combined be 50% higher than the lower mode. This requirement shall be verified by FEA.

Discussion: When vibration modes combine, the total amplification is determined by multiplying the two dynamic amplifications. Consequently, a very large increase in response result. If the higher natural frequency is at least 50% higher, then this product cannot be significantly greater than the larger of the two amplitudes.

3.3.7 STATIC DEFLECTION

Discussion: The three major optical systems (M1M3 mirror cell, Secondary mirror cell and Camera Assembly) incorporate hexapods to properly position the optical assemblies. There is a direct correlation between natural frequency and static deflections. If the telescope mount assembly meets the natural frequency requirements, the static deflections will be within the range of the hexapods. Consequently, there is no separate static deflection requirement.

3.3.8 WIND LOADING

Specification: The TMA must meet its operational requirements with the operational wind speeds described in the LSST Summit Environmental Conditions Requirements (LTS-54). This included motions about the azimuth and elevation axis. The TMA must meet its functional requirements, such as closing the M1M3 mirror cover, up to the marginal conditions wind speed. The wind speeds provided in LTS-54 are for the exterior of the enclosure. The wind speeds interior to the enclosure and impinging on the TMA shall be assumed to be half these values.

Discussion: As long as the telescope mount assembly meets its natural frequency requirements, it will be assumed to meet its performance requirements under wind loading. LSST PO will provide the analysis to verify acceptability of the TMA's wind response.

3.3.9 VIBRATION EXCITATION

Discussion: Components such as the mirror cover or the balancing system that will not be operated during normal telescope operations do not need to comply to this section.

3.3.9.1 DYNAMICAL BALANCING

Specification: All rotating equipment shall be dynamically balanced according to a standard specification, which must be approved by the LSST PO.

3.3.9.2 NATURAL FREQUENCY AVOIDANCE

Specification: TMA components shall not operate within the 6 to 25 Hz frequency range that can excite the telescope's prominent natural frequencies.

3.3.9.3 VIBRATION ISOLATION

Specification: All components that have the potential to produce vibrations and that do not require stiff mounting for proper performance shall be vibration isolated. Other than for the top end assembly, small fans used to ventilate enclosed spaces need not comply with this requirement when approved by the LSST PO. Fans located on the top end assembly must also be both dynamically balanced and vibration isolated.

Discussion: The Top End Assembly (TEA) thermal control system will require a large number of fans which constitute the majority of the TEA's vibration sources.

3.3.10 SEISMIC REQUIREMENTS

The seismic peak spectral accelerations (PSA) summarized in Document-13228 shall be used as input for the seismic requirements. Alternatively, the power spectral density (PSD) versions of these accelerations as provided in Document-13381 may be utilized.

Discussion: All aspects of the seismic requirements were adopted from the various Chilean seismic codes, which are provided in Document-13381. The PSAs provided in Document-13228 were developed from these Chilean seismic codes. These codes recommend utilizing a return period of 10 times the design life of an assembly for the equivalent of a survival level event. Consequently, since the telescope has a 30 year design life it is required to withstand a 300 year event without catastrophic failure.

These codes also recommend not combining the effects of the orthogonal accelerations (the two horizontal directions and the vertical direction), that the vertical acceleration be assumed to be 2/3 of the horizontal accelerations, and that time domain analysis not be utilized.

3.3.10.1 SEISMIC SURVIVAL EVENT

Specification: The Telescope Mount Assembly shall be designed to survive a 300 year return seismic event without catastrophic failure. The 300 year return seismic event, which has a 10% chance of occurring over the 30 year life of the telescope, is referred to as a survival level event. Catastrophic failure shall be defined as fracture or rupture that allows any element to separate or fall, or produces the possibility of personnel injury.

Discussion: For the survival level event (300 year return period) the horizontal peak ground acceleration (PGA) is 0.45 G and the maximum single degree resonator acceleration (SDR) is 1.21 G. The vertical accelerations were determined using the common assumption that the vertical accelerations are 2/3 the horizontal accelerations. Since the telescope's natural frequencies are near the peak seismic accelerations, the telescope will likely experience the maximum SDR accelerations. As a result of the interaction of the natural frequencies, some components, especially on the top end, will experience even more severe accelerations.

3.3.10.2 SEISMIC RECOVERABLE EVENT

Specification: The Telescope Mount Assembly shall be designed to survive a 150 year return seismic event without significant damage. The 150 year return seismic event, which has a 20% chance of occurring over the 30 year life of the telescope, is referred to as a recoverable level event. Permanent damage is any yielding of primary structure, damage that exceeds 2% of the TMA total cost or damage that requires more than 6 months to repair.

Discussion: For the recoverable level event (150 year return period) the horizontal PGA is 0.34 G and the maximum SDR acceleration is 0.92 G. The vertical accelerations were determined using the common assumption that the vertical accelerations are 2/3 the horizontal accelerations. Since the telescope's natural frequencies are near the peak seismic accelerations the telescope will likely experience the maximum SDR accelerations. As a result of the interaction of the natural frequencies, some components, especially on the top end, will experience even more severe accelerations.

3.3.10.3 SEISMIC OPERABLE EVENT

Specification: The Telescope Mount Assembly shall be designed to survive a 30 year return seismic event without any damage. The 30 year return seismic event will likely occur during the life of the telescope and is referred to as an operable level event.

Discussion: For the operable level event (30 year return period) the horizontal PGA is 0.25 G and the maximum SDR acceleration is 0.68 G. The vertical accelerations were determined using the common assumption that the vertical accelerations are 2/3 the horizontal accelerations. Since the telescope's natural frequencies are near the peak seismic accelerations, the telescope will likely experience the maximum SDR accelerations. As a result of the interaction of the natural frequencies some components, especially on the top end, will experience even more severe accelerations.

3.3.10.4 SEISMIC MAINTENANCE EVENT

Specification: All temporary configurations and maintenance equipment shall be designed to withstand a seismic acceleration of 0.20 G in any direction without significant damage. This requirement shall not apply to very short term configurations that utilize a minimal amount of time (< 1 hr) such as the time used to remove an item from the telescope and place it on a cart.

3.3.10.5 TMA SEISMIC ANALYSIS

Discussion: Per the SOW, the TMA shall be analyzed using dynamic FEA methods that accurately determine the propagation of vibrations throughout the telescope; for example see "Seismic Analysis of the LSST Telescope," Document-13381. At a minimum, the TMA shall be analyzed in both the horizon pointing orientation and the zenith pointing orientation. For both these orientations, seismic accelerations shall be applied in two orthogonal horizontal directions of which one is parallel to the elevation axis. Seismic acceleration shall also be applied in the vertical direction. These three accelerations shall be considered independent and their effects need not be combined with each other, however, they must be combined with the gravitational effects. Safety factors congruent with the analysis method shall be included in the analysis. Commonly used 3σ PSD vibration analysis methods are inherently conservative and further safety factors need not be applied. These methods typically overestimate the maximum acceleration by 50%.

3.3.10.6 TOP END COMBINED SEISMIC ACCELERATIONS

Specification: In addition to the seismic requirements above, the TMA shall be able to withstand the combined seismic and gravitational accelerations determined in Document-13228 for the M2 mirror cell assembly and camera. The analysis method used to determine these accelerations is inherently conservative (SF = 1.5) and additional safety factors do not need to be applied.

Discussion: The accelerations for the M2 mirror cell assembly and camera provided in Document-13228 were determined for the vibration amplifications resulting from TMA natural frequencies and top end assembly natural frequencies required in this document. As a result of variations between the baseline TMA design and the Contractor's TMA design, and variation between the LSST analysis method and the Contractor analysis method, some variations between the Contractor determined accelerations and LSST determined accelerations are inevitable. Since the M2 mirror cell assembly and camera were built to the LSST values, the TMA should be able to withstand both these values and the Contractor determined values.

3.3.11 STRUCTURAL DESIGN

3.3.11.1 STRUCTURAL STRESS

Specification: Stresses in all members shall be maintained within safe working values for all possible combinations of fabrication, erection, operation, and survival conditions. Dead loads, live loads, temperature effects, wind effects, and seismic loads shall be combined per an approved standard when determining the critical cases for maximum stresses, buckling loads and deflections. Unless otherwise stated in this document or other requirements documents, the safe working load shall be the calculated failure load divided by the factors of safety in section 3.3.11.2 and 3.3.11.3. Material properties from a common industrial reference (ASTM, ASM, etc) and approved by the LSST PO shall be utilized.

Discussion: The factors of safety required below are minimum values and the Contractor is free to utilize greater values when warranted.

3.3.11.2 STRUCTURAL YEILD FACTOR OF SAFETY

Specification: Unless specified otherwise by the LSST PO, a minimum Factor of Safety of 1.5 in yield under any combination of operational and environmental loading shall be used during the course of the Work.

Discussion: The commonly used definition of 0.2% permanent offset for yield is inadequate for telescope applications. Permanent strains below 0.2% produce hysteresis which interferes with the telescope's repeatability. By imposing the minimum factor of safety in yield of 1.5 negligible permanent strain is ensured.

3.3.11.3 STRUCTURAL ULTIMATE AND BUCKLING FACTOR OF SAFETY

Specification: Unless specified otherwise by LSST PO, a minimum Factor of Safety of 2.0 for ultimate failure and buckling under any combination of operational and environmental loading shall be used during the course of the Work.

3.3.12 STRUCTURAL JOINTS

3.3.12.1 JOINT DESIGNS

Specification: The Contractor shall design all bolted and dowelled connections to preclude the possibility of joint movement, slippage, local yielding and/or hysteresis under operational loading. The design of all bolted connections and joints is subject to approval by the LSST PO.

Discussion: The operational success of the TMA and all subassemblies bolted to it is strongly dependent on structural deflections and strains being both minimal and highly repeatable.

3.3.13 FASTENERS STANDARDS

Specification: Except when approved by the LSST PO, all bolts, nuts, screws, and other fasteners shall be medium strength, coarse thread (class 8.8 or grade 5) and conform to ASTM, ASME/ANSI, DIN, ISO or SAE standards. Only new bolts, washers, nuts and other fastening hardware shall be used. All fastening hardware shall have a zinc, cadmium, or galvanized corrosion resistant coating except as specified by LSST PO in stray light sensitive locations which will have a black coating. All bolts shall be properly lubricated at the time of installation. Dry, rusty, or otherwise contaminated fastening hardware will not be allowed.

3.4 ELEVATION CENTER SECTION

The Elevation Center Section is the main structural component of the elevation assembly. It includes the elevation assembly bearing axis. All the elevation assembly components and the payloads are supported directly or indirectly by the center section. The center section also supports the M1M3 mirror surface access platform for cleaning and inspection of the mirror which will be supplied by the LSST PO.

3.4.1 M1M3 MIRROR CELL ASSEMBLY INTERFACE

Specification: The M1M3 mirror cell assembly shall interface to the central section assembly through four intermediate structures (M1M3 mirror cell piers) and conform with the TMA to M1M3 Mirror Cell Interface drawing LTS-130. These intermediate structures shall be readily detachable from both the elevation center section and the M1M3 mirror cell assembly.

Discussion: When removing the M1M3 mirror cell assembly, two of the four piers remain attached to the center section and the other two must be removed with the M1M3 mirror cell assembly.

3.4.2 CELL PIERS MOUNTING REPEATABILITY

Specification: The mounting repeatability of the cell piers to the central section assembly at zenith pointing shall not exceed +/-1mm in any direction, or tilts of +/- 5.7e-3 degrees (1e-4 rads).

Discussion: This repeatability requirement ensures that the M1M3 mirror cell assembly will stay within its position tolerance.

3.5 TOP END ASSEMBLY

The Top End Assembly (TEA) is comprised of the two circular light baffles forming the top end ring, the central assembly and the spiders that connect the central assembly to the telescope's structure.

3.5.1 SPIDERS

3.5.1.1 SPIDER DESIGN

Specification: The spider configuration shall meet the natural frequency requirements in section 3.3.3 and the obstruction requirements in 3.2.4.

3.5.1.2 HOLLOW SPIDER

Specification: The spiders shall be hollow to allow for routing of the many hoses and cables required to operate the camera, M2 cell assembly, hexapods, rotator, camera cable wrap and thermal control system as specified in LTS-217. The spiders must provide a minimum useable combined internal cross section of 1200 cm^2. The height and width of the hollow sections must be adequate to pass all the hoses and cables through. At a minimum both the height and width shall be at least 34 mm. These spiders must also be open and accessible at each end for installing cables and utilities.

3.5.2 CENTRAL ASSEMBLY

The central assembly is composed of the camera, its hexapod and rotator, the M2 mirror cell assembly, its hexapod and baffle, the camera cable wrap, a thermal control system and the associated structure.

The camera, hexapods, camera rotator and M2 mirror cell assembly and M2 baffle are considered TMA payloads and will be supplied by LSST PO. The thermal control system, camera cable wrap and associated structure are considered components of the TMA and shall be provided by the Contractor. The central assembly also contains 6 electrical cabinets that are considered components of the TMA

As a result of the competing requirements between performance, on telescope accessibility and payload removal, significant interaction will be required between the TMA Contractor and LSST PO personnel in regard to the design of the central assembly. As elaborated in the statement of work, these interactions and the resulting accommodations shall be considered part of the scope of the TMA contract.

3.5.2.1 CENTRAL ASSEMBLY CONFIGURATION

Specification: The central structure of the central assembly shall be constructed of two separate subassemblies: the spider spindle and the integrating structure. The spiders shall connect to a permanently installed subassembly referred to as a spider spindle. The spider spindle also functions as the base of the secondary mirror hexapod. A separate substructure referred to as the integrating structure shall be bolted to the spider spindle. The purpose of the integrating structure is to allow the assembly of the camera, camera rotator, camera hexapod, camera cable wrap, thermal control system and relevant electrical cabinets into a single assembly, supported by the integrating structure. This conglomeration, referred to as the camera support assembly, is tested and installed as a single unit.

3.5.2.2 CENTRAL ASSEMBLY - M2 HEXAPOD INSTALLATION POSITIONING

Specification: The spider spindle shall be designed to facilitate the attachment of the M2 hexapod as defined in the interface LTS-181.

Discussion: This interface definition of LTS-181 provides space between the hexapod actuators and the spider spindle to incorporate intermediate blocks. The purpose of these 50 mm thick intermediate blocks is to accommodate variation in length of the final actuator from the baseline actuator, and to provide for static positioning between the M2 mirror cell assembly and the TMA. These blocks provided by the TMA Contractor will be developed in collaboration between the hexapod Contractor, the TMA Contractor and the LSST PO. These items are only expected to be 6 rectangular steel blocks (~165 mm by ~100 mm) requiring minor machining.

3.5.2.3 CENTRAL ASSEMBLY - M2 MIRROR CELL ASSEMBLY AND CAMERA COLLISION

Specification: The central assembly shall be designed to avoid possible collision resulting from motions of the M2 mirror cell assembly and the camera produced by their hexapod motions. The ICDs providing the motion of these hexapods are available through LTS-221.

Discussion: The camera is mounted on a hexapod. The possible range of motion of the camera hexapod moves the back of the utility trunk. If the clearance between the central assembly and the camera is insufficient, there is a risk of a collision. The M2 mirror cell assembly is also mounted on a hexapod and the hexapod motion produces a risk of the steel mirror cell structure colliding with the central structure.

3.5.2.4 CENTRAL ASSEMBLY – INTEGRATING STRUCTURE MOUNTING REPEATABILITY

Specification: The mounting repeatability of the integrating structure to the central assembly shall not exceed +/-1mm in any direction or tilts of +/- 2e-2 degrees (3e-4 rads).

Discussion: This repeatability requirement ensures that the camera support assembly will stay within its position tolerance after remounting on the TMA. The range of the camera hexapod incorporates budget for static positioning uncertainty which includes this +/1 mm.

3.5.2.5 CENTRAL ASSEMBLY THERMAL SYSTEM

Specification: To prevent heated air from escaping the central assembly and degrading the image quality, the interior of the central assembly shall be enclosed and the air conditioned by the Contractor supplied thermal control system according to the thermal control section 3.9.2 of this document.

3.5.2.6 CENTRAL ASSEMBLY PANELS

Specification: To allow ample natural ventilation during servicing, the central assembly enclosed space shall have at least three removable panels. Each panel shall be at least 0.870 M x 1.015 M. Two of the panels shall have their surface normals horizontal and one shall have its surface normal vertical down. These panels shall be configured to facilitate access to the electronics housed inside the central assembly, and access to the camera end of the cable wrap. The panels shall be none metallic and insulting (G10 fiberglass or equivalent). They shall be removable by a single person. The panels shall be marked with language in English and Spanish noting the asphyxiation hazard and requiring removal of all panels before accessing. Moderate seals shall be provided to minimize air escaping, however, fully "air tight" sealing is not practical and some air leakage will be allowed as per section 3.9.2.

Discussion: The interior of the central assembly houses refrigeration lines. Leaks from these refrigeration lines would produce an air quality hazard.

3.5.2.7 CENTRAL ASSEMBLY ELECTRICAL CABINETS

Specification: In addition to the above components, the central assembly shall provide six high quality, durable, metal and accessible, enclosed 19" electrical cabinets (10U tall by 14" deep). Each of these electrical cabinets will support 25 Kg of electronics. Two of these electrical cabinets shall be attached to the integrating structure and removed with the camera support assembly. These two electrical cabinets are intended to support the camera hexapod, camera rotator and their safety interlock controller. The other four electrical cabinets shall be attached to the spider spindle and remain with the spider spindle when the camera support assembly is removed. Two of these four racks are intended to support the M2 hexapod, M2 mirror cell assembly and their safety interlock controller. The last two racks will be used to support minor equipment such as a bore sight camera.

All the racks shall be thermally controlled by the top end thermal control system by circulating air from the inside of the central assembly. Additionally the cabinets on the spider spindle may require thermal insulation.

3.5.3 TOP END NATURAL FREQUENCIES

Specification: The TMA shall be design to meet the natural frequency requirements of either section 3.5.3.1 or 3.5.3.2. For either case, the resonance frequencies shall be demonstrated analytically by Contractor via FEA of the entire telescope (TMA with payloads). The natural frequencies of the top end assembly shall be determined with all the masses supported in it included. Output from the structural resonance frequency FEA shall include all natural frequencies under 20 Hz. The M2 mirror cell assembly payload and camera payload shall be modeled as lumped masses representing the payload masses, per LTS-213, and supported by hexapods. In the FEA model, the stiffness of the camera and M2 hexapod actuators shall be 100,000 N/mm (570,000 lb/in).

3.5.3.1 TOP END NATURAL FREQUENCIES INFINITE SUPPORT

Specification: The minimum natural frequencies of the top end assembly shall be 12.0 Hz as demonstrated through FEA assuming an infinitely stiff pier and M1M3 mirror cell assembly.

