Requirements for

K1DM3: THE KECK I DEPLOYABLE TERTIARY MIRROR

Version 3.1
October 17, 2014

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1 INTRODUCTION

The National Science Foundation (NSF) has, through its MRI program, funded the design, fabrication, and commissioning of a new and deployable (D) tertiary mirror (M3) for the Keck I (K1) telescope, with the acronym "K1DM3". The K1DM3 is intended to help enable rapid changes between any of the instruments mounted at the Cassegrain, Nasmyth, or bent Cassegrain foci of Keck I. This technology will advance the capability of the W. M. Keck Observatory (WMKO) to perform time domain astronomy (TDA), e.g. high-cadence observations of a single target on multiple nights or target-of-opportunity (ToO) observations of a new and rapidly changing source. The Principal Investigator (PI) of the K1DM3 project is J. Xavier Prochaska of the University of California Observatories (UCO). The Co-PIs are Jerry Nelson of UCO and Taft Armandroff of WMKO. It is planned that the majority of design and fabrication work will occur in the UCO shops with support and assistance from WMKO staff. Program management for the project is under the WMKO Instrument Program Manager and the project will follow the WMKO development process phases and with reviews at each phase conducted by WMKO.

This document details the systems requirements for K1DM3. These are intended to maximize the scientific impact of K1DM3 while maintaining the efficiency and performance of the existing Keck I telescope.

2 SCOPE AND APPLICABILITY

This document establishes requirements for all aspects of the Keck I deployable tertiary mirror (K1DM3).

This revision of the document incorporates updates and additions resulting from the K1DM3 Preliminary Design (PD) phase. The requirements established in this document will also guide the next and final design phase, Detailed Design.

3 REFERENCES

3.1 Related Documents

1. Adkins, S. (2009). Average annual atmospheric conditions for the summit of Mauna Kea. Waimea, HI: W. M. Keck Observatory.

2. Adkins, S. (2013). K1DM3 Design Note, Tertiary Mirror in Beam Positioning Requirements, Version 1. Waimea, HI: W. M. Keck Observatory.

3. Gordon, Colin G. (1992). Generic Criteria for Vibration-Sensitive Equipment. *SPIE 1619*, pp. 71-85.

4. The Institute of Electrical and Electronic Engineers, Inc. [IEEE] (2009). IEEE Standards Style Manual. Retrieved from http://www.ieee.org/portal/site/iportals

5. Nelson, J. E., Mast, T. S., & Faber, S. M. (1985). The Design of the Keck Observatory and Telescope (10 Meter Telescope). University of California and the California Institute of Technology.

6. Prochaska, J.X., Pistor, C., Cabak, G., Cowley, D.J., Nelson, J. (2012). Keck 1 deployable tertiary mirror (K1DM3). *SPIE*, 8444, pp.4-X

7. Prochaska, J.X., Nelson, J., Armandroff, T. (2013). MRI: Development of a Deployable Tertiary Mirror for the Keck I Telescope. NSF proposal AST-1337609.

8. Thompson, A. & Taylor, B. (2008). The NIST Guide for the use of the International System of Units. NIST Special Publication 811, 2008 Edition. Gaithersburg, MD: National Institute of Standards and Technology.

3.2 Referenced Standards

3.2.1 Industry Consensus Standards

Table 1 lists the industry consensus standards referenced in this document in alphabetical order by standardizing organization. Unless otherwise noted all references to standards are included because compliance with some part of each standard is required.

Table 1: Referenced standards

Source (Organization or Standardizing Body)	Number	Title
ANSI	Y14.1-2012	Decimal Inch Drawing Sheet Size And Format
ANSI	Y14.34-2008	Parts Lists, Data Lists, And Index Lists: Associated Lists
ANSI	Y14.3-2012	Orthographic and Pictorial Views
ANSI / ASME	Y14.18M-1986 (R1998)	Optical Parts (Engineering Drawings and Related Documentation Practices)
ANSI/ASME	Y14.36M-1996 (R2008)	Surface Texture Symbols
ASME	HPS-2003	High Pressure Systems
ASME	Y14.5-2009	Dimensioning and Tolerances - Mathematical Definitions of Principles
ASME	Y14.100-2013	Engineering Drawing Practices
ASME	Y32.10-1967 (R1994)	Graphic Symbols for Fluid Power Diagrams
ASTM	E595-93 (2003)e1	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
ATA	Spec 300-2001.1	Specification for Packaging of Airline Supplies
CENELEC	EN 50082-1:1997[1]	Electromagnetic compatibility – Generic immunity standard – Part 1: Residential, commercial and light industry
Council of the European Communities	EMC 89/336/EEC[1]	Council Directive 89/336/EEC of 3 May 1989 on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive)
County of Hawaii	2005 edition	Hawaii County Code 1983 (2005 edition), as amended
Department of Defense	MIL-STD-171E	Finishing of Metal and Wood Surfaces
Department of Defense	MIL-G-174B	Military Specification Glass, Optical
Department of Defense	MIL-HDBK-217F-2[1]	Reliability Prediction of Electronic Equipment
Department of Defense	MIL-C-675C(AR)	Coating of Glass Optical Elements (Anti-Reflection)
Department of Defense	MIL-STD-810F	Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
EIA	EIA-310-D	Cabinets, Racks, Panels, and Associated Equipment