3.5.3.2 TOP END NATURAL FREQUENCIES WITH LSST PO SUPPLIED MODELS

Specification: The minimum natural frequencies of the top end assembly shall be 11.0 Hz as demonstrated through FEA using the LSST PO supplied models of the pier and M1M3 mirror cell assembly.

3.6 FLOORING, PLATFORMS, LADDERS AND STAIRS

3.6.1 PERSONNEL ACCESS

Specification: The Contractor shall provide all flooring, stairs, ladders, and other means of personnel access on the telescope meeting OSHA safety standards. The layout and design of all of these items shall be approved by LSST.

Discussion: To receive LSST PO approval, all floors, platforms, ladders and stairs must be easily accessible and provide ergonomically acceptable personnel access to the equipment and components of the TMA. Stationary flooring, stairs and ladders that do not move with the telescope are not considered components of the telescope mount. The fixed flooring and stairs for the telescope pier along with the perimeter walkway surrounding the telescope will be provided by a separate facilities contract. The TMA contract may modify these items as necessary as long as these modifications do not compromise safety or functionality.

3.6.2 LIGHT MANUFACTURING FLOORS

Specification: All flooring, unless specified otherwise, shall meet the most up-to-date international building code for light manufacturing floors.

3.6.3 PERFORATED FLOORS

Specification: To facilitate air circulation, all stairs and elevated platforms shall be perforated.

3.6.4 COATING FOR NON PERFORATED FLOORS

Specification: Floors that are not perforated shall be coated with non-skid surfaces that are durable and suitable for personnel access. The coatings shall comply with a common industrial standard and be approved by LSST PO.

Discussion: It is the preference of the LSST PO that the Contractor use common industrial standards that they have experience with rather than for the LSST PO to dictate specific standards.

3.6.5 PROTECTION

Specification: Railings, toe-kick panels, and other personnel fall protection barriers shall be provided as required. These items shall meet OSHA standards.

3.6.6 AZIMUTH FLOOR

3.6.6.1 AZIMUTH FLOOR COVERAGE

Specification: Flooring shall be provided that covers the entire azimuth assembly. This flooring may utilize a recessed section to accommodate the motion of the M1M3 cell envelope, LTS-216, when the telescope changes elevation angle.

3.6.6.2 AZIMUTH FLOOR VENTING

Specification: Proper operation of the telescope environmental control system requires moderate levels of venting through this floor. These vents must be dispersed near the outer perimeter of the telescope mount assembly and vent into the telescope pier. This venting will be provided in consultation with LSST PO personnel.

3.6.6.3 AZIMUTH FLOOR INTERFACE WITH M1M3 MIRROR CELL CART

Specification: The azimuth floor shall be compatible with the removal/installation procedure for the M1M3 mirror cell and cart as provided in the TMA to Mirror Cell Cart Interface Drawing LTS-169.

3.6.6.4 AZIMUTH FLOOR INTERFACE WITH M1M3 MIRROR CELL CART RAILS

Specification: The azimuth floor shall accommodate the LSST supplied cart rails. The cart rails on the telescope shall match the height of the cart rails in the facility within +/-2 mm vertically and +/-3 mm laterally. The interface definition between the rails and the TMA will be provided by LSST.

3.6.6.5 AZIMUTH FLOOR INTERFACE WITH M1M3 MIRROR CELL HARD STOPS

Specification: Hard stops shall be included in the azimuth floor to prevent the M1M3 mirror cell cart from travelling farther than required to install/remove the M1M3 mirror cell assembly. The hard stops shall be adjustable in the distance they allow the cart to travel.

3.6.6.6 AZIMUTH FLOOR INTERFACE WITH FACILITY FLOOR

Specification: The azimuth floor diameter shall be compatible with the TMA to Pier Interface Drawing LTS-77.

3.6.6.7 UTILITY FLOOR

Specification: As part of the azimuth flooring, the TMA shall be configured to provide a utility floor to access the M1M3 mirror cell assembly entrance portal. This utility floor shall extend from under the M1M3 mirror cell to the boundary between the TMA and the perimeter walkway. This floor shall be level with the perimeter walkway and suitable for traversing with wheeled carts. This floor shall be at least 5 meters wide.

3.6.6.8 UTILITY FLOOR REMOVAL

Specification: At least half the utility floor shall be removable. A removable section or sections shall cover the entire area of the crane access hatches in the two elevated floors of the telescope pier. The floor may be removable in multiple sections. Each section shall be secured by bolted joints. These sections shall be removable by the dome's overhead crane. The removal process may require the telescope to be either zenith pointing or horizon pointing.

3.6.7 ELEVATION PLATFORM

Specification: Platforms shall be installed on both sides of the elevation assembly to provide access to the elevation axis bearing and elevation cable wrap. The height of these platforms shall be compatible with the maintenance and repairs or the elevation axis bearing and elevation cable wrap. These platforms shall be designed to meet the latest version of the international building code (IBC) for light manufacturing floor and to accommodate the deployable platforms, 3.6.8.

3.6.8 DEPLOYABLE PLATFORMS

Specification: The TMA shall provide two deployable platforms to access the camera that can be fully deployed in less than 5 minutes.

Discussion: The two deployable platforms, required below, are expected to require a substantial design and analysis effort. An appropriate level of resource allocation is recommended.

3.6.8.1 CAMERA ACCESS

Specification: Two deployable platforms shall provide access to the camera, one for each elevation platform. These platforms shall provide access to the camera when the telescope is in the horizon pointing orientation. The platform shall be motorized for deployment and retraction. Each platform shall have the capacity of safely supporting at least 275 Kg (600 lbs or 2 workers and an assortment of tools). The deployable platforms design envelope is detailed in document LTS-179.

3.6.8.2 DEPLOYABLE PLATFORMS EXTENSION

Specification: Each deployable platform shall include manually deployable, transverse extensions required for accessing the lens of the camera and the camera hexapod/rotator as described in document LTS-179. At a minimum, the interlock systems shall prevent the motion of the deployable platforms when the extensions are extended. Each extension shall have the capacity of safely supporting at least 125 kg (or 1 workers and an assortment of tools). This 125 Kg capacity is not in addition to the 275 Kg capacity of the deployable platforms.

3.6.8.3 DEPLOYABLE PLATFORMS INTERLOCK

Specification: Safety interlocks for this system shall conform to the safety interlock system LTS-99 and interface control document LTS-173. At a minimum, safety interlocks shall prevent the deployment of these platforms unless the telescope is locked in the horizon pointing position by the Locking Pin Assemblies. Safety interlocks shall prevent the operation of the elevation drives when the platform is deployed. Safety interlocks shall also prevent the operation of the deployable platforms when the platform extensions are deployed.

3.6.8.4 DEPLOYABLE PLATFORMS LABELING

Specification: The platform shall also have the appropriate labeling to describe the load capacity, operations, and the safety locks.

3.6.9 STAIR/LADDER/HATCH ACCESS

Specification: Either stairs or ladders shall provide access to all floors and platforms of the telescope. A stairway or ladder shall provide access to the top of the center section of the telescope. A stairway or ladder shall provide access from the top platform inside the telescope pier to the main floor of the telescope. This access will require two hatches/ladders in the Utility Floor. Access to the elevation axis platform shall be via a stairway.

3.6.9.1 UTILITY FLOOR HATCHES LOCATION

Specification: The telescope utility floor hatches shall be located outside of the telescope sweeping volume when moving in elevation. This requires that if the telescope moves in elevation while the hatches are open that a collision does not result.

Discussion: It is the Contractors responsibility to provide a safe configuration which requires that the hatch be in a location that is difficult to access unintentionally.

3.6.9.2 UTILITY FLOOR HATCHES SIGNAGE

Specification: The telescope utility floor hatches shall be marked with “stand clear” signage or equivalent.

3.6.9.3 UTILITY FLOOR HATCHES SENSORS

Specification: A position sensor shall be attached to the telescope utility floor hatches to verify they are in the closed position. In addition, a position sensor shall be attached to the telescope utility floor ladders to verify they are in the stowed position.

Discussion: These sensors will be used by the interlock system before enabling motion of the mount.

3.6.9.4 UTILITY FLOOR LADDER TERMINATION

Specification: The ladders shall not terminate at unsafe locations inside the telescope pier for any azimuth angle. This requires that the ladder not terminate over a stairwell.

3.7 DRIVE AND BEARING SYSTEMS

3.7.1 DRIVE SYSTEM CONFIGURATION

Specification: Drive and bearing systems shall be provided that are consistent with the telescope mount slew rate, tracking, pointing, duty cycle, environment and all other requirements in this document. The drive and bearing systems shall be configured to facilitate repairs and maintenance. The drive units shall be removable and replaceable as complete assemblies. The azimuth and elevation bearings shall be conveniently removable and replicable. This requires that these items can be removed and replaced without removal or disassembly of unrelated TMA structures, components or payloads.

Discussion: The drive units must be conveniently removable to meet the requirements of section 7.1

3.7.2 DRIVE SYSTEM COMPOSITION

Specification: Unless otherwise stated, the Contractor shall provide the drive system with all necessary operational equipment. At a minimum this will include the electrical motors, motor controls, ~~,~~ position tapes, capacitor banks and tape reader for both the azimuth and elevation axis. The Contractor is required to specify, provide and install both encoder systems.

3.7.3 AZIMUTH DRIVES LOCATION

Specification: To minimize the variation in dynamic properties with azimuth angle, the azimuth drives shall be attached to and move with the azimuth assembly.

Discussion: Other than the requirement above, the type, location and number of drives shall be determined by the Contractor. It is the Contractor's responsibility to produce a drive system that meets all the requirements.

3.7.4 DRIVE SYSTEM THERMAL CONTROL

Specification: The Contractor shall provide drive motors with glycol/water cooling. The motor cooling system shall utilize the glycol/water coolant mix supplied to the telescope. The cooling system shall be self regulating to ensure that the temperature of the motor is between +2 °C and -4 °C of ambient. (See Thermal Control section 3.9 for more details.)

The observatory facility will supply the 40% glycol- 60% water coolant with a temperature at least 5 °C below ambient for all operating conditions.

3.7.5 DRIVE SYSTEM REGENERATIVE BRAKING

Specification: The drive motors shall utilize regenerative braking when decelerating under normal operations. The resulting energy shall be absorbed by the capacitor bank. The requirements for the capacitor bank are in document LTS-180.

Discussion: The drive system must have the maximum practical efficiency to minimize the production of heat. The regenerative braking and capacitor bank system reduces thermally induced image degradation and reduces the utility line load to acceptable levels. The capacitor bank is similar in capacity to the

Vulcan Laser capacitor bank in the UK. The Vulcan example however has 1000 times the power requirements.

3.7.6 DRIVE SYSTEM POWER OFF BRAKING

Specification: Besides the regenerating braking used during decelerating, the drive system shall have power off emergency braking. This braking system shall be able to stop motion in both axes without power and shall automatically engage if power is interrupted. These brakes may be either integral to the drive motors or a separate system. These brakes also function as parking brakes. The braking system deceleration shall be within the normal operating deceleration limits. Since the TMA does not have an azimuth locking pin system, the azimuth brake system shall be configured such that a component can be replaced while still holding the position.

Discussion: As a result of the extra hazards involved in unintended elevation axis motions, the elevation axis is also required to have a locking pin system as described in the ancillary components and equipment section.

3.7.7 SOFTWARE LIMITS, LIMIT SWITCHES AND HARD-STOPS TRAVEL LIMITS

Specification: For both the elevation axis and the azimuth axis, in both directions and in the following order adjustable software limits, operational direction limit switches (elevation only), fixed software limits, fixed directional limit switches, power off limit switches and finally hard stops shall restrict the travel to safe limits. All limit switches shall be physical, electrical switches. Except where otherwise specified, each safety limit shall be designed with the assumption that the limit is approached with the axis rotating at the maximum slew velocity. The exception shall be the fixed directional limits, which have separate velocity assumptions. Consequently, the total system can absorb substantially more energy than would normally be encountered at the maximum slew velocity (normal braking, power off braking, hard stops). The inputs for the software limits shall be the tape encoders. All limit switches shall be actual independent switches, not utilize the tape encoders as inputs and they shall interact with the motor drives via the safety interlock systems and bypassing the Mount Control Systems (MCS).

Each limit shall be configured so that no damage will occur if it is driven past. Each limit shall engage as soon as practical after passing the previous limit. Except where otherwise specified the spacing between the limits shall be sufficient to prevent them from interfering with each other. The fixed software limits shall limit the travel to the specified pointing ranges. All limits and the hard stops shall apply decelerations within the slewing decelerations limits.

Different than the hardware limits, the software limits shall be activated before the actual limit is reached and stop near the limit. The initiation of the stopping shall be based on the current position/velocity and shall stop using a motion profile consistent with the slew limits. Note: This action is similar to an automobile stopping before a STOP sign at an intersection.

Discussion: Excess range is required, beyond the pointing limits, to activate the limits and compress the hard stops. This will require an extra ~10 degrees of motion in azimuth and ~7 degrees in elevation range in each direction. The adjustable software limits and the operational limit switch will need to be routinely overridden to point the telescope to zenith pointing and horizon pointing during maintenance.

3.7.7.1 ADJUSTABLE SOFTWARE TRAVEL LIMITS

Specification: The first limit encountered shall be the adjustable software limits in the MCS. These limits shall be adjustable to less than the fixed limits. This limit shall not remove power from the drives; it shall only prevent further motion in the limiting direction and apply motor braking within the slew deceleration limits so a complete stop is reached within +/-0.1 degree of the adjustable software limit. The TMA can then be driven back into its normal travel range. When in engineering mode the mount control system shall be able to override the adjustable software limits. This is required for routine maintenance.

Discussion: Since they are aided by gravity, uncontrolled elevation axis motions are more problematic than uncontrolled azimuth motions. Consequently, the adjustable software limits for the elevation axis will likely be set near the normal operational limits of the elevation axis (elevation 15 to 86.5 degrees). This maximizes the range available to stop the elevation axis motion resulting from a drive system malfunction. These adjustable software limits will be routinely overridden to reach the maintenance elevation range of 0 to 90 degrees zenith angle. The azimuth adjustable software range will initially be set near the fixed software range. It will only be modified if it is determined that the fixed range is hazardous. For the elevation axis the adjustable software limit can be adjusted past the operational directional travel limit switches, however, this is not expected in practice.

3.7.7.2 OPERATIONAL DIRECTIONAL TRAVEL LIMIT SWITCHES (ELEVATION AXIS ONLY)

Specification: For the elevation axis only, normally the first limit switch encountered after the adjustable software limits shall be the operational directional limit switch. This limit switch shall not remove power from the drives, it shall only prevent further motion in the limiting direction and apply normal braking. The TMA can then be driven back into its normal motion range. These limit switches shall be set as close to the normal operational limits (elevation 15 to 86.5) as possible.

3.7.7.3 FIXED SOFTWARE TRAVEL LIMITS

Specification: The next limit encountered shall be the fixed software limits which interface with the mount control system. This limit shall not remove power from the drives and apply motor braking within the slew deceleration limits. The TMA can then be driven back into its normal motion range. The fixed software shall limit the travel to the specified pointing ranges for both azimuth and elevation motions. They shall engage before the limit, brake within the slew deceleration limits and stop at the limit or not more than 0.2 degrees beyond the limit. When in engineering mode the mount control system shall be able to override the fixed software limits. This is required to test the directional limit switches. This override shall require special authorized access.

Discussion: The fixed software limit must allow the alignment of the elevation assembly with its locking pins at zenith and horizon pointing.

3.7.7.4 FIXED DIRECTIONAL TRAVEL LIMIT SWITCHES

Specification: The limit switch encountered after the fixed software limits shall be the fixed directional limit switch. This limit switch shall not remove power from the drives; it shall only prevent further motion in the limiting direction and apply motor braking within the slew deceleration limits. The TMA can then be driven back into its normal motion range. In regard to spacing between these limit switches and the power off travel limits, these switches shall assume that the axis is moving at the greatly reduced speed required for the engineering mode.

3.7.7.5 POWER OFF TRAVEL LIMIT SWITCHES

Specification: The second limit switch encountered after the directional limit switch shall be the power off limit switch. These limit switches shall be intermediate between the directional limit switches and the hard stops. They shall directly remove power from the drives and engage the power off brakes. An engineering procedure shall then be required to recover.

3.7.7.6 HARD STOPS TRAVEL LIMITS

Specification: After all other software and electronic limits, the rotational motions of the TMA about both axes shall be physically limited by energy absorbing shock absorbers commonly referred to as "hard stops." These devices shall limit the deceleration to safe levels by absorbing the rotational kinetic energy through mechanical springs, hydraulic dampers and/or air charged bladders. The TMA shall not contact these physical limits within the range allowed by the electrical limit switches. These hard stops shall not be sacrificial and shall be reusable after performing.

Discussion: The purpose of the hard stops is to limit the motion of the TMA in the event of inadequate braking. For example, this may result from a significant out of balance in the elevation assembly. Although the design velocity of the hard stops is only the maximum slew velocity, a runaway motion would be stopped by a combination of normal braking, power off braking and hard stops. Consequently, the total limit system can absorb substantially more velocity than produced by the maximum slew velocity.

3.7.8 SOFTWARE AND POWER OFF VELOCITY LIMITS

Specification: For both the elevation axis and the azimuth axis, in both directions and in the following order, adjustable software limits, fixed software limits and power off limits shall restrict the maximum velocity to the prescribed limits. The inputs for the software limits shall be the tape encoders, while the inputs for the power off limits shall be the tachometers. The software limits shall interact with the MCS and the power off limits shall interact directly with the motor controller.

3.7.8.1 ADJUSTABLE SOFTWARE VELOCITY LIMITS

Specification: The first velocity limit encountered with increasing velocity shall be the adjustable software limits. These limits shall be adjustable to less than or equal to the fixed limits. These limits shall not remove power from the drives; they shall only prevent further increase in the velocity.

3.7.8.2 FIXED SOFTWARE VELOCITY LIMITS

Specification: The second velocity limit encountered with increasing velocity shall be the fixed software limits. These limits shall be set to the maximum slew velocity of section 2.2.2.1. These limits shall not remove power from the drives; they shall only prevent further increase in the velocity.

3.7.8.3 POWER OFF VELOCITY LIMITS

Specification: The last velocity limit encountered with increasing velocity shall be the power off limit. These limits shall be 5-10% over the fixed software limit. They shall use the tachometers as inputs. They shall directly remove power from the drives and engage the power off brakes. An engineering procedure shall then be required to recover.

3.7.9 SOFTWARE ACCELERATION AND JERK LIMITS

Specification: For both the elevation axis and the azimuth axis, in both directions, and in the following order adjustable software limits and fixed software limits shall restrict the maximum accelerations and jerk to safe limits. The inputs for these software limits shall be the tape encoders, and interface with the mount control system (MCS).

3.7.9.1 ADJUSTABLE SOFTWARE ACCELERATION AND JERK LIMITS

Specification: The first set of accelerations and jerk limits encountered with increasing magnitude shall be the adjustable software limits which interface with the mount control system (MCS). These limits shall be adjustable to less than or equal to the fixed limits. These limits shall not remove power from the drive; they shall only prevent further increase in the accelerations and jerk.

3.7.9.2 FIXED SOFTWARE ACCELERATION AND JERK LIMITS

Specification: The second set of accelerations and jerk velocity limit encountered with increasing velocity shall be the fixed software limits which interface with the mount control system. These limits shall be set to the maximum slew values of section 2.2.2.1. These limits shall not remove power from the drives; they shall only prevent further increase in the accelerations and jerk.

3.7.10 AZIMUTH AND ELEVATION ENCODER SYSTEMS

3.7.10.1 AZIMUTH TAPE ENCODER SYSTEM

Specification: The azimuth encoder tape shall be a Heidenhain ERA 8400C full circle scale tape with tensioning cleat, and outside diameter with 40um markings. It shall be stationary with the pier and continuous with only a single seam. At least four Heidenhain ERA 8480 scanning heads shall be utilized and shall move with the azimuth assembly.

3.7.10.2 ELEVATION TAPE ENCODER SYSTEM

Specification: Two Heidenhain ERA 8401C segmented scale tapes shall be used one on each side of the elevation assembly. Both tapes shall be continuous with no seams. At least two Heidenhain ERA 8480 scanning heads shall be used per tape encoder. The elevation scanning heads shall be mounted on the azimuth assembly.

3.7.10.3 TAPE ENCODER SYSTEM DIGITIZER

Specification: At least two, one on each side, Heidenhain EIB 749 external interface digitizers shall be used with the scanning heads within the shortest possible distance of the scanning heads.

3.7.10.4 ENCODER SYSTEM RANGE

Specification: The encoder systems must be able to determine position through the entire possible range of motion up to the complete compression of the hard stops.

3.7.10.5 ENCODER SYSTEM ABSOLUTE POSITION

Specification: The encoder system must provide absolute position. Relative position only systems will not be considered adequate. Systems that rely on home switches shall not be considered absolute positioning.

3.7.10.6 ENCODER SYSTEM RESOLUTION

Specification: The encoder system measured position shall have a resolution better than 1milliarcsecond per axis after interpolation.

3.7.11 AZIMUTH BEARING TRACK SEGMENT JOINTS

Specification: The TMA shall meet all its requirements when the bearings are traversing across the bearing track segment joints.

Discussion: As a result of the transportation limitation (Puclaro tunnel diameter) and the large diameter of the azimuth track, this track will need to be shipped in at least 2 segments. The joints connecting these segments have been problematic on other telescopes.

3.7.12 BRAKING AND HARD STOP DECELERATION LIMITS

Specification: The braking and hard stop deceleration maximum and minimum limit values are identical to the slewing acceleration limits. These limits apply to regenerative braking, power off emergency braking, limit switch braking and hard stop braking.

3.7.13 AZIMUTH TOPPLE BLOCK SYSTEM

Specification: The TMA shall incorporate a topple block system or similar device along with the azimuth hard stops to meet the azimuth range requirement.

Discussion: The purpose of the topple block system is to accommodate the larger than 360 degree azimuth range of travel. If the topple block moves during an exposure, it could potentially degrade that one exposure. This event will be extremely rare, consequently it is considered acceptable.

3.8 ANCILLARY COMPONENTS AND EQUIPMENT

Specification: Ancillary equipment includes all components that are permanently attached to the TMA that are not included elsewhere in this document. Contractor shall supply all ancillary TMA mechanical and electrical hardware associated with each system, and shall provide all necessary amplifiers, wiring, utility routing, hangers, cable trays and connections to the appropriate control system to operate the systems. Design of all utility routing shall be subject to approval by the LSST PO.

At a minimum, the ancillary TMA equipment is comprised of the following systems and assemblies:

- Elevation Locking Pin Assemblies
- Balancing System
- Damping System
- Cable Wrap Assemblies and Utility Routing
- M1M3 Mirror Cover Assembly
- Status and Sensing Systems
- Safety Tie Points
- Seismic restraints
- M2 Baffle Temporary Support

3.8.1 ELEVATION LOCKING PIN ASSEMBLIES

A locking pin system is only required for the elevation axis and not for the azimuth axis. The power off braking system for the azimuth axis also functions as a parking brake, and is adequate to prevent unintended motion.

3.8.1.1 LOCKING PIN CONFIGURATION

Specification: The elevation assembly shall be fitted with locking pins that fully restrain rotation and are designed to accommodate the individual removal of any of the payloads specified herein this document.

The locking pins shall provide two discrete locked pointing orientations for the elevation assembly as follows:

- Elevation assembly vertical orientation (zenith pointing)
- Elevation assembly horizontal orientation (horizon pointing)

Discussion: The purpose of these locking pins is to allow the safe installation, removal and replacement of equipment from the elevation assembly for assembly, maintenance and engineering operations. When assemblies are removed from the elevation assembly a potentially unsafe imbalance is created. The locking pins are intended to keep the elevation assembly from rotating when subjected to these imbalances.

3.8.1.2 LOCKING PIN INSERTION POSITIONS

Specification: All locking pins shall be manually deployed (inserted) and manually retracted (stowed). Locking pins shall be physically restrained from movement when placed in any one of their three insertion positions described below. This restraint shall function to not allow the pin to accidentally be deployed or retracted without deliberate action upon the part of the observatory personnel. The positions shall be clearly marked.

The locking pins shall have three distinct insertion positions:

- Retracted Position. When in the fully retracted position (stowed), the elevation assembly shall be completely free to rotate throughout its full range of travel.
- Test position. When in the test position, the elevation assembly shall be free to only rotate a small amount (~ 1 degree). This position shall be used for verification of elevation assembly balance, i.e., after engineering operations (e.g., M1M3 cell replacement) occurs.
- Locked Position. When the locking pins are inserted into their fully deployed position, the elevation assembly shall not be free to rotate any amount from the locked position. (This configuration will be used for payload removal).

3.8.1.3 LOCKING PIN POSITION SWITCHES

Specification: The locking pin positions shall be fitted with safety rated, positive action, control-safe, electrical signal-switch devices (limit switches) that provide a distinct signal to the local safety controller that the locking pin is engaged in one of its three specific insertion positions.

Discussion: In the locking position, the local safety controller will operate in such a way as to remove power to the elevation assembly drive system. The limit switch will be control-safe (i.e., a cut, short or brake in the limit switch electrical cable will be detected by the Local Safety Controller).

3.8.1.4 LOCKING PIN SAFETY FACTOR

Specification: Two locking pins shall be utilized (one on each side). Each locking pin shall be designed with a minimum factor of safety of 2.0, based on material yield strength. This requirement shall be met with the largest combination of imbalance or loading possible when performing assembly, maintenance or engineering operations, including the worst case survival conditions (e.g., during a seismic event). Although the two locking pins are intended to be used simultaneously, for design and analysis all loads shall be assumed to act on either locking pin.

3.8.1.5 ZENITH POINTING LOCKING POSITION ACCURACY

Specification: The zenith pointing angle accuracy with the elevation locking pins in their locked position shall not exceed +/- 0.03 deg PV.

Discussion: The M1M3 mirror cell cart lifting mechanism has ~40mm of travel. This accuracy requirement limits the utilization of this travel for locking pin non-repeatability to +/- 5mm.

3.8.1.6 HORIZON POINTING LOCKING POSITION ACCURACY

Specification: The horizon pointing angle accuracy with the elevation locking pins in their locked position shall not exceed +/-0.01 deg PV.

Discussion: This accuracy requirement enables the removal of the camera support assembly from the TMA in its locked position at horizon pointing. Removal of the camera support assembly requires that guide rods control its motion for the ~5 meters of extraction. This accuracy requirement adds ~+/-1mm to the clearance required between the guide rods and their bearings.

3.8.2 BALANCING SYSTEM

3.8.2.1 BALANCING SYSTEM CONFIGURATION

Specification: The TMA shall include a system to balance the elevation assembly. The balancing system must be able to balance the elevation assembly in the direction along the optical axis and perpendicular to both the optical axis and the elevation axis. Consequently the elevation assembly will remain balanced for any elevation angle.

Discussion: Balancing will be performed with the locking pin assemblies in their test position. Balancing may be performed in either the zenith or horizon pointing orientations.

3.8.2.2 BALANCING SYSTEM TESTING

Specification: The mass balance shall be demonstrated empirically during the factory acceptance testing and during the site acceptance testing. These demonstrations shall be performed at:

- 90 degree elevation angle (zenith pointing)
- 0 degree elevation angle (horizon pointing)

3.8.2.3 MOTORIZED FINE BALANCING OF TELESCOPE

Specification: Fine balancing of the telescope's elevation assembly about the elevation axis shall be provided by motorized units moving masses. These motorized units shall be operable manually from the mount control system. Orthogonal assemblies are required to balance the telescope in both directions: along the optical axis and perpendicular to it. For both directions, the fine balancing shall have a range of ±2000 N·m and a resolution of ±10 N·m. The motorized units shall be capable of moving through their entire range in less than 4 minutes. Since the elevation drive motor current will be used to determine the out of balance, this current must be displayed adjacent to the controls for these fine balancing motorized units.

Discussion: This capacity requirement allows for rebalancing of the elevation assembly with the approximately 17 metric tons M1M3 mirror monolith at any location within its normal operating range of ±10 mm. Sufficient excess capacity of ~20% is available to allow for minor telescope alterations.

3.8.2.4 COARSE BALANCING OF TELESCOPE

Specification: Coarse balancing of the telescope elevation assembly around the elevation axis during integration may be provided by repositioning of motorized fine balancing units, repositioning of other components and by repositioning/installing counter-balance weights. The TMA shall accommodate at least +/-50 KN-m of coarse balance in any direction perpendicular to the elevation axis to accommodate uncertainty in the mass and CG locations of the payloads. Each standard counter-balance weight shall not weigh more than can be reasonably handled by a typical observatory worker at the site using standard handling equipment, such as the enclosure overhead crane. Weight plates shall be fitted with lifting lugs. Sufficient mass budget and secure mounting locations shall be provided for these counter balance masses to cover the uncertainty in the telescope balance.

The motorized fine balancing units shall be designed to allow repositioning along the optical axis by +/- 0.5 meters. The motorized fine balancing unit shall be relocated to the maximum range inside this +/- 0.5 meters before any counter-balanced weights are added.

Coarse balancing, with the fine balancing system installed and in the mid range, shall be within 200 N-m.

Discussion: Relocating the balancing units to achieve coarse balance reduces the quantity of parasitic mass. Some relocation of the damping units along the optical axis is also specifically allowed.

3.8.3 DAMPING SYSTEM

Specification: The Telescope Mount Assembly shall incorporate a passive damping system capable of providing 5% added damping to the telescope mount in both directions perpendicular to the optical axis. The 5% damping shall be applied to the first frequency in these two directions. These damping units shall have sufficient tuning capacity to accommodate the change in first frequency between the Contractor's factory test facility and the site.

Discussion: Since the effectiveness of the added damping varies with frequency, the 5% performance requirement only applies to the first natural frequency in both directions perpendicular to the optical axis. The higher frequencies have minimal effect on the telescope performance. The variation in frequency, required for the tuning range, between the Contractor's factory test facility and site can be determined by FEA.

3.8.4 CABLE WRAP ASSEMBLIES AND UTILITY ROUTING

3.8.4.1 CABLE WRAPS AND CABLE ROUTING

Specification: Contractor shall provide three cable wraps (azimuth cable wrap, elevation cable wrap and camera cable wrap) and all necessary cable routing to accommodate all the utility lines required for operation of the telescope mount, M1M3 mirror cell assembly, M2 mirror cell assembly (with hexapod) and camera (with hexapod and rotator). These utility lines are identified in the ICD LTS-217. The azimuth and elevation wraps can either be self driven or utilize the motions of the telescope mount assembly.

3.8.4.2 UTILITIES AND SERVICES LINES

Specification: All utilities and services lines required for operation of the TMA or specified in LTS-217, for operation of the payloads, shall be supplied by the Contractor. These utilities and services shall be provided by the Contractor from their connection in the telescope pier, before the azimuth cable wrap up to and including the interfaces to the payloads.

3.8.4.3 CABLE WRAPS SPARE CAPACITY

Specification: At a minimum, the azimuth and elevation cable wrap assemblies and all carriers, ways, conduits and other cable management devices shall be designed to allow for 50% future expansion of the quantity of utility lines above what is required in LTS-217.

Discussion: The utilities listed for the camera cable wrap already have spares included.

3.8.4.4 CABLE WRAPS OPERATION

Specification: All pointing, tracking, and slewing requirements of the TMA shall be met while the TMA experiences the effects of the cable wraps.

Discussion: To meet the operational requirements, the cable wraps must provide smooth operation and must not impart any excess drag or intermittent friction or stiction into the rotational axes.

3.8.4.5 CAMERA CABLE WRAP

Specification: The camera cable wrap shall be designed in accordance with LTS-218.

Discussion: The camera cable wrap is expected to require a substantial design and analysis effort. Allocation of appropriate level of resources is recommended.

3.8.4.6 AZIMUTH CABLE WRAP CONFIGURATION

Specification: The azimuth cable wrap shall be a maypole type and not a power chain type cable wrap. Each cable wrap shall be capable of meeting its full range of rotation for its respective axis as specified in this document, without damage to the wrap, cables, hoses, or telescope.

3.8.4.7 ELEVATION CABLE WRAP CONFIGURATION

Specification: The elevation cable wrap sag shall not be more than 10% greater than is required to accommodate the total elevation motion.

Discussion: The sag of all cables of the elevation cable wrap must be minimized to reduce the possible interference with personnel standing on the perimeter walkway. Personnel will not be allowed on the perimeter walkway during TMA operations. This requirement is intended to reduce the hazard if this restriction is violated.

3.8.4.8 CABLE WAYS

Specification: The Contractor shall provide all necessary cable carriers, ways, conduits, and other devices to support, direct, and organize the routing of cabling and other utilities to the required locations of the TMA. The design of these devices shall provide for a neat and orderly distribution of utilities to and on the TMA. The design and layout of these devices shall be subject to approval by LSST. At a minimum, the Contractor shall provide cable carriers, way, and conduits to the following locations:

- M1M3 Mirror Cell Assembly
- Top End Assembly
- M2 Mirror Cell Assembly and M2 Hexapod
- Camera rotator and Hexapod (from integrating structure)
- Camera (from camera cable wrap)

The required cable ways dimensions shall be determined from LTS-217.

3.8.4.9 CABLE WAYS DESIGN

Specification: Carriers and ways shall be based upon Common off the Shelf (COTS) equipment. Where cable carriers and ways are used they shall have removable dividers and shelves installed to maintain the relationships between cables and hoses. Cable carriers shall be made of self lubricating materials, and be capable of all required bend radii and movements.

3.8.4.10 ROUTING THROUGH THE TOP END SPIDERS

Specification: The routing of cables and utility lines to the top end assembly shall be through the hollow spiders. Hard piping shall be utilized through the spiders unless approved by the LSST PO.

Discussion: Routing hard piping through the spider is preferable but may place an unnecessary restriction on the design.

3.8.4.11 ELECTRICAL CONNECTORS

Specification: All the cabling required for the operation of the TMA or required by LTS-217 shall be continuous without using intermediate connectors. Connectors shall only be provided where required for installation, maintenance or repairs. All connectors shall meet the specifications of LTS-98.

3.8.4.12 COOLING LINES

Specification: The utilities routing and cable wraps shall specifically include cooling lines running to and from the M1M3 Cell Assembly, Top End Assembly thermal control system, Capacitor Bank, drive motors and through the camera cable wrap. All rigid coolant lines shall be insulated with standard piping insulation approved by the LSST PO. All glycol/water and refrigeration plumbing moving with the telescope shall be supplied by the Contractor. It is allowable and recommended that the main piping be replaced by multiple smaller lines with equivalent head loss through the cable wraps. All flexible lines carrying liquids, coolants or oils shall have shut off valves and unions at each end for maintenance.

Discussion: Except the camera detectors, all of the TMA components will be cooled directly or indirectly through glycol/water coolant. The M2 mirror cell assembly is cooled by the top end thermal control system. The camera is principally cooled by an entirely separate LSST PO supplied refrigerant system, however it also utilizes glycol/water cooling. The coolant mains for the telescope will consist of 2” to 3" diameter piping carrying a glycol/water mixture. Most of this cooling will be utilized by the M1M3 thermal control system. Smaller piping will be used to bleed off of the 2” to 3" piping to provide cooling for other various components.

3.8.4.13 PIPING JOINTS

Specification: All piping joints shall be welded and not threaded except when specifically approved by LSST PO. These piping joints specifically include all glycol/water, refrigeration and compressed air joints. All joint welding shall be performed according to an LSST PO approved common industrial standard. Threaded joints are allowable at both ends of all flexible conduits to facilitate replacement.

Discussion: Threaded joints present an unnecessary leak hazard.

3.8.4.14 PIPING CLEANLINESS

Specification: All piping shall be thoroughly cleaned, purged with dry nitrogen, and capped at each termination prior to shipping, then again following assembly of the TMA in the facility. This piping specifically includes all glycol/water, refrigeration and compressed air lines.

3.8.4.15 PIPING LABELING

Specification: All piping shall be clearly and permanently labeled. At a minimum that labeling shall be on the rigid piping at both ends of every flexible section.

Discussion: Labeling at the ends of flexible sections reduces the chances of hoses being cross connected.

3.8.5 M1M3 MIRROR COVER ASSEMBLY

3.8.5.1 M1M3 MIRROR COVER CONFIGURATION

Specification: The TMA shall include an M1M3 mirror cover attached to the center section. This mirror cover shall cover all of the M1M3 not covered by the M2 mirror cell assembly when the telescope is zenith pointing. When open, the mirror cover assembly shall not vignette or otherwise obscure the light path. The mirror cover shall not present a hazard to the lens of the camera.

Discussion: The purpose of the M1M3 mirror cover is to limit dust settling on the M1M3 mirror and protect the mirror from liquids or small object that may dislodge from the telescope dome. Since the inner 3.4 meters of the 8.4 meter diameter mirror is protected from above by the large M2 mirror cell assembly, the mirror cover need not cover the entire mirror. This area covered directly under the M2 cell assembly is considered adequately protected. Most of the area not covered by the M1M3 mirror cover is actually filled by the camera.

3.8.5.2 M1M3 MIRROR COVER CONTROL

Specification: The M1M3 mirror cover assembly shall be controlled by the mount control system. If the cover has separate sections, the control systems shall be configured to allow individual control of each section in engineering mode.

3.8.5.3 M1M3 MIRROR COVER STATUS

Specification: The TMA shall publish the M1M3 mirror cover status. This status shall include mirror cover closed and open limit switches and an encoder system to determine the intermediate positions.

3.8.5.4 M1M3 MIRROR COVER BRAKING SYSTEM

Specification: The M1M3 mirror cover shall have a power off braking system to maintain it in the open or closed positions. This brake shall be sufficient to maintain the M1M3 cover in position during any motion or operation state of the TMA.

3.8.5.5 M1M3 MIRROR COVER MANUAL POWER CUTOFF SWITCH

Specification: The M1M3 mirror cover assembly shall have a manual power cutoff switch located on the elevation assembly so that it can be deactivated manually when needed and cannot be operated by the mount control system. The status of that switch shall be reported to the mount control system. When the deployable platforms are not parked, the M1M3 mirror cover shall not be operable (disabled by the interlock system).

3.8.5.6 M1M3 MIRROR COVER OPENING/CLOSING DURATION

Specification: The M1M3 mirror cover shall fully open or close when commanded within 60 seconds with the elevation assembly at any elevation angle (from zenith to horizon). The motion shall be smooth and controlled with no components moving unconstrained.

3.8.5.7 M1M3 MIRROR COVER MARKING

Specification: The M1M3 mirror cover is not intended to support observatory personnel walking on it and shall be marked as such in both English and Spanish in language approved by the LSST PO.

3.8.5.8 M1M3 MIRROR COVER PROTECTION LEVEL

Specification: The M1M3 mirror cover shall protect the M1M3 assembly from small objects (2.5 kg or 5-lb hand tools) dropped from a 17-meter height equivalent to the ceiling of the enclosure. Significant damage to the mirror cover is allowable from this fall as long as the object does not penetrate to the mirror. The M1M3 mirror cover system shall protect the M1M3 assembly from spilled liquids falling or dripping from above, such as water seeping through the dome seals. If the area under the M2 mirror cell assembly is not covered, the mirror cover shall be designed to prevent falling objects or liquids from flowing, sliding or bouncing from the mirror cover through the uncovered section.

Discussion: A hermetic (water tight) seal is not expected. The cover is only expected to redirect liquids away from the M1M3 mirror when the telescope is zenith pointing.

3.8.5.9 M1M3 MIRROR COVER MATERIAL AND LUBRICATION

Specification: Since the purpose of the mirror cover is to protect the mirror and keep it clean, the mirror cover shall be constructed from materials that do not flake, shed or otherwise deposit material on the mirror over the design lifetime of the system. The lubrication systems shall be sealed to prevent oil or grease from migrating onto the optical surface.

3.8.5.10 M1M3 MIRROR COVER OPEN POSITION

Specification: When open, the mirror cover shall be outside the clear optical path and shall not unnecessarily obstruct the flow of ambient air through the elevation assembly.

3.8.5.11 M1M3 MIRROR COVER BALANCE IMPACT

Specification: The balance of the TMA shall not be affected by the opening or closing of the M1M3 mirror cover by more than 100 N-m unless approved by LSST.

3.8.6 STATUS AND SENSING SYSTEM

Specification: The TMA Contractor shall provide telemetry from all sensors installed on the TMA. The sensors shall monitor power supplies' output parameters. All sensor signals shall be provided to the mount control system. All sensors shall be provided with their required readout electronics, software, and calibration equipment as required. If the TMA utilizes hydrostatic bearings, the bearings shall have sensors that measure the film thickness for every single bearing. The type, capacity and location of each sensor shall be chosen via consultation with the LSST PO during the design phase of the contract.

Discussion: After delivery of the TMA, the LSST PO will supply and install additional sensors. The Contractor will need to consult with the LSST PO to ensure mounting and cable routing is feasible for these sensors which will include:

- Thermal sensors
- Anemometers
- Accelerometers
- Retro reflectors

The retro reflectors may be installed early and used during factory acceptance tests and during construction on the summit. They will be used during operations to determine the position of the optics relative to the mount.

3.8.6.1 AZIMUTH CABLE WRAP STATUS AND SENSING SYSTEM

Specification: The TMA shall provide sensors to monitor the pressure and temperature of all piping at the azimuth cable wrap to pier interface. This shall include the glycol/water coolant, camera refrigeration, compressed air and hydrostatic oil line (if utilized). Both supply and return shall be monitored. All sensors shall have both a local display and be monitored by the MCS. All sensors shall be compatible with the fluids that they are monitoring. All sensors shall have measurement ranges compatible with the expected operational ranges. Similar sensors shall be utilized as much as possible.

3.8.7 SAFETY TIE POINTS

Specification: The TMA shall include at least 24 safety rated fall protection tie points on the TMA as required for maintenance of the TMA and the payloads. All tie points shall be installed in locations chosen in consultation with LSST safety personnel. All tie points shall meet OSHA standards.

Discussion: Some tie points will be on the top end for the M2 removal and camera removal safety. Some tie points will be on the mount for working on the deployable platforms.

3.8.8 SEISMIC RESTRAINTS

Specification: The TMA shall incorporate seismic restraints to prevent any relative motion between components from seismic accelerations. This specifically requires that the azimuth bearing system does not allow any significant upward or overturning motion of the azimuth assembly during a seismic event. Any relative motions that are possible must be approved by the LSST PO. These seismic restraints shall follow the requirements of section 3.3.10.

Discussion: Besides the threat of components escaping, relative motions produce impacts which result in high accelerations.

3.8.9 LSST M2 BAFFLE TEMPORARY SUPPORT

Specification: The temporary baffle support shall be provided with the TMA and designed in conjunction with LSST PO personnel. This temporary support is only used for short intervals and only when the TMA is locked in the horizon pointing orientation. Consequently it is only required to meet the seismic maintenance requirements.

Discussion: Removal and installation of the M2 mirror cell assembly requires the temporary relocation of the M2 baffle assembly inside the TMA. A small section of the middle stray light baffle could be made removable if necessary for attaching the M2 baffle to that temporary support.

3.9 THERMAL CONTROL

Specification: All components of Telescope Mount Assembly shall be selected so that they dissipate minimal heat. This requires that all heat sources be insulated and thermally controlled. The Contractor shall identify heat sources and specify their thermal control systems. Auxiliary components such as the mirror cover or balancing units that are not operated during observing need not be insulated or thermally controlled. Heat sources that are too small to be practically thermally controlled need not be thermally controlled if approved by the LSST PO.

Discussion: The telescope mount assembly must be designed to reduce and to control thermal effects during operation. The decision to not require thermal control of a heat source will be made by the LSST PO according to its location relative to the optical system and its heat dissipation.

3.9.1 GLYCOL WATER THERMAL CONTROL SYSTEM

Discussion: The LSST PO will provide all chillers, pumps and plumbing required to provide the glycol/water coolant to the azimuth cable wrap. LSST will provide the 40% glycol 60% water coolant system up to the azimuth cable wrap with a temperature 5 °C below ambient for all operating conditions.

3.9.1.1 SURFACE TEMPERATURE

Specification: Unless otherwise stated the surface temperature for all heat producing components shall be actively maintained to within +1 °C to -3 °C of ambient by the TMA's glycol/water thermal control. This requirement specifically applies to the following:

- Azimuth Drives
- Elevation Drives
- Drive system electronics attached to the telescope
- Capacitor Bank
- Top end assembly thermal control system

Discussion: The LSST PO will provide the M1M3 thermal control system.

3.9.1.2 INSULATION

Specification: Insulation surrounding equipment shall be of a non-deteriorating type consistent with the operation, design life and environmental conditions of the Site. Insulation shall be modular, easily removable and replaceable, and of a non-degrading type. The insulation shall be at least R = 0.7 K·m²/W (4 h·ft²·°F/Btu).

3.9.1.3 COOLING SYSTEM CONFIGURATION

Specification: Unless otherwise stated or approved by the LSST PO, each of these heat sources shall be individually thermally controlled. To minimize the effect of one thermal control system on the others the thermal control shall be provided by mixing valves and not throttle valves. The mixing valve bypasses shall be designed to have head losses similar to their respective heat exchangers. Separate supply and return plumbing shall be provided and no heat source may be discharged into the supply plumbing.

Discussion: When thermal control is provided by a throttle value the flow to the other components is affected which makes it difficult to control multiple components simultaneously.

3.9.2 TOP END THERMAL CONTROL

3.9.2.1 TOP END THERMAL CONTROL GLYCOL/WATER SUPPLY

Specification: The TMA shall supply glycol/water coolant to the central assembly of the top end assembly. The coolant is used to supply both the top end thermal control system and the camera utility trunk. The coolant flow shall be sufficient to provide for all the loads provided in the top end thermal control section.

Discussion: Chilled glycol/water is supplied to the top end assembly 5C cooler than the ambient air temperature. The supply and return lines in LTS-217 are sized to provide 15 liter/min (4 gallon/m) flow rate. However, it is the responsibility of the Contractor to ensure that the lines size are appropriate and may increase these sizes if necessary.

3.9.2.2 TOP END THERMAL CONTROL SYSTEM CONFIGURATION

Specification: The top end thermal control system shall utilize a glycol/water central thermal control cabinet. It shall be attached to and removed with the integrating structure. It shall reside inside the semi air tight central assembly. This cabinet principally consists of heat exchanger, fans and a mixing valve control system. Except for the camera, all components on the top end shall be thermally controlled by cooling air supplied by the top end thermal control system.

The Contractor is also responsible for providing all the fans and ducting required inside the top end assembly. The enclosed space of the central assembly shall be used as the supply plenum. Heated air from the major heat sources which include the 6 electrical cabinets and the M2 mirror cell assembly shall be ducted directly to the thermal control cabinet.

Discussion: Utilizing only a single central thermal control cabinet and ducting the cooling air minimizes the coolant leak potential and allows for effective condensation collection which is critical since the top end assembly resides above the M1M3 mirror. The condensation collection system will also contain minor glycol/water leaks from the heat exchanger in the thermal control cabinet.

3.9.2.3 TOP END THERMAL CONTROL SYSTEM COOLING LOAD REQUIREMENTS

Specification: The top end assembly thermal control system provides cooling air for the LSST components (camera's utility trunk, camera hexapod/rotator, the secondary mirror (M2) assembly and the associated local electronics within the 6 electrical cabinets) and the TMA components (fans , cable wrap drive and electronics) located on the top end assembly. The total heat load of the LSST components is 1.75 kW. The Contractor is responsible for providing sufficient cooling capacity to accommodate both the LSST component heat load and heat load from the TMA components.

The temperature of the air leaving the heat exchanger shall be between -2 °C and 0 °C of ambient. The air temperature inside the enclosed space of the central assembly shall not exceed 2 °C above ambient.

Discussion: Other than for its utility trunk, the camera has an entirely separate refrigeration system.

3.9.2.4 M2 MIRROR CELL ASSEMBLY THERMAL CONTROL SYSTEM COOLING AIR

Specification: The TMA is required to provide the cooling capacity, the ports for attaching the four fans used for the M2 thermal control system and the 2x6 inch diameter return ducting from the ports to the thermal control cabinet. Two of the ports are supply and two are return. This 500 W heat load is included in the 1.75 kW LSST heat load.

Discussion: Thermal control for the M2 mirror cell assembly is provided by circulating air between the M2 Mirror cell assembly and the enclosed space of the central assembly. All ducting and fans required for this are provided with the M2 mirror cell assembly.

3.9.2.5 CAMERA UTILITY TRUNK, HEXAPOD/ROTATOR THERMAL SYSTEM COOLING AIR

Specification: The TMA shall provide the fans and ducting necessary to provide cooling air to the camera utility trunk and camera hexapod/rotator. Sufficient air shall be provided to limit the temperature rise to 2 °C for the 300 Watts of heat escaping from this assembly. The return air shall be along the utility trunk and cabling that connects the camera to its rotator.

The air flow shall be sufficient to account for any air leaking from the central assembly. The design flow rates shall assume a 5% air flow leakage rate. The air leaking from the central assembly shall not exceed 5% of the total air flow.

Discussion: Unlike the M2 mirror cell assembly thermal control system, the TMA provides the fans and ducts required for the camera utility trunk and camera hexapod/rotator.

3.9.2.6 TOP END ELECTRICAL CABINETS

Specification: The TMA thermal control system shall provide 950W of cooling capacity for the electrical cabinets. Each of the 6 cabinets shall have sufficient air flow to provide 200 W of cooling while limiting the temperature rise to 2 C. The calculations shall assume a pressure drop through the cabinets based on established standards.

Discussion: The actual heat load for each cabinet will vary between 0 and 200 W. Since the distribution of the heat load between the cabinets is undefined, each cabinet must have enough air flow for the maximum heat load. Since the most likely increase in heat load will result from an increase in electronics all the cooling load buffer is contained in this specification.

3.9.2.7 LEAK CONTROL AND DETECTION

Specification: The TEA thermal control system shall be designed to minimize the possibility of coolant leaks. At a minimum this requires that the thermal control cabinet be leak tight except as required to accommodate air flow and that a condensation line lead from a catchment at the bottom of the cabinet into the condensation system. Sensors shall monitor the supply and return pressure for the coolant to the top end thermal control system. The Contractor shall provide other leak detection equipment to be approved by the LSST PO.

3.9.2.8 CAMERA CABLE WRAP COOLANT LINE

Specification: Coolant shall be provided through the camera cable wrap to the camera. The coolant supply rate shall be sufficient to remove 4.5 kW of heat with a temperature rise of not more than 5 °C.

3.9.3 VENTILATION OF ENCLOSED SPACES

Specification: To expedite equalization between the ambient air temperature and the structure, all enclosed spaces shall be actively ventilated by fans exhausting away from the telescope's optical system. This venting shall supply at a minimum 30 air changes per hour. Where practical, the ventilation shall be below the main telescope floor to allow removal by the facility's down draft system. Enclosed spaces that are too small to be practically actively vented may only be passively vented if approved by the LSST PO.

Discussion: All enclosed spaces should be minimized in the TMA design. The decision to not require active ventilation of a specific volume will be made by LSST according to its location relative to the optical system and its volume.

3.9.4 MINIMIZATION OF CONDENSATION HAZARD

Specification: All cooled equipment shall be insulated to minimize the production of condensation and to minimize the effects of any condensation that occurs. Condensation traps and lines shall be provided, and the condensation discharged to below the pier platforms and inside of the pier.

Discussion: Although the telescope will not be intentionally operated near or below the dew points, a condensation hazard exists since in general the temperature of these components will be below ambient. The pier design has a containment vessel system for this purpose. The LSST PO may provide waivers for this requirement when it is deemed unnecessary or impractical.

3.9.5 HYDROSTATIC BEARING PUMPS AND COOLER

Specification: Hydrostatic bearings, their pumps and cooler shall be located in the facilities utility/machinery room which is at the far end of the summit support facility. The floor of the utility/machinery room is 32 meters below the top of the telescope pier. The piping length from the machinery room to the connection to the azimuth cable drape is 120 meters. The oil temperature shall be conditioned to within +2.0 to -4C of ambient before leaving the utility/machinery room.

Discussion: Most of the telescope's and facility's support equipment is located in the summit support facilities utility/machinery room. This room was located as far away as practical from the telescope to prevent equipment from interfering with the telescope's operation by introducing vibrations or heat.

3.10 MOUNT CONTROL SYSTEM

Specification: The TMA shall include a mount control system (MCS) that incorporates all electronics, servo control, algorithms and software necessary to safely operate the TMA systems through either connection to the Telescope Control System (TCS) or through a stand-alone Engineering User Interface (EUI) for maintenance and diagnostic purposes.

3.10.1 LOCAL OPERATION

Specification: The Telescope Mount Assembly control system shall include a local operation mode for pointing, slewing, tracking, and for the operation of all TMA auxiliary equipment. This auxiliary equipment specifically includes the mirror cover and balancing units. The local mode shall also report the values for all sensors associated with the above. For local control the telescope mount assembly control system shall include a manual control station conveniently located at the telescope maintenance platform.

Discussion: Local operation implies that the telescope can be controlled at the telescope for maintenance and testing.

3.10.1.1 LOCAL OPERATION PERFORMANCE LIMITS

Specification: The local control station shall be configured to only allow azimuth and elevation accelerations and velocities that are 10% of the slewing limits.

Discussion: The reduced limits are necessary to limit hazards from the telescope's large dynamic capability.

3.10.2 REMOTE OPERATION

Specification: The control system shall be remotely accessible and controllable (e.g. using Remote Desktop, VNC or equivalent from a remote computer). Remote control implies that the telescope can be operated from the control room or an equivalent remote facility.

3.10.3 OPERATION MODES

3.10.3.1 OBSERVING MODE

Specification: During normal operations while observing, the mount control system shall be connected to and driven by the Telescope Control System (TCS) according to LTS-159.

Discussion: The control system controls all the automatic procedures.

3.10.3.2 ENGINEERING MODE

Specification: An engineering mode shall be provided for maintenance and engineering tests. In engineering mode, the control system shall provide hierarchical safety levels to the user that can be bypassed using relaxed safety limits in order to test and maintain the systems. The MCS shall safely allow operation in engineering mode.

Discussion: An example of an engineering operation is moving a telescope axis beyond the software limits to test the electronic limit switches.

3.10.4 READINESS

Specification: The MCS shall be operational and ready to receive and act upon commands within 5 minutes of a cold, power-off start of its hardware. The MCS shall recover all static information required to operate after a restart or reboot. This information shall include, but is not limited to: zero points, lookup tables, and configuration parameters.

3.10.5 CONNECTION TO THE TCS

Specification: The mount control system software shall be compatible with the LSST Communications infrastructure based on the Data Distribution Service (DDS) standard to communicate with the TCS following the interface document LTS-159.

Discussion: The LSST PO will provide to the Contractor a reference implementation of the agreed interface. The implementation will include tools to simplify the integration of the LSST communications infrastructure on the controller. The LSST Control System is based on a distributed concurrent architecture, comprised of many processors, sensors and devices making an interconnected network. Coordination of the elements is achieved by the exchange of messages through the system interfaces. In this architecture, the principle of control is Supervisory Control with time critical loops closed at the local level, and with non time critical elements acting as “set-point” computation elements.

The control system necessitates a communications layer that provides an efficient and reliable way of exchanging messages between the different systems and components of the LSST complex. The messages consist of control information that needs to be predictably delivered and status information utilized to monitor system performance.

The communications layer is built on industry standard software known generically as *communications middleware*. The Data Distribution Service (DDS) (http://www.omg.org) has been selected as the standard for LSST. Using this standard it is possible to exchange messages in a *command/response* or *publish/subscribe* model, according to the required functionality.

3.10.6 MOUNT CONTROL SYSTEM

Specification: The TMA shall be controlled via a Mount Control System (MCS). This computer shall at a minimum run the Engineering user Interface software and shall also implement the interface with the LSST communications infrastructure. The controller computer(s) shall be a rack-mounted IBM-PC compatible hardware platform running Linux OS. The controller shall not consume more than 50% of its processing capability. The system shall not consume more than 50% of its hard disk capacity.

Discussion: This computer is expected to be located in the facility computer room. On site LSST will provide the network infrastructure (Ethernet link with a minimum bandwidth of 100 Mb/s). The Contractor will provide the means to connect to the network.

3.10.7 MCS SYSTEM INTERFACES

Specification: The Mount Control System shall incorporate all the necessary interfaces for communications and anything else required to successfully operate the systems in any of the observing or engineering modes defined in the document. The naming convention shall be consistent throughout the software (commands, telemetry and events) to simplify maintenance. The MCS shall perform all requests sent through its interface without need of reboot or re-initialization, unless the request demands such an operation.

3.10.8 CONTROL COMMANDS

Specification: The MCS shall include all the commands in the command interface in the TCS to Telescope Mount Assembly Interface Control Document (LTS-159).

Discussion: It is expected that the commands and telemetry list will be updated with the Contractor during the design of the TMA.

3.10.9 TELEMETRY

Specification: The MCS shall publish all the telemetry organized in topics as described in the TCS to Telescope Mount Assembly Interface Control Document (LTS-159).

3.10.10 EVENTS

Specification: The MCS shall publish events associated with significant changes in the controller status as described in the TCS to Telescope Mount Assembly Interface Control Document (LTS-159).

Discussion: Significant events include state changes, errors, reaching limits, out-of-range, etc.

3.10.11 TIME

Specification: The MCS shall utilize the time provided by the LSST summit network using Precision Time Protocol (PTP) IEEE 1588-2008 or later. The systems do not need to be directly synchronized with each other; instead they are using the same time.

3.10.12 MCS MOUNT POSITIONING COMMAND

Specification: The MCS shall handle position, velocity and time commands sent from the TCS, with accuracy needed to meet the motion requirements when under TCS control.

Discussion: Testing and integration will also require that the MCS be able to operate the camera cable wrap. However, since operating the camera cable wrap when the camera is installed and connected will be hazardous. This function must be removed/disabled in the final MCS.

3.10.13 MCS CAMERA CABLE WRAP POSITIONING COMMAND

Specification: The camera cable wrap shall be slaved to the camera rotator.

Discussion: Testing and integration will require an alternative method to operate the camera cable wrap since the rotator will not be installed.

3.10.14 MCS POSITIONING UPDATE FREQUENCY

Specification: The mount control system positioning update frequency shall be a minimum of 20 Hz.

3.10.15 MCS POSITIONING TOLERANCES

Specification: The MCS shall continuously determine and report if it is within the tolerances for the position and velocity for all pointing and tracking motions. The tolerances for position and velocity shall be user-configurable parameters to within the precision of the relative encoders. The default tolerances shall be defined by the specifications for the mount drive systems specifications.

Discussion: In regard to the TMA motion requirements, error allocations within the MCS are not specified. The distribution of the total allowable error between all the contributing effects including control system error, mount vibration, bearing, encoders etc. is the responsibility of the Contractor. The cumulative effect must not exceed the overall requirements. Any error arising from the TCS is the responsibility of the LSST PO.

3.10.16 MCS MOTION PROFILE

Specification: When slewing not under TCS control, the MCS shall use a motion profile that keeps position, velocity, acceleration and jerk within the required ranges and meets the slew and settling time requirements. This motion profile shall conform to both the fixed and software limits. These requirements shall be met for both axis and for accelerating, decelerating and braking. When tracking not under TCS control, the MCS shall simply compute tracking positions at a given velocity. The tracking velocity shall be selectable by the user.

Discussion: For testing purposes, when not under TCS control, the MCS needs to be able to generate its own trajectory. When under TCS control, the MCS will use the TCS computed trajectory.

3.10.17 MCS FIXED RATE OF MOTION SOFTWARE LIMITS

Specification: The MCS shall limit the rotational velocity, acceleration and jerk of the TMA to the specified maximum rates, for both axes. A method shall be available to modify these values if it is found to be necessary, however, they can only be reduced below the specified limits. This modification method shall be designed to prevent casual modification through the EUI to ensure that it is only modified by authorized personnel.

Discussion: The power off braking deceleration and hard stops, which will likely be an inherent property of the braking system, need not be modifiable through the MCS.

3.10.18 MCS ADJUSTABLE RATE OF MOTION SOFTWARE LIMITS

Specification: Besides the fixed software limits above, for both axes the maximum rotational velocity, acceleration and jerk shall have adjustable software limits readily adjustable from the EUI. Separate limits shall be provided for the observing and engineering modes. These software limits shall be adjustable but shall not exceed the fixed software limits. The MCS shall move the telescope axes at near the maximum allowable software limited velocity when covering large distances. When slewing, the MCS shall not be required to meet the pointing or tracking requirements.

Discussion: During normal maintenance, the motion limits are reduced to decrease the hazards involved with a moving telescope. However, during testing the maximum motions can be required. This mandates separate limits for observing and engineering modes.

3.10.19 MCS FIXED SOFTWARE RANGE OF TRAVEL LIMITS

Specification: The MCS shall control the TMA through its full range of travel in azimuth and elevation motions. The fixed software limits shall limit the range to the values specified in the pointing section (2.0). A method shall be available to modify these values if it is found to be necessary, however, they can only be reduced below the specified limits. This modification method shall be designed to prevent casual modification through the EUI to ensure that it is only modified by authorized personnel.

Discussion: The MCS must provide sufficient motion in the engineering mode to allow testing of the limit switches.

3.10.20 MCS ADJUSTABLE RANGE OF TRAVEL LIMITS

Specification: The MCS shall also have adjustable software limits for the range of both axes. Under engineering operations the MCS should be capable of exceeding the adjustable software limit but at velocity and acceleration limits only 10% of their normal values. The programmable software limits shall be reconfigurable only through an engineering operation and not changeable during normal operations. For the azimuth axis, these programmable limits shall be initially set at ± 270 degrees. For the elevation axis these programmable limits shall be initially set at the observing angles which are elevation angles between 15 degrees to 86.5 degrees.

3.10.21 MOTION NEAR A RANGE OF TRAVEL SOFTWARE LIMIT

Specification: Motion controllers shall be commanded to decelerate as they reach a range of travel software limit, and come to a stop within the tolerances of section 3.7.

3.10.22 TELEMETRY BUFFER

Specification: The MCS shall be able to buffer 5 minutes of telemetry locally in accordance with the telemetry persistence requirements.

Discussion: This requirement will be satisfied by the configuration of the communications infrastructure. The Contractor only needs to provide enough memory in the controller to buffer the data.

3.10.23 ENGINEERING USER INTERFACE

Specification: The MCS shall include an Engineering User Interface (EUI) which provides the features summarized below. The engineering display shall exercise all the functionality of the MCS, provide access to the reading of all the MCS sensors and shall be able to operate the actual LSST telescope onsite. The engineering display shall be used during factory assembly and testing to operate the MCS. It shall be used during factory and site acceptance testing. It shall be used to test the conformance to the TMA-TCS interface ICD.

Discussion: Although the EUI will be used for all the above purposes, its main function is to operate the telescope during maintenance and servicing.

3.10.23.1 SOFTWARE IMPLEMENTATION

Specification: The implementation of the EUI software shall be based on LabVIEW graphic programming language and framework. The EUI is not required to use the LSST communications infrastructure to communicate internally with the systems. However, as mentioned before, all software objects shall be consistently named. If available, the 64-bit version of LabVIEW and Linux shall be used. All LabVIEW licenses shall be registered to AURA. The source code shall be delivered with the control system software including all tools to recompile.

Discussion: Low level code (such as PLC code) is not included here.

3.10.23.2 MOUNT SYSTEM STATUS

Specification: The EUI shall provide a summary of the mount control system status and the output of all sensors. At a minimum, the interface shall provide access to the configuration and calibration parameters of the control system, to provide for commands to each of the components of the TMA, to provide standard tests for maintenance of the system and to provide monitoring capabilities of the telemetry published by the mount control system.

3.10.23.3 INFORMATION DISPLAY

Specification: The Engineering User Interface (EUI) shall provide a summary of the performance of the TMA. At a minimum, the Engineering User Interface shall display (values and plot) the position, velocity and acceleration of the TMA, the power consumption and provide statistical tools to compare the components performances.

3.10.23.4 TELEMETRY LOGGING

Specification: The EUI shall be able to log pertinent data locally for testing purposes and have enough storage space for at least 2 days of telemetry archiving.

Discussion: During normal operation, all TMA telemetry will be logged by LSST in the engineering facility database.

3.10.23.5 ENGINEERING AND MAINTENANCE POSITIONING

Specification: The EUI shall provide commands for and produce motions of the TMA to any location within its software allowable travel or offset motions from the current position for both the elevation and azimuth axis. The MCS shall move the telescope to the new position through the most time efficient motion profile, while remaining within its motion limits.

3.10.23.6 SOFTWARE LIMITS CHANGE

Specification: The EUI shall display all software limits, both fixed and adjustable. In engineering mode only, the user shall be able to change the adjustable limits from the EUI. However, the EUI shall restrict these values to the fixed level values, and require special authorized personnel access to modify them.

3.10.23.7 POWER UP/REBOOT

Specification: The EUI shall provide a way to reboot the system and to turn it on/off remotely. The reboot of the system shall be optimized for rapid execution. Whenever the system is powered up or rebooted it shall begin in a static (no motion) state and remain so until it is specifically commanded otherwise. After a power up/reboot, a 10 second motion delay shall occur concurrently with an audible and visible alarm before either axis can move.

Discussion: The TMA is expected to be turned on permanently during normal operation. In case of power loss, the system is expected to be able to restart automatically following the controller states defined in LTS-159.

3.10.24 NATURAL FREQUENCY AVOIDANCE

Specification: In all operations modes the motor control system shall be compatible with the natural frequencies of the TMA. Operation of the motors shall avoid excitation of these natural frequencies for both slewing and tracking.

Discussion: Natural frequency avoidance is often referred to as "notching."

3.10.25 HYDROSTATIC BEARINGS

Specification: For hydrostatic oil bearings, the MCS shall control their operation and monitor their status. At a minimum, the MCS shall monitor oil pressure, pump status, film thickness, bulk oil and shoe/guide-pad oil outlet temperatures.

3.10.26 M1M3 MIRROR COVER

Specification: The MCS shall control and monitor the position of the M1M3 mirror cover (and the local power cutoff switch) and shall make this information available to the TCS.

3.10.27 CONTROL AND MONITORING OF THERMAL CONTROL SYSTEMS

Specification: The MCS shall monitor and report the temperature of all significant heat sources of the TMA as identified in section 3.9. For all actively cooled components and where overheating can occur, thermal sensors shall be secured between the insulation and the component, and monitored as a status signal to the MCS. Mixing valves that regulate the individual thermal control systems shall be locally controlled.

Discussion: The mixing valve utilizes a very simple control system which regulates the mixing valve based on the items temperature.

3.10.28 STATUS INFORMATION

Specification: The MCS shall monitor and report the current status or change of status of the control systems and the sensors. At a minimum, the following information shall be reported continuously through the required LSST communications system:

- Position of the TMA as determined by the servo controller
- Position of the TMA as determined by the absolute encoder
- Velocity of the TMA as determined by the servo controller
- Velocity of the TMA as determined by the tachometers or by other auxiliary device
- Acceleration of TMA as determined by the servo controller
- State of all limit switches (software and electrical)
- Output current for each motor as determined by the servo controller
- Position or state of all auxiliary devices, such as locking pins, brakes, mirror cover, etc.
- Position of the deployable camera platforms
- Faults, warnings, or errors within the servo controller

3.10.29 SOFTWARE MANUALS AND DOCUMENTATION

Specification: All manuals and documentation needed to support safe operation of the control system shall be delivered. Where applicable, software shall be documented to enable debugging. The source code shall be delivered with the control system software including all tools to recompile and to verify binary equivalence.

3.10.30 BEST SOFTWARE PRACTICES

Specification: The MCS shall conform to the LSST software requirements as specified in document LTS-224, “Control Software Development Best Practices.”

3.11 INTERLOCKS AND SAFETY REQUIREMENTS

Specification: The TMA shall be compatible with the LSST telescope global interlock system requirements specified in the LSST Summit Safety Interlock System document (LTS-99) and with the TMA to Interlock System Interface Control Document (LTS-173).

3.11.1 PERSONNEL AND EQUIPMENT SAFETY

Specification: The Telescope Mount Assembly shall include brakes, dampened hard stops, stow pins for horizon and zenith pointing, emergency stops, safety interlocks and any other mechanisms necessary to ensure protection of personnel and components during normal operation and maintenance.

3.11.2 SAFETY INTERLOCK CONTROLLER

Specification: The Telescope Mount Assembly shall provide a safety interlock controller as defined in LTS-99 to implement the TMA interlocks.

3.11.3 SAFETY STANDARDS

Specification: The Telescope shall be designed to OSHA & Chilean safety standards.

Discussion: OSHA safety standards and Chilean safety standards are very similar. If the telescope is designed to OSHA safety standards then it will likely meet all the Chilean safety standards.

3.12 ELECTRICAL REQUIREMENTS

Specification: The telescope mount assembly shall meet the electrical requirements in LTS-96 and LTS-98 documents.

Discussion: The objective of these standards is to support efficient operations and minimize the dispersion of final design elements across the summit support facility and the base facility.

3.12.1 ELECTRICAL POWER

Specification: Power shall be provided at each major TMA subsystem location. The site will provide 380Y/220 V (3Ø "Y" connection, grounded neutral), 50Hz (Chilean standard) UPS power to critical components. The TMA and all of its components shall be designed to operate under the site power.

Discussion: A local backup generator will be available on site to provide enough power for operation in case of power grid failure.

3.12.2 ELECTRICAL POWER REMOVAL AND RESTORATION

Specification: The TMA and all of its components shall be designed to allow removal and restoration of power without requirements on other assemblies and/or subsystems.

3.12.3 ELECTRICAL OVER CURRENT PROTECTION

Specification: All electronic/electrical equipment must have over-current protection (e.g. thermal breakers, fuses, lightning arresters, ground-fault interrupts, surge protection, etc. as required). Fuses shall be easily accessible for replacement. All electronic/electrical equipment shall have a main line circuit breaker or power switch. When available, over current protection shall be provided according to the component manufacturer's specifications.

3.12.4 ELECTRICAL CONNECTORS

Specification: All the cabling required for the operation of the TMA or required by LTS-217 shall be continuous without using intermediate connectors. Connectors shall only be provided where required for installation, maintenance or repairs. All connectors shall meet the specifications of LTS-98. The Contractor shall provide only high-quality, rough-service electrical connectors consistent with high reliability operation and EMC constraints. Connectors shall be capable of being rapidly disconnected for service of all subassemblies. Connectors shall be sized so that within a localized assembly and/or subsystem incorrect connection is not possible. Only if absolutely necessary and approved by LSST PO, will connectors be custom keyed. Proper and appropriate strain relief shall be provided to ensure reliability and to minimize effect of cabling loads on the TMA.

3.12.5 ELECTRICAL CABLING AND TUBING

Specification: Power and signal cables shall be shielded from low and high-frequency interference. Whenever possible, power and signal wires shall be routed separately. The cabling design shall avoid ground loops. Cables and tubing shall be compatible with use within the cable wraps utilizing acceptable flexibility, size, weight and life cycles considered. All cables which go through cable wrap systems shall resist cork-screwing, and be capable of withstanding multiple reverse bends over the full specified lifetime of the telescope (i.e., continuous flexing). The jacketing material shall be resistant to oil and abrasion, and remain flexible through the survival temperatures as listed in LTS-54. All utilities shall be strain relieved at all disconnects and end points.

Shielded cables and armored fiber optic cables must also meet the above requirements. Cables designated for power must also meet the specifications for voltage and amperage capacities as per the latest U.S. National Electric Code NFPA 70.

3.12.6 RACK SPACE

Specification: Adequate rack space on the TMA shall be determined early in the design process for Contractor-supplied electronics. Contractor shall supply all required electronics.

Discussion: There is a substantial quantity of rack space inside the telescope pier and before the azimuth cable wrap available for the TMA Contractors utilization.

3.12.7 ELECTRICAL OUTLETS

Specification: Contractor shall supply at least eight general purpose electrical outlets, per LTS-52, on the TMA for powering tools and equipment during engineering and maintenance operations. The capacity and location of these outlets shall be determined with consultations with the LSST PO during the design phases of the project.

4 TELESCOPE MOUNT ASSEMBLY FABRICATION REQUIREMENTS

4.1 MATERIALS AND WORKMANSHIP

4.1.1 MATERIAL QUALITY

Specification: All materials used shall be new, of high grade commercial quality, and fulfilling the requirements of a standard commercial specification. They shall be consistent with all requirements in this document, including life cycle, reliability, and maintainability. They shall be sound and free from defects, both internal and external, such as cracks, laminations, inclusions, blow holes or porosity. Substitution of other materials, equipment, or designs not specified on submitted drawings will only be permitted where it can be shown that such items are at least equal in quality and properties to the ones originally specified. Substitution (to obtain improved performance or reduced cost) is subject to written approval by LSST.

4.1.2 WORKMANSHIP

Specification: Workmanship shall be of a high grade of commercial practice and adequate to achieve the accuracies and surface finishes called for on all drawings and in the specifications. All manufacturing processes, such as plating, welding or heat treatment, shall be specified and performed in such a manner as to achieve the strength and properties required without introducing any material defects such as hydrogen embrittlement, excessive grain growth, or residual stress concentrations.

4.1.3 EDGES AND ENDS FINISHES

Specification: All metal edges shall be free of burrs and sharp corners. No sharp edges that might constitute a hazard to personnel or equipment (cabling) shall remain on the finished components of the Assembly. The edges and ends of all plates, tubes, and fabricated sections shall be finished using appropriate methods.

4.1.4 STRUCTURAL STEEL

Specification: The TMA structure shall be fabricated from common structural steels (A36, A588, A572, etc.), fulfilling the requirements of the US or European structural steel standards. Material certification is required for all materials used in structural areas. Contractor shall submit evidence to the LSST PO that the material mills have complied with the requirements contained herein this document and/or the specifications established by Contractor's design. All structural steel to be used in the construction of the work shall be examined and tested at the mills in accordance with the requirements established by the material specifications. Reports of all mill tests, including analyses and physical tests, shall be supplied to the LSST PO. These reports shall include material certification sheets for all structural steel components. An effective means of identification of the material from the time it is shipped from the mill to the time it is erected at the Site shall be maintained. All hot rolled steel plates, shapes, sheet piling, and bars shall be new steel conforming to ASTM standards.

Where the construction specifications require materials, products, processes, equipment, etc. to be installed or applied in accordance with manufacturers' instructions, directions, or specifications etc. they shall be construed to mean that said application by the manufacturer of the material concerned is for use under conditions similar to those at the site. Such instructions shall be submitted to the LSST PO for review before any fabrication has begun.

Discussion: Meeting the seismic requirements will likely require the use of higher strength and more costly structural steel (A572 grade 60) rather than the lower strength and less costly steel (A36) for many structural components.

4.2 FASTENERS

Specification: Assembly and tightening of all bolted connections shall be performed in conformance with a common industrial standard approved by the LSST PO.

Discussion: It is the preference of the LSST PO that the Contractor use common industrial standards that they have experience with rather than for LSST to dictate specific standards.

4.3 WELDING

4.3.1 WELDING STANDARD

Specification: Welding shall be performed in accordance with a common industrial standard approved by the LSST PO.

Discussion: It is the preference of the LSST PO that the Contractor use common industrial standards that they have experience with rather than for LSST to dictate specific standards.

4.3.2 WELDING EQUIPMENT

Specification: The welding plant shall be of modern design and of adequate capacity to provide the required current to each welding point without significant fluctuation and to provide a continuous, full thickness weld, or as specified on the construction specifications.

4.3.3 WELDING TOLERANCES

Specification: Suitable allowances for contraction and expansion during welding shall be made in the lengths of the steel parts prior to welding, so that the final machined lengths are correct within the accepted tolerances.

4.3.4 WELDING PREPARATION

Specification: All structural members shall be accurately cut and fitted, securely fixed, and jigged or braced before welding to hold and maintain the parts to the drawing dimensions. The surfaces to be welded shall be dry, clean and free from loose scale, grease or unsuitable protective paints or coatings. The welding procedures shall be such that distortion and lock-in stresses are minimized. Tack welds, temporary stiffeners, tie bars, controlled peening, pre-heating, and stress relieving during welding may be used for this purpose.

4.3.5 WELDING OPERATORS

Specification: All welding operators employed in the work shall have passed a recognized qualification test for the appropriate class of work that they perform. Welding procedures shall be approved by LSST before the work is started. Trial welds to demonstrate the soundness of any proposed welding method and the competence of operators may be requested by the LSST PO prior to welding.

4.3.6 WELDING INSPECTION

Specification: All welding shall be subject to rigorous examination as to size, profile, weld cleanliness and freedom from pinholes and surface cracks.

4.3.7 WELDING LEAKAGE TESTS

Specification: Where welded components are to be used for sumps or collection pathways for oil containment, leakage tests shall be required and verified.

4.3.8 WELDING REPAIRS

Specification: Repairs to rejected welds shall be made using a procedure that is acceptable to the LSST PO. Repaired welds shall be re-examined in the same manner as the original weld.

4.4 STRESS RELIEVING

Specification: Any fabrication processing that imparts substantial stress into a component requires stress relieving. This includes all structural welds which shall be stress relieved after welding and/or prior to final machining unless approved by the LSST PO. Shop drawings shall include heat treatment specifications for all parts requiring heat treating. Temperature-time charts and records of heating, quenching treatments, material tests, etc., shall be kept and identified with the parts and submitted to the LSST PO as required for approval. Manufacturing processes such as forging that require substantial yielding shall require stress relieving.

Discussion: Stress relieving after typical machining (milling and drilling) is not required.

4.5 SURFACE FINISHES, COATINGS AND PAINTING

Specification: All materials used in the construction of the TMA that are subject to corrosion shall have surface treatments that are consistent with the 30-year design life of the telescope. All surface treatments shall be performed in accordance with a common industrial standard approved by the LSST PO.

Discussion: It is the preference of the LSST PO that the Contractor use common industrial standards that they have experience with rather than for LSST to dictate specific standards.

4.5.1 SURFACE FINISHES SELECTION

Specification: Surface finishes selection has to be approved by the LSST PO as suiting the location and function of each member. These finishes shall not adversely affect the functioning of the telescope, nor require additional maintenance during the life of the telescope. High-emissivity coatings and low-emissivity coatings shall be used where specified in section 3.2.5.

4.5.2 SURFACE FINISHES QUALITY

Specification: All parts of the telescope shall be finished so as to promote cleanliness of the telescope and to avoid contamination of any mirror surface or instrument. It is of prime importance that all protective coatings are of high quality and long life due to the high cost of recoating and the resulting interference with telescope operation. The LSST PO reserves the right to inspect all surface preparation for each individual coating prior to application. All metallic surfaces, other than mating machined surfaces, shall be painted or otherwise permanently protected against atmospheric corrosion. All exterior surfaces of the TMA shall be finished with a highly durable paint or an equivalent coating approved by the LSST PO. All structural steel not exposed to view shall be at a minimum primed with an inorganic zinc coating

4.5.3 SURFACE FINISHES DURABILITY

Specification: All finishes shall be durable against atmospheric and sun exposure, airborne dust impact, personnel access on and around the structure, and any other expected wear conditions.

5 TMA PACKING AND SHIPPING REQUIREMENTS

5.1 PACKING PREPARATION

Specification: It is the responsibility of the TMA Contractor to provide adequate packaging for all materials and equipment to protect them from damage in transit and storage. Although the Contractor is not responsible for providing the marine transportation, it is the Contractor's responsibility to ensure that all packaging is adequate for the marine environment. Due attention shall be paid to protection of bearing surfaces and other exposed critical surfaces to prevent damage. Special care shall be taken with electrical and electronic components, which shall be packed with a dehumidifying agent to effectively deal with condensation.

5.2 PACKING IDENTIFICATION

Specification: Proper identification of parts and adequate provision for slinging and handling of equipment without damage shall be made. All packaging, packing materials, slinging, and handling equipment design shall be approved for use by the LSST PO.

5.3 PACKING DISASSEMBLY

Specification: After completion of acceptance testing at the Contractor's facility, the TMA shall be disassembled into a minimum number of parts and subassemblies required for shipping and reassembly. The sizes and weights of the resulting assemblies must not exceed the maximum truck load sizes, and weights on the road (and tunnel) to the Site in LTS-54. Contractor shall design the structural components of the TMA, and disassemble them, in such a way as to meet these restrictions.

5.4 SHIPPING CONTAINERS

Specification: The parts and subassemblies shall be packaged in approved shipping containers. It may be advantageous for some subassemblies to remain in their integrated form that will not fit in a container. These subassemblies shall be packaged to survive shipping and must be approved by the LSST PO.

5.5 SHIPPING

Specification: Contractor shall be responsible for all aspects of shipping, including shipping arrangements, shipping, handling, storage costs and transportation permits from their fabrication site to a deep water port suitable for shipping to the site and approved by the LSST PO. The LSST PO will be responsible for arranging overseas shipping, customs and port of entry fees, taxes, and all other costs associated with transporting the assembly components from the port to the site.

6 TMA SITE ASSEMBLY AND INSTALLATION REQUIREMENTS

6.1 COMPONENT REQUIREMENTS FOR ON SITE ASSEMBLY

Specification: All major subassemblies shall include lifting provisions to allow proper handling during assembly and subsequent possible removal. All components of the TMA shall be designed to allow for straightforward handling and installation. TMA components shall be sized to allow passage into the completed dome and lower enclosure assembly through the dome slit and the standard doors.

6.2 ON SITE ASSEMBLY

Specification: It is the responsibility of the TMA Contractor to provide the onsite assembly, installation, and testing effort.

Discussion: On site testing procedure will be determined in collaboration between the TMA Contractor and the LSST PO.

6.3 HANDLING ON SITE

Specification: Except where stated elsewhere in this document, all lifting & handling equipment, tools, jig, and other items required for site assembly shall be provided by the Contractor. Both a construction crane and the dome crane will be provided by the LSST PO.

6.4 INSTALLATION PERSONNEL

Specification: The TMA shall be assembled by an installation team provided by the TMA Contractor. If any TMA assembly procedure requires specially trained personnel the Contractor shall provide them.

7 TMA MAINTENANCE REQUIREMENTS

Specification: The telescope mount assembly shall be designed to facilitate maintenance and the removal of the major optical assemblies as specified herein this document. The TMA shall be designed to minimize required maintenance, and shall be configured such that all necessary maintenance operations can be easily carried out without risk to personnel, the telescope or the optical systems.

7.1 SCHEDULED PREVENTIVE MAINTENANCE AND GENERAL MAINTENANCE

Specification: All scheduled preventive maintenance shall be specified and provided with final documentation. The time intervals for each type of maintenance shall be provided. Unless approved by the LSST PO, all components shall be designed such that the intervals for all maintenance are one year or greater. Each scheduled preventive maintenance and general maintenance activity shall be designed to take no longer than eight hours (a normal daytime shift) by two trained technicians.

Discussion: General maintenance encompasses activities that are required occasionally but not at specific intervals, such as cleaning. This requirement is intended to allow for all maintenance to be accomplished during a normal work day.

7.2 CORRECTIVE MAINTENANCE

Specification: The telescope mount assembly shall be designed such that all components that are subject to failure can be readily replaced. Any corrective maintenance (repair) procedures that requires two experienced technician more that a single 10 hour day shall require LSST PO approval. All equipment and procedures required for this replacement shall be provided with the mount. The list of components at a minimum shall include:

- drives
- brakes
- bearings
- gear sections
- braking surfaces
- cabling and utility lines through cable wraps

7.3 MODULAR DESIGN

Specification: Wherever possible, Contractor’s subsystems shall be organized into modules for ease of mounting/dismounting and servicing, particularly any components that have critical alignments or adjustment that would be easier to achieve in a separate work area and then installed on the telescope.

7.4 MAINTENANCE DOCUMENTATION

Specification: Written instructions for the removal, installation, servicing, alignment, and adjustment shall be provided by Contractor for all TMA subsystems. All maintenance procedures shall be approved by the LSST PO.

7.5 MAINTENANCE EQUIPMENT

Specification: The Contractor shall provide all special tools and equipment necessary for initial set-up, maintenance, and servicing operations required throughout the design lifetime of the TMA. This excludes common hand tools such as wrenches, sockets, etc. Custom stands, sights and instruments necessary for initial set-up of the system, debugging, and regular maintenance shall be delivered as special tooling and equipment. Any special handling fixtures, such as spreader bars required for handling TMA components shall be deliverable with the TMA. Special tools shall be marked with an appropriate part number. Contractor shall provide all alignment and calibration tools, including software routines for all mechanical, electrical and software components of the TMA.

At a minimum the Contractor shall provide all the following maintenance equipment. The appropriate ICD are available through LTS-221.

- Surrogate mass assemblies
- Camera Support Assembly Lifting Fixture
- Guide Rods for Camera installation/removal or similar
- Guide Rods for M2 assembly maintenance
- Second integrating structure with offset

Discussion: Both integrating structures are identical. The second integrating structure is required for onsite testing and calibration before installation of the survey camera.

7.5.1 SURROGATE MASS ASSEMBLIES

Specification: The Contractor shall supply all surrogate masses required to demonstrate the balance and performance of the Telescope Mount Assembly at the TMA Contractor's facility. These surrogates replicate the mass properties (mass and center of gravity) of the Telescope Mount Assembly payloads. Except for the M1M3 mirror cell assembly, these surrogates shall be supplied with the Telescope Mount Assembly and delivery to the site. They are required for balancing the telescopes elevation assembly during testing, integration and maintenance when the camera (camera/rotator/hexapod) and/or the secondary mirror assembly (M2 assembly/hexapod) are not installed. All surrogate masses delivered to the site will become the property of LSST.

The Contractor is also responsible for any minor surrogate masses required for testing. This specifically includes masses to represent the electronics in the top end electrical cabinets. Although two integrating structures are required by the Contractor so that both TMA testing and camera support assembly integration can proceed simultaneously, only one set of minor surrogate masses are required.

Discussion: For the onsite testing the actual M1M3 mirror cell will be used for testing with a surrogate mirror installed. The M1M3 mirror cell and the M1M3 surrogate mirror will be supplied by LSST. The M1M3 mirror cell assembly and surrogate M1M3 mirror may be available for factory testing depending on scheduling and construction locations.

7.5.1.1 CAMERA WITH HEXAPOD / ROTATOR SURROGATE MASS

Specification: The camera with hexapod and rotator surrogate mass shall attach to the TMA integrating structure following the TMA to Camera Hexapod interface LTS-182. To replicate the actual installation and removal procedures, this surrogate shall be designed as described in LTS-219. This surrogate mass shall be constructed from materials that do not flake, shed or otherwise deposit material that could fall on the M1M3 mirror below. It shall be easily cleanable. It shall be able to be stored vertically and be rotated horizontally with a crane. The camera support assembly surrogate mass shall be installable on the TMA at horizon pointing using the camera support assembly lifting fixture, after integration with the second integrating structure and offset.

To provide a reasonable representation of the actual camera, with hexapod and rotator, the natural frequency of the surrogate mass when installed on the TMA shall not vary by more than +/-1 Hz from the natural frequency of the camera, with hexapod and rotator. This requirement shall be demonstrated by FEA.

Discussion: This surrogate mass will be used for actual TMA maintenance when the elevation assembly needs to be balanced without the camera support assembly installed.

7.5.1.2 M2 MIRROR CELL ASSEMBLY / M2 BAFFLE / M2 HEXAPOD SURROGATE MASS

Specification: The M2 mirror cell assembly with M2 baffle and M2 hexapod surrogate mass shall attach to the TMA according to the TMA to M2 Hexapod interface document LTS-181. To ensure enough clearance with the camera support assembly during camera installation/removal, the surrogate mass shall not violate the M2 mirror cell envelope LTS-127.

To provide a reasonable representation of the actual M2 mirror cell assembly, with hexapod and baffle, the natural frequency of the surrogate mass when installed on the TMA shall not vary by more than +/-1 Hz from the natural frequency of the M2 mirror cell assembly, with hexapod and baffle. This requirement shall be demonstrated by FEA.

Discussion: This surrogate mass will not be used for actual TMA maintenance. A separate surrogate supplied with the M2 hexapod will be used for this purpose.

7.5.1.3 SURROGATE MASS RETRO REFLECTORS

Specification: Three laser tracker retro reflectors shall be installed on each surrogate mass for a total of 9 retro reflectors. These reflectors shall be positioned at 120 +/-1 degree about the optical axis. They shall be positioned such that they can be targeted by a laser tracker installed in the top center of the M1M3 surrogate mass during shop testing campaign and in the top center of the M1M3 surrogate mirror during on site testing campaign

Discussion: The laser trackers will be used to determine the relative motion of the three optical systems in displacement and rotation.

7.5.1.4 SURROGATE MASS INSTALLATION ALIGNMENT FEATURES.

Specification: For installation, all surrogate masses shall use the same alignment features as the items they are representing.

7.5.2 CAMERA SUPPORT ASSEMBLY LIFTING FIXTURE

Specification: A camera support assembly lifting fixture shall be provided to install and remove the camera support assembly from the TMA as a single assembly. This fixture shall be balanceable so that its CG can be aligned with the CG of the camera support assembly and with the crane hook attachment. It shall be provided with a small electric motor driven balancing system, adequate for remote balancing. It shall be designed by the TMA Contractor in collaboration with the LSST PO and supplied by the TMA Contractor.

Discussion: The entire camera, camera rotator, hexapod, camera cable wrap, thermal control system, two electrical cabinets and integrating structure are removed as a single camera support assembly. This allows the integration and testing of the entire assembly before installation on the TMA. The removal is accomplished by the overhead crane and the camera support assembly lifting fixture. This fixture is balanced so that its CG is aligned with the CG of the camera support assembly. Consequently, there is no tendency of these components to rotate about a horizontal axis. The camera support assembly cart will use the same interfaces to the camera support assembly as the integrating structure.

7.5.3 CAMERA SUPPORT ASSEMBLY GUIDE RODS

Specification: Unless another LSST PO approved method is adopted, guide rods along with their sliders shall be provided to guide the installation and removal of the camera support assembly. They shall be designed by the TMA Contractor in collaboration with the LSST PO and supplied by the TMA Contractor. The TMA Contractor is responsible for providing a safe and jam free method of installing and removing the camera support assembly.

Discussion: The entire camera, camera rotator, hexapod, camera cable wrap and integrating structure are removed as a single camera support assembly. This allows the integration and testing of the entire assembly before installation on the Telescope Mount Assembly (TMA). Guide rods and sliders are used to prevent contact of the camera support assembly with the M2 mirror cell assembly and integrating structure. Since the guide rods and their sliders closely interact with the central assembly of the top end assembly, these components are considered part of the TMA and supplied by the Contractor.

Since the Contractor is responsible for providing an effective method for removal and installation, the LSST PO will consider alternative methods if proposed by the Contractor.

7.5.4 M2 ASSEMBLY GUIDE RODS AND STRAPS

Specification: Guide rods with their sliders shall be designed for on-telescope maintenance of the M2 assembly. They shall be designed by the TMA Contractor in collaboration with the LSST PO and supplied by the TMA Contractor. The interface of these guide rods to the M2 mirror cell assembly is provided in LTS-128.

The Contractor shall provide attachment location on the TMA for straps from the M2 mirror cell structure to all four TMA piers. These locations shall provide hoist ring mounting holes. Each location shall be rated to safely support the entire mass of the M2 Mirror cell assembly. They shall be aligned along the optical axis with the CG of the M2 mirror cell assembly and baffle, when they are in the special access configuration. The actual straps will be provided by the LSST PO.

Discussion: Maintenance and repairs of the M2 cell assembly requires access to the back of the assembly. The "back" of the assembly is opposite the optical surface and is covered with removal panels. A special access configuration will be provided for on-telescope maintenance to the M2 assembly without removal of the camera. Since the guide rods and their sliders closely interact with the central assembly of the top end assembly, these components are considered components of the TMA and supplied by the Contractor.

The straps are used to provide transverse support to counteract minor seismic motions. Mounting features are provided in the M2 mirror cell assembly to accommodate these straps. Normally only the two lower straps will be utilized.

7.5.5 SECOND INTEGRATING STRUCTURE WITH OFFSET

Specification: A second complete and identical integrating structure (with offset) shall be provided to be used during maintenance. The camera assembly surrogate mass will be mounted on this second integrating structure and installed on the TMA for testing and maintenance.

Discussion: The Contractor does not need to provide an extra camera cable wrap, electrical cabinets, etc. However, the Contractor will need to provide the minor surrogate masses to represent these items as described in section 7.4.1.

7.5.6 M1M3 MIRROR SURFACE ACCESS PLATFORM SUPPORT SYSTEM INTERFACE

Specification: The TMA shall accommodate washing and drying of the M1M3 mirror when it is installed. In general, washing and drying the M1M3 principally affects the design of the M1M3 mirror cell assembly which is not considered a subassembly of the TMA and has minimal effect on the TMA design. However, the TMA shall allow access to the mirror and may require some minimal accommodations on the center section for this procedure. The only accommodations envisioned are a series of several bolt holes for supporting the platform. They shall be designed by the LSST PO in collaboration with TMA Contractor and supplied by the TMA Contractor. A valved and capped, 1.5 inch diameter connection off of the compressed air line, before it enters the M1M3 mirror cell assembly, is needed for drying and is required per LTS-217.

7.6 ACCESS AND REMOVAL OF MAJOR SUBSYSTEMS

Specification: The telescope mount assembly shall be designed to allow for access and removal/installation of the three major optical subsystems for maintenance, Primary / Tertiary (M1M3) Mirror cell assembly, secondary (M2) Mirror cell assembly and camera support assembly. Each of these assemblies must be removable as near complete assemblies with minimal mount disassembly. Since they require significant interaction with the facility, the telescope mount assembly must be designed to facilitate these removal methods. Only minor deviations will be considered and must receive written authorization from LSST PO personnel.

Discussion: The removal of the three major optical systems is not independent. Since the camera assembly protrudes through the central hole of the M2, the M2 mirror cell assembly cannot be removed without first removing the camera assembly. The camera assembly and M2 assembly must be removed with the telescope in the horizon pointing orientation. If all three optics are to be removed, the camera assembly and M2 cell assembly must first be removed with the telescope in the horizon pointing orientation and must be replaced with surrogate masses. The telescope can then be repositioned to the zenith orientation and the M1M3 cell removed. As a result of its large mass it is not practical to provide a surrogate mass for the M1M3 cell assembly.

For each optical assembly removal method outlined below, all the piping and cabling must first be disconnected. Consequently, all connections to these assemblies must be appropriate for repeated connection/disconnection. For each case reinstallation is in the opposite order as removal.

7.6.1 M1M3 CELL ASSEMBLY REMOVAL AND INSTALLATION

Specification: The TMA shall be compatible with the installation/removal of the M1M3 cell assembly from the TMA as a single unit by the specially built M1M3 mirror cell cart, LTS-169. This cart, which rides on rails into the telescope, will be supplied by the LSST PO. The rails will also be supplied by the LSST PO and installed by the Contractor in the TMA. The M1M3 cell assembly can only be removed with the telescope locked in the zenith pointing orientation.

It is also the responsibility of the Contractor to provide TMA bearings and drives that are compatible with the installation/removal of the M1M3 mirror cell assembly. Other than to support the rails where they span the gap between the rotating TMA and the fixed perimeter walkway, no temporary supports will be allowed.

Discussion: A lift system on the M1M3 cart connects the cart to the cell. The appropriate M1M3 pier flanges are disconnected and the M1M3 mirror cell is lowered by the cart. The rear piers will be disconnected at their bottom flanges and the forward piers will be disconnected at their top flanges. The cart and M1M3 mirror cell assembly with the forward piers still attached is then driven out of the telescope. Since a surrogate mass is not available for the entire M1M3 mirror cell assembly, neither the camera nor M2 mirror cell assembly can be removed once the M1M3 mirror cell assembly has been removed.

Although a more rigid configuration could be produced by increasing the attachments between the mirror cell and the TMA, the M1M3 cell assembly is attached by only four M1M3 piers to the center section of the elevation assembly. Attaching at only these four locations facilitates removal of the entire assembly, minimizes the transfer of structure flexure and vibrations through to the mirror cell, and improves the mirror seeing by increasing the air flow.

7.6.2 M2 CELL ASSEMBLY REMOVAL & INSTALLATION

Specification: The TMA shall be compatible with the installation/removal of the M2 mirror cell assembly from its hexapod as a single unit by the facility enclosure's overhead crane. This operation shall be conducted with the telescope horizon pointing. The TMA must have sufficient clearance to allow for the vertical removal of the M2 mirror cell assembly. Insufficient crane height is available for complete extraction. Consequently, a slot shall be provided in the TMA to allow the M2 mirror cell assembly to be removed transversely to the optical axis once the crane has lifted it to its maximum height. This slot shall reduce the required crane height by at least 0.65 meter over the height required to remove the M2 axially over the baffles of the top end ring.

Before the M2 mirror cell assembly is removed, the M2 baffle is disconnected and replaced with a mirror cover. Since the M2 baffle is too large to be removed, it is stowed within the TMA. The baffle stowage mechanism is a component of the TMA. It shall be designed by the TMA Contractor in collaboration with the LSST PO and supplied by the TMA Contractor. A small portion of the intermediate stray light baffle of LTS-213 may need to be removable to provide crane access for this procedure.

Discussion: Through the use of a lifting fixture the M2 mirror cell assembly is removed by the over head crane. First the M2 baffle is disconnected from the M2 cell assembly and temporarily stowed within the Telescope Mount Assembly (TMA). This may require the removal of a small portion of the intermediate baffle to provide crane assess. The M2 cell assembly is next disconnected from its hexapod flange and the hexapod remains attached to the TMA. The M2 assembly is then lifted out of the TMA and lowered onto its cart. All the lifting fixtures required for this operation will be supplied by the LSST PO.

Once the M2 mirror cell assembly has been removed it must be replaced with a surrogate mass if the telescope needs to be operated about the elevation axis. This surrogate mass will be supplied by the hexapod Contractor and is not the same surrogate mass used by the TMA Contractor to test the TMA. This surrogate mass attaches to the M2 hexapod flange and only represents the M2 mirror cell assembly. It does not represent the M2 hexapod.

Removal of the M2 cell assembly directly vertically out of the TMA would require an increase in the height of the dome by approximately 0.5 meters. This increase in height would produce an increase in mass, cost, power, thermal load and vibrations. Consequently this modification was not incorporated.

7.6.3 CAMERA SUPPORT ASSEMBLY INSTALLATION AND REMOVAL

Specification: The TMA shall be compatible with the installation/removal of the camera support assembly as a single unit by extraction along the optical axis, while the telescope is locked in the horizon pointing orientation. Before removal, a lifting fixture shall be attached to the camera support assembly. When the lifting fixture is in its installation position, its CG shall be aligned with both the CG of the camera support assembly and crane hook attachment. Proper positioning of these CGs will require a small motor driven counter weight on the lifting fixture. Guide rods will be used to prevent contact of the camera support assembly with the M2 mirror cell assembly and integrating structure. The lifting fixture, with motorized counterweight, and the guide rods are components of the TMA. They shall be designed by the TMA Contractor in collaboration with the LSST PO and supplied by the TMA Contractor. The Contractor shall also provide a second integrating structure and offset which are required for temporary balance of the elevation assembly.

Discussion: By aligning the CG of the lifting fixture with the CG of the camera support assembly and the crane attachment location, the optical axis of the camera support assembly will remain horizontal during installation/removal.

Once the camera support assembly has been removed its mass must be replaced if the telescope needs to be operated about the elevation axis. The surrogate mass used by the TMA Contractor for testing along with the second integrating structure and second offset will be used for this configuration. This surrogate mass, which represents the camera with hexapod and rotator, attaches to the identical flange as the camera hexapod. Additional Surrogate masses required to match the total mass of the camera support assembly will be supplied by the LSST PO.

7.6.4 M1M3 MIRROR CELL ASSEMBLY MAINTENANCE ACCESS

Specification: The TMA shall be configured such that the access port of the M1M3 Cell assembly is directly accessible from the utility floor as stated in the Utility Floor section.

7.6.5 M2 CELL ASSEMBLY SPECIAL ACCESS CONFIGURATION

Specification: The TMA shall accommodate the special access configuration for the temporary relocation of the M2 assembly along the optical axis without removal of the camera support assembly. This special access configuration shall provide at least 0.75 meter of clearance behind the M2 cell assembly. During this relocation, the M2 assembly shall be supported by the overhead crane and guided by guide rods through the structure of the central assembly of the top end assembly. These guide rods shall be locked into place once the M2 assembly has been relocated. These guide rods shall be designed by the TMA Contractor in collaboration with the LSST PO and supplied by the TMA Contractor. The lifting equipment utilized for this application shall be the same LSST supplied equipment used to remove the M2 mirror cell assembly. Once the M2 mirror cell assembly is in this special configuration, straps from the mirror cell to the top end assembly piers provide resistance to seismic motions.

7.6.6 SERVICING CRANE ACCESS

Specification: The Telescope Mount Assembly shall keep clear the areas identified in drawing LTS-223. These areas are used to access the camera with the overhead crane during servicing.

7.7 SPARES AND CONSUMABLES

Specification: Adequate consumables to meet 30 years of service shall be provided for all components that are not expected to survive the 30 year life. Servicing instructions shall include inspections of such equipment to evaluate conditions on a periodic basis. A list of all components that are not expected to meet the 30 year life shall be provided along with their predicted life time.

At least one spare shall be provided for all major components that could fail during the TMA's lifetime. At a minimum this requires that one complete assembly of each of the following shall be provided.

- azimuth motor assembly
- elevation motor assembly
- azimuth brake assembly
- elevation brake assembly
- elevation axis bearing
- azimuth axis bearing
- azimuth encoder head
- elevation encoder head
- motor controller

8 CODES AND STANDARDS

Specification: Standardized codes and regulations shall form a partial basis of compliance for design and construction. The most current released edition available shall be used. In the case of conflict between a standard and this document, this document shall prevail. Example standards to be used include:

- International Building Code
- AISC American Institute of Steel Construction AISC Manual of Steel Construction, 9th ed. AISC Specification for the Design, Fabrication, And Erection of Structural Steel for Buildings
- AWS American Welding Society AWS D1.1-92 "Structural Welding Code – Steel"
- ASTM American Society for Testing and Materials
- ANSI American National Standards Institute
- SSPC Steel Structures Painting Council, Good Painting Practice, Steel Structure Painting
- U.S. Occupancy Safety and Health Administration (OSHA)
- Environmental Protection Agency (EPA)
- National Fire Protection Association (NFPA): National Electric Code
- International Code Council (ICC): International Building Code, Fire Code
- Chilean Standards from "Normas de Chile"
- National Optical Astronomy Observatory Risk Management Policy
- Department Of Energy National Laboratories

Only US, European or Chilean Standard may be utilized. It is the responsibility of the Contractor to determine the most appropriate standard for each application, however each standard chosen shall be approved by LSST. The Contractor shall submit copies of the standards referenced when requested by LSST.

Discussion: It is the preference of the LSST PO that the Contractor use common industrial standards that they have experience with rather than for LSST to dictate specific standards.

9 QUALITY ASSURANCE

Included in each major numbered specification listed in this document is a requirement verification method. These verification methods specify the minimum standards of verification required by the LSST PO to ensure that the individual requirements and specifications are met. All verification activities shall be the responsibility of the Contractor. The Contractor shall be solely responsible for providing any and all test equipment, analyses, inspections, personnel, and other means necessary to verify that the specifications and requirements have been met.

All equipment and standards used in acceptance testing shall be calibrated and traceable to established standards to ensure accuracy and integrity of testing. These tests shall be satisfactorily performed to demonstrate compliance with the stated requirements in this specification prior to the Assembly acceptance. All the test results shall be summarized in a verification document.

The following methods shall be used to verify the design and performances of the TMA:

- **Inspection (I):** simple mechanical and electrical examination or other forms of investigation
- **Analysis (A):** mathematical models or simulations or other scientific principles to provide evidence that stated requirements were met
- **Test (T):** determination by technical means of the properties or performances to be met
- **Demonstration (D):** actual operation of the system to demonstrate that the performances are met

The Contractor shall be responsible for performance of all verifications shown in the verification matrix to verify conformance to the requirements.

All analyses, test results (with calibration records) and other verification reports shall be provided to the LSST PO in written report electronic (MS Word or Excel) format. All reports shall include Title, Author, Date and Revision Number.

LSST TELESCOPE MOUNT ASSEMBLY VERIFICATION MATRIX					
	REQUIREMENTS	**I**	**A**	**T**	**D**
2	TELESCOPE MOUNT ASSEMBLY PERFORMANCE REQUIREMENTS	NA			
2.1	POINTING REQUIREMENTS	NA			
2.1.1	POINTING RANGE IN ELEVATION		x		x
2.1.2	POINTING RANGE IN AZIMUTH		x		x
2.1.3	ABSOLUTE POINTING ACCURACY	NA			
2.1.4	RELATIVE POINTING ACCURACY		x	x	x
2.1.5	POINTING REPEATABILITY			x	x
2.1.6	RELATIVE OFFSET POINTING BETWEEN ADJACENT FIELDS		x	x	x
2.2	SLEWING REQUIREMENTS		x	x	x
2.2.1	SLEW AND SETTLE TIME FOR AN OFFSET OF 3.5 DEGREES		x	x	x
2.2.2	SLEWING RATE LIMITS		x	x	x
2.2.2.1	MAXIMUM SLEWING RATE		x	x	x
2.2.2.2	MINIMUM SLEWING RATE		x	x	x
2.2.3	MOTION PROFILE		x	x	x
2.2.4	DUTY CYCLE		x		
2.3	TRACKING REQUIREMENTS	NA			
2.3.1	TRACKING RANGE IN AZIMUTH		x	x	x
2.3.2	TRACKING RANGE IN ELEVATION		x	x	x
2.3.3	TRACKING VELOCITY RANGE		x	x	x
2.3.4	TRACKING DRIFT		x	x	x
2.3.5	TRACKING JITTER		x	x	x
2.3.5.1	TRACKING JITTER ABOUT ELEATION AXIS		x	x	x
2.3.5.2	TRACKING JITTER ABOUT AZIMUTH AXIS		x	x	x
3	TELESCOPE MOUNT ASSEMBLY DESIGN REQUIREMENTS	NA			
3.1	GENERAL REQUIREMENTS	NA			
3.1.1	ALT-AZ TMA DESIGN	x			
3.1.2	TOTAL MOVING MASS REQUIREMENT		x	x	
3.1.3	TOTAL FIXED MASS REQUIREMENT		x	x	
3.1.4	INTERFACE WITH PIER	x	x		
3.1.5	MAXIMUM ALLOWABLE ENVELOPE	x	x		
3.1.6	ENVIRONMENTAL REQUIREMENTS		x		
3.1.7	RELIABILITY AND LIFETIME REQUIREMENTS		x		
3.1.7.1	FATIGUE AND WEAR		x		
3.1.8	COMMONALITY OF DESIGN	x	x		
3.1.9	COMMON COMPONENTS	x	x		
3.1.10	OBSTRUCTION TO VENTILATION	x	x		
3.1.11	VENTING REQUIREMENTS	x	x		
3.1.12	DE-RATING REQUIREMENTS	x	x		
3.1.13	LIGHT SOURCES AVOIDANCE	x			
3.1.14	COMPONET LABELING	x			

3.2	OPTICAL REQUIREMENTS	NA			
3.2.1	OPTICAL LOCATIONS		x	x	
3.2.2	OPTICAL AXIS DEFINITION		x	x	
3.2.3	FIELD OF VIEW	x	x		
3.2.4	CLEAR OPTICAL PATH	x	x		
3.2.5	CLEAR APERTURE OBSCURATION		x		
3.2.6	STRAY LIGHT ATTENUATION	x			
3.2.6.1	STRAY LIGHT BAFFLES	x			
3.2.6.2	STRAY LIGHT VANES	x			
3.2.7	AXES ALIGNMENT	NA			
3.2.7.1	PARALLELISM BETWEEN GRAVITATIONAL VECTOR AND AZIMUTH AXIS		x	x	
3.2.7.2	PERPENDICULARITY BETWEEN GRAVITATIONAL VECTOR AND AZIMUTH AXIS		x	x	
3.2.7.3	PERPENDICULARITY BETWEEN ELEVATION AND OPTICAL AXES		x	x	
3.3	STRUCTURAL REQUIREMENTS	NA			
3.3.1	BASIC REQUIREMENTS	NA			
3.3.1.1	STRUCTURAL INTERFACE REPEATABILITY	x	x		
3.3.1.2	STRUCTURAL HYSTERESIS	x	x		
3.3.2	PAYLOADS		x		
3.3.3	NATURAL FREQUENCIES		x		
3.3.3.1	NATURAL FREQUENCIES INFINITE SUPPORT		x		
3.3.3.2	NATURAL FREQUENCIES WITH LSST SUPPLIED FEA MODELS		x		
3.3.4	VARIATION IN NATURAL FREQUENCIES WITH AZIMUTH ANGLE	x	x		
3.3.5	VARIATION IN NATURAL FREQUENCIES WITH ELEVATION ANGLE		x		
3.3.6	VIBRATION COUPLING		x		
3.3.7	STATIC DEFLECTION	NA			
3.3.8	WIND LOADING		x		
3.3.9	VIBRATION EXCITATION	NA			
3.3.9.1	DYNAMIC BALANCE		x	x	
3.3.9.2	NATURAL FREQUENCY AVOIDANCE		x		
3.3.9.3	VIBRATION ISOLATION	x	x		
3.3.10	SEISMIC REQUIREMENTS	NA			
3.3.10.1	SEISMIC SURVIVAL EVENT		x		
3.3.10.2	SEISMIC RECOVERABLE EVENT		x		
3.3.10.3	SEISMIC OPERABLE EVENT		x		
3.3.10.4	SEISMIC MAINTENANCE EVENT		x		
3.3.10.5	TMA SEISMIC ANALYSIS		x		
3.3.10.6	TOP END COMBINED SEISMIC ACCELERATIONS		x		
3.3.11	STRUCTURAL DESIGN	NA			
3.3.11.1	STRUCTURAL STRESS		x		
3.3.11.2	STRUCTURAL YEILD FACTOR OF SAFETY		x		
3.3.11.3	STRUCTURAL ULTIMATE AND BUCKLING FACTOR OF SAFETY		x		

3.3.12	JOINT DESIGN		x		
3.3.13	FASTENERS STANDARDS	x			
3.4	ELEVATION CENTER SECTION	NA			
3.4.1	M1M3 MIRROR CELL ASSEMBLY INTERFACE	x	x	x	x
3.4.2	CELL PIERS MOUNTING REPEATABILITY	x	x		
3.5	TOP END ASSEMBLY	NA			
3.5.1	SPIDERS	NA			
3.5.1.1	SPIDER DESIGN	x	x		
3.5.1.2	HOLLOW SPIDERS	x			
3.5.2	CENTRAL ASSEMBLY	NA			
3.5.2.1	CENTRAL ASSEMBLY CONFIGURATION	x			
3.5.2.2	CENTRAL ASSEMBLY - M2 HEXAPOD INSTALLATION POSITIONING	x	x	x	
3.5.2.3	CENTRAL ASSEMBLY - M2 MIRROR CELL ASSEMBLY AND CAMERA COLLISION	x	x		
3.5.2.4	CENTRAL ASSEMBLY INTEGRATING STRUCTURE MOUNTING REPEATABILITY	x	x		
3.5.2.5	CENTRAL ASSEMBLY THERMAL SYSTEM	x	x		
3.5.2.6	CENTRAL ASSEMBLY PANELS	x			
3.5.2.7	CENTRAL ASSEMBLY ELECTRICAL CABINETS	x	x		
3.5.3	TOP END NATURAL FREQUENCIES		x		
3.5.3.1	TOP END NATURAL FREQUENCIES INFINITE SUPPORT		x		
3.5.3.2	TOP END NATURAL FREQUENCIES WITH LSST SUPPLIED MODELS		x		
3.6	FLOORING, PLATFORMS, LADDERS AND STAIRS	NA			
3.6.1	PERSONNEL ACCESS	x			
3.6.2	LIGHT MANUFACTURING FLOORS		x		
3.6.3	PERFORATED FLOORS	x			
3.6.4	COATING FOR NON PERFORATED FLOORS	x	x		
3.6.5	PROTECTION	x			
3.6.6	AZIMUTH FLOOR	NA			
3.6.6.1	AZIMUTH FLOOR COVERAGE	x			
3.6.6.2	AZIMUTH FLOOR VENTING	x			
3.6.6.3	AZIMUTH FLOOR INTERFACE WITH M1M3 MIRROR CELL CART	x		x	x
3.6.6.4	AZIMUTH FLOOR INTERFACE WITH M1M3 MIRROR CELL RAILS	x		x	x
3.6.6.5	AZIMUTH FLOOR INTERFACE WITH M1M3 MIRROR CELL HARD STOPS	x	x		x
3.6.6.6	AZIMUTH FLOOR INTERFACE WITH FACILITIES FLOOR	x			
3.6.6.7	UTILITY FLOOR	x			
3.6.6.8	UTILITY FLOOR REMOVAL	x			x
3.6.7	ELEVATION PLATFORM	x	x		
3.6.8	DEPLOYABLE PLATFORMS	x			
3.6.8.1	CAMERA ACCESS		x	x	x
3.6.8.2	DEPLOYABLE PLATFORMS EXTENSION		x	x	x
3.6.8.3	DEPLOYABLE PLATFORMS INTERLOCK		x	x	x
3.6.8.4	DEPLOYABLE PLATFORMS LABELING	x			

3.6.9	STAIR/LADDER/HATCH ACCESS	x			
3.6.9.1	UTILITY FLOOR HATCH LOCATIONS	x			
3.6.9.2	UTILITY FLOOR HATCH SIGNAGE	x			
3.6.9.3	UTILITY FLOOR HATCH SENSORS	x		x	x
3.6.9.4	UTILITY FLOOR HATCH TERMINATIONS	x			
3.7	DRIVE AND BEARING SYSTEM	NA			
3.7.1	DRIVE SYSTEM CONFIGURATION	x			
3.7.2	DRIVE SYSTEM COMPOSITION	x	x		
3.7.3	AZIMUTH DRIVES LOCATION	x			
3.7.4	DRIVE SYSTEM THERMAL CONTROL		x	x	
3.7.5	DRIVE SYSTEM REGENERATIVE BRAKING		x	x	x
3.7.6	DRIVE SYSTEM POWER OFF BRAKING		x	x	x
3.7.7	SOFTWARE LIMITS, LIMIT SWITCHES, AND HARD STOP TRAVEL LIMITS		x	x	x
3.7.7.1	ADJUSTABLE SOFTWARE TRAVEL LIMITS		x	x	x
3.7.7.2	OPERATIONAL DIRECTIONAL TRAVEL LIMIT SWITCHES		x	x	x
3.7.7.3	FIXED SOFTWARE TRAVEL LIMITS		x	x	x
3.7.7.4	FIXED DIRECTIONAL TRAVEL LIMIT SWITCHES		x	x	x
3.7.7.5	POWER OFF TRAVEL LIMIT SWITCHES		x	x	x
3.7.7.6	HARD STOPS TRAVEL LIMITS		x	x	x
3.7.8	SOFTWARE AND POWER OFF VELOCITY LIMITS		x	x	x
3.7.8.1	ADJUSTABLE SOFTWARE VELOCITY LIMITS		x	x	x
3.7.8.2	FIXED SOFTWARE VELOCITY LIMITS		x	x	x
3.7.8.3	POWER OFF VELOCITY LIMITS		x	x	x
3.7.9	SOFTWARE ACCELERATION AND JERK LIMITS		x	x	x
3.7.9.1	ADJUSTABLE SOFTWARE ACCELERATION AND JERK LIMITS		x	x	x
3.7.9.2	FIXED SOFTWARE ACCELERATION AND JERK LIMITS		x	x	x
3.7.10	AZIMUTH AND ELEVATION ENCODER SYSTEMS	NA			
3.7.10.1	AZIMUTH TAPE ENCODER SYSTEM	x			
3.7.10.2	ELEVATION TAPE ENCODER SYSTEM	x			
3.7.10.3	TAPE ENCODER SYSTEM DIGITIZER	x			
3.7.10.4	ENCODER SYSTEM RANGE	x		x	x
3.7.10.5	ENCODER SYSTEM ABSOLUTE POSITION	x		x	
3.7.10.6	ENCODER SYSTEM RESOLUTION		x	x	x
3.7.11	AZIMUTH BEARING TRACK SEGMENT JOINTS		x	x	x
3.7.12	BRAKING AND HARD STOP DECCELERATION LIMITS		x	x	x
3.7.13	AZIMUTH TOPPLE BLOCK SYSTEM		x	x	x
3.8	ANCILLARY COMPONENTS AND EQUIPMENT	x			
3.8.1	ELEVATION LOCKING PIN ASSEMBLIES	NA			
3.8.1.1	LOCKING PIN CONFIGURATION	x			
3.8.1.2	LOCKING PIN INSERTION POSITIONS	x			
3.8.1.3	LOCKING PIN POSITION SWITCHES	x		x	
3.8.1.4	LOCKING PIN SAFETY FACTOR		x		
3.8.1.5	ZENITH POINTING LOCKING POSITION ACCURACY		x	x	x
3.8.1.6	HORIZON POINTING LOCKING POSITION ACCURACY		x	x	x

3.8.2	BALANCING SYSTEM	NA			
3.8.2.1	BALANCING SYSTEM CONFIGURATION	x	x		
3.8.2.2	BALANCING SYSTEM TESTING			x	x
3.8.2.3	MOTORIZED FINE BALANCING OF TELESCOPE	x	x	x	x
3.8.2.4	COARSE BALANCING OF TELESCOPE	x	x	x	x
3.8.3	DAMPING SYSTEM		x	x	
3.8.4	CABLE WRAP ASSEMBLIES AND UTILITY ROUTING	NA			
3.8.4.1	CABLE WRAPS AND CABLE ROUTING	x	x	x	x
3.8.4.2	UTILITIES AND SERVICES LINES	x			
3.8.4.3	CABLE WRAPS SPARE CAPACITY	x	x		
3.8.4.4	CABLE WRAPS OPERATION		x	x	x
3.8.4.5	CAMERA CABLE WRAP	x			
3.8.4.6	AZIMUTH CABLE WRAP CONFIGURATION	x			
3.8.4.7	ELEVATION CABLE WRAP CONFIGURATION	x			
3.8.4.8	CABLE WAYS	x			
3.8.4.9	CABLE WAYS DESIGN	x			
3.8.4.10	ROUTING THROUGH THE TOP END SPIDERS	x			
3.8.4.11	COOLING LINES	x			
3.8.4.12	PIPING JOINTS	x			
3.8.4.13	PIPING CLEANLINESS	x			
3.8.4.14	PIPING LABELING	x			
3.8.5	M1M3 MIRROR COVER ASSEMBLY	NA			
3.8.5.1	M1M3 MIRROR COVER CONFIGURATION	x	x		
3.8.5.2	M1M3 MIRROR COVER CONTROL			x	x
3.8.5.3	M1M3 MIRROR COVER STATUS	x		x	x
3.8.5.4	M1M3 MIRROR COVER BRAKING SYSTEM		x	x	x
3.8.5.5	M1M3 MIRROR COVER POWER CUTOFF SWITCH	x		x	x
3.8.5.6	M1M3 MIRROR COVER OPENING/CLOSING DURATION			x	x
3.8.5.7	M1M3 MIRROR COVER MARKING	x			
3.8.5.8	M1M3 MIRROR COVER PROTECTION LEVEL		x		
3.8.5.9	M1M3 MIRROR COVER MATERIAL AND LUBRICATION	x	x		
3.8.5.10	M1M3 MIRROR COVER OPEN POSITION	x	x		
3.8.5.11	M1M3 MIRROR COVER BALANCE IMPACT		x		
3.8.6	STATUS AND SENSING SYSTEM	x	x	x	x
3.8.6.1	AZIMUTH CABLE WRAP STATUS AND SENSING SYSTEM	x	x	x	x
3.8.7	SAFETY TIE POINTS	x	x		
3.8.8	SEISMIC RESTRAINTS	x	x		
3.8.9	LSST M2 BAFFLE TEMPORARY SUPPORT	x	x		x
3.9	THERMAL CONTROL	x	x		
3.9.1	GLYCOL WATER THERMAL CONTROL SYSTEM	NA			
3.9.1.1	SURFACE TEMPERATURE		x		

3.9.1.2	INSULATION	x			
3.9.1.3	COOLING SYSTEM CONFIGURATION	x	x	x	
3.9.2	TOP END THERMAL CONTROL	NA			
3.9.2.1	TOP END THERMAL CONTROL SYSTEM GLYCOL/WATER SUPPLY	x	x	x	
3.9.2.2	TOP END THERMAL CONTROL SYSTEM CONFIGURATION	x	x	x	x
3.9.2.3	TOP END THERMAL CONTROL SYSTEM COOLING LOAD REQUIREMENTS		x	x	x
3.9.2.4	M2 MIRROR CELL ASSEMBLY THERMAL CONTROL SYSTEM AIR COOLING	x	x	x	
3.9.2.5	CAMERA HEXAPOD/ROTATOR THERMAL CONTROL SYSTEM COOLING AIR	x	x	x	x
3.9.2.6	TOP END ELECTRICAL CABINETS	x	x	x	x
3.9.2.7	LEAK CONTROL AND DETECTION	x	x	x	x
3.9.2.8	CAMERA CABLE WRAP COOLANT LINE	x	x		
3.9.3	VENTILATION OF ENCLOSED SPACES	x	x	x	
3.9.4	MINIMIZATION OF CONDENSATION HAZARD	x	x		
3.9.5	HYDROSTATIC BEARINGS PUMPS AND COOLERS	x	x	x	x
3.10	MOUNT CONTROL SYSTEM	x		x	x
3.10.1	LOCAL OPERATION	x		x	x
3.10.1.1	LOCAL OPERATION PERFORMANCE LIMIT			x	x
3.10.2	REMOTE OPERATION	x		x	x
3.10.3	OPERATION MODES	NA			
3.10.3.1	OBSERVING MODE			x	x
3.10.3.2	ENGINEERING MODE			x	x
3.10.4	READINESS			x	x
3.10.5	CONNECTION TO THE TCS			x	x
3.10.6	MCS MOUNT CONTROLLER		x	x	x
3.10.7	MCS SYSTEM INTERFACES			x	x
3.10.8	CONTROL COMMANDS	x		x	x
3.10.9	TELEMETRY	x		x	x
3.10.10	EVENTS	x		x	x
3.10.11	TIME	x			
3.10.12	MCS MOUNT POSITIONING COMMAND			x	x
3.10.13	MCS CAMERA CABLE WRAP POSITIONING COMMAND			x	x
3.10.14	MCS POSITIONING UPDATE FREQUENCY	x	x		
3.10.15	MCS POSITIONING TOLERANCES			x	x
3.10.16	MCS MOTION PROFILE		x	x	x
3.10.17	MCS FIXED RATE OF MOTION SOFTWARE LIMITS	x		x	x
3.10.18	MCS ADJUSTABLE RATE OF MOTION SOFTWARE LIMITS	x		x	x
3.10.19	MCS FIXED SOFTWARE RANGE OF TRAVEL LIMITS	x		x	x
3.10.20	MCS ADJUSTABLE RANGE OF TRAVEL LIMITS	x		x	x
3.10.21	MOTION NEAR A RANGE OF TRAVEL SOFTWARE LIMIT	x		x	x
3.10.22	TELEMETRY BUFFER		x	x	x

3.10.23	ENGINEERING USER INTERFACE	x		x	x
3.10.23.1	SOFTWARE IMPLEMENTATION	x			
3.10.23.2	MOUNT SYSTEM STATUS	x			
3.10.23.3	INFORMATION DISPLAY	x			
3.10.23.4	TELEMETRY LOGGING	x	x		x
3.10.23.5	ENGINEERING AND MAINTENANCE POSITIONING	x	x	x	x
3.10.23.6	SOFTWARE LIMITS CHANGE	x		x	x
3.10.23.7	POWER UP/REBOOT	x		x	x
3.10.24	NATURAL FREQUENCY AVOIDANCE		x		
3.10.25	HYDROSTATIC BEARINGS	x		x	x
3.10.26	M1M3 MIRROR COVER	x		x	x
3.10.27	CONTROL AND MONITORING OF THERMAL CONTROL SYSTEMS	x		x	x
3.10.28	STATUS INFORMATION	x		x	x
3.10.29	SOFTWARE MANUALS AND DOCUMENTATION	x			
3.10.30	BEST SOFTWARE PRACTICES	x			
3.11	INTERLOCKS AND SAFETY REQUIREMENTS	x	x	x	x
3.11.1	PERSONNEL AND EQUIPMENT SAFETY	x	x		
3.11.2	SAFETY INTERLOCK CONTROLLER	x	x		
3.11.3	SAFETY STANDARDS	x			
3.12	ELECTRICAL REQUIREMENTS	x	x		
3.12.1	ELECTRICAL POWER	x		x	
3.12.2	ELECTRICAL POWER REMOVAL AND RESTORATION			x	x
3.12.3	ELECTRICAL OVER CURRENT PROTECTION	x	x		
3.12.4	ELECTRICAL CONNECTORS	x			
3.12.5	ELECTRICAL CABLING AND TUBING	x	x		
3.12.6	RACK SPACE	x	x		
3.12.7	ELECTRICAL OUTLETS	x		x	
4	TELESCOPE MOUNT ASSEMBLY FABRICATION REQUIREMENTS				
4.1	MATERIALS AND WORKMANSHIP	NA			
4.1.1	MATERIAL QUALITY	x			
4.1.2	WORKMANSHIP	x			
4.1.3	EDGES AND ENDS FINISHES	x			
4.1.4	STRUCTURAL STEEL	x			
4.2	FASTENERS	NA			
4.3	WELDING	NA			
4.3.1	WELDING STANDARD	x			
4.3.2	WELDING EQUIPMENT	x			
4.3.3	WELDING TOLERANCES	x	x		
4.3.4	WELDING PREPARATION	x			
4.3.5	WELDING OPERATORS	x			
4.3.6	WELDING INSPECTION	x			
4.3.7	WELDING LEAKAGE TESTS	x		x	
4.3.8	WELDING REPAIRS	x			

4.4	STRESS RELIEVING	x	x		
4.5	SURFACE FINISHES, COATINGS AND PAINTING	x	x		
4.5.1	SURFACE FINISHES SELECTION	x	x		
4.5.2	SURFACE FINISHES QUALITY	x	x		
4.5.3	SURFACE FINISHES DURABILITY	x	x		
5	TMA PACKING AND SHIPPING REQUIREMENTS	NA			
5.1	PACKING PREPARATION	x			
5.2	PACKING IDENTIFICATION	x			
5.3	PACKING DISASSEMBLY	x			
5.4	SHIPPING CONTAINERS	x			
5.5	SHIPPING	x	x		
6	TMA SITE ASSEMBLY AND INSTALLATION REQUIREMENTS	NA			
6.1	COMPONENT REQUIREMENTS FOR ON SITE ASSEMBLY	x	x	x	
6.2	ON SITE ASSEMBLY PROCEDURES	x	x		
6.3	HANDLING ON SITE	x			
6.4	INSTALLATION PERSONNEL	x			
7	TMA MAINTENANCE REQUIREMENTS	x			
7.1	SCHEDULED PREVENTATIVE MAINTENANCE AND GENERAL MAINTENANCE	x	x		x
7.2	CORRECTIVE MAINTENANCE	x	x		x
7.3	MODULAR DESIGN	x			
7.4	MAINTENANCE DOCUMENTATION	x			
7.5	MAINTENANCE EQUIPMENT	x			
7.5.1	SURROGATE MASS ASSEMBLIES	x	x		x
7.5.1.1	CAMERA WITH HEXAPOD / ROTATOR SURROGATE MASS	x	x		x
7.5.1.2	M2 MIRROR CELL ASSEMBLY / M2 BAFFLE / M2 HEXAPOD SURROGATE MASS	x	x		x
7.5.1.3	SURROGATE MASS RETRO REFLECTORS	x			
7.5.1.4	SURROGATE MASS INSTALLATION ALIGNMENT FEATURES	x			
7.5.2	CAMERA SUPPORT ASSEMBLY LIFTING FIXTURE	x	x	x	x
7.5.3	CAMERA SUPPORT ASSEMBLY GUIDE RODS	x	x	x	x
7.5.4	M2 ASSEMBLY GUIDE RODS AND STRAPS	x	x	x	x
7.5.5	SECOND INTEGRATING STRUCTURE WITH OFFSET	x			x
7.5.6	M1M3 MIRROR SURFACE ACCESS PLATFORM SUPPORT SYSTEM INTERFACE	x			
7.6	ACCESS AND REMOVAL OF MAJOR SUBSYSTEMS		x		x
7.6.1	M1M3 CELL ASSEMBLY REMOVAL AND INSTALLATION		x		x
7.6.2	M2 CELL ASSEMBLY REMOVAL & INSTALLATION		x		x
7.6.3	CAMERA SUPPORT ASSEMBLY INSTALLATION AND REMOVAL		x		x
7.6.4	M1M3 MIRROR CELL ASSEMBLY MAINTENANCE ACCESS	x			
7.6.5	M2 CELL ASSEMBLY SPECIAL ACCESS CONFIGURATION	x	x		x
7.6.6	SERVICING CRANE ACCESS	x	x		x
7.7	SPARES AND CONSUMABLES	x	x		
8	CODES AND STANDARDS	x			