1. This reference for information only.

Table 1: Referenced standards, continued

Source (Organization or Standardizing Body)	Number	Title
EIA	EIA-649[1]	National Consensus Standard For Configuration Management
EIA	EIA RS-232-C, August 1969	EIA Standard RS-232-C Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Data Interchange
FCC	Title 47 CFR Part 15[1]	Radio Frequency Devices
IEEE	802.3U revision 95	Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method & Physical Layer Specifications: Mac Parameters, Physical Layer, Medium Attachment Units and Repeater for 100 Mb/S Operation (Version 5.0)
IEEE	1012-2004	Standard for Software Verification and Validation
International Code Council (ICC)	IBC-2006	2006 International Building Code®
ISO/IEC	ISO / IEC 12207:1995	Information Technology - Software life cycle processes
National Electric Manufacturers Association	250-1997	Enclosures for Electrical Equipment (1000 Volts Maximum)
National Fire Protection Association (NFPA)	NFPA 55, 2013 edition	Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks
NFPA	NFPA 70, 2014 edition	National Electric Code
NFPA	NFPA 99, 2012 edition	Health Care Facilities Code, chapters 1 to 5, standards on medical gas and vacuum systems
Naval Surface Warfare Center	NSWC 98/LE1[1]	Handbook of Reliability Prediction Procedures for Mechanical Equipment
OSHA	Title 29 CFR Part 1910	Occupational Safety And Health Standards
Telcordia	GR-63-CORE	NEBS™ Requirements
TIA/EIA	TIA/EIA-568-B	Commercial Building Telecommunications Cabling Standards
Underwriters Laboratories Inc.	Standard for Safety 508	Industrial Control Equipment

1. This reference for information only.

3.2.2 WMKO Standards

WMKO software standards are also referenced in this document. References to these standards are included because compliance with some part of each standard is required.

Table 2: WMKO standards

Source (Organization or Standardizing Body)	Number	Title
WMKO	KSD 3	Software Items for Acceptance Review
WMKO	KSD 8	KTL: the Keck Task Library
WMKO	KSD 46	DCS Keywords Reference Manual
WMKO	KSD 46a	DCS Keyword Reference Manual (partial)
WMKO	KSD 50	Keck II C Style and Coding Standards
WMKO	KSD 201	How to Set Up a config.mk Build
WMKO	KSD 210	WMKO Software Standards
WMKO	[None] revision dated 051013	ADDEMDUM concerning SOLIDWORKS MODELING DATA REQUIREMENTS FOR CONTRACT PURPOSES

3.3 Referenced Drawings

Table 3 lists the drawing numbers, revisions and date, source and title for all drawings referenced in this document.

Table 3: Referenced drawings

Ref. #	Drawing #	Revision/Date	Source	Title
1	199-06-01	B/9/29/89	TIW Systems, Inc.	Tertiary Module Assembly Drawing W. M. Keck Telescope
2	608-TM-00	B/9/29/89	TIW Systems, Inc.	W. M. Keck Telescope Tertiary Module Details, General Notes
3	608-TT-00	E/2/13/09	TIW Systems, Inc.	W. M. Keck Telescope Tertiary Tower Elevations
5	110-10-07	C/7/31/95	WMKO	Keck I Telescope Travel Limits

4 REVISION HISTORY

Version	Date	Author	Reason for revision / remarks
1.0	January 15, 2013	SMA	First release
1.1	August 29, 2013	JXP	Towards a version for PD
1.2	September 19, 2013	SMA	Additional edits towards PD release
2.0	October 4, 2013	SMA	Release for PD phase
3.0	October 6, 2014	SMA	Update for PDR and DD phase
3.1	October 17, 2014	SMA	Modify table 8 to harmonize with K1DM3 mirror specifications document, corrected stability tip value in table 9.

5 BACKGROUND

5.1 Purpose

The purpose of the background section of this document is to provide context and related information for the requirements defined in later sections of this document.

5.2 Units and Terminology

This requirements document adopts SI units. By definition adoption of SI units confirms that all drawings and documentation for WMKO instruments shall use metric units of measure.

WMKO uses as its primary reference the 2008 edition of National Institute of Standards and Technology (NIST) special publication 811, Guide for the Use of the International System of Units (SI), referred to hereafter as NIST 811. In order to avoid help with consistency a brief comment on the symbols and written names of angular measures common in astronomy, 1/60 of a degree and 1/3600 of a degree may be in order. The term arc minute is used to refer to 1/60 of a degree and the symbol ' is used consistently in WMKO requirements documents to indicate angular measurements in arc minutes. As described in NIST 811 there is no space between the numerical quantity and the symbol, i.e. 5', not 5 '. There is no abbreviation for arc minute (the one word form, “arcminute” is also in common usage). Similarly, the term arc second is used to refer to 1/3600 of a degree and the symbol " is used consistently in WMKO requirements documents to indicate angular measurements in arc seconds. There is no abbreviation for arc second (the one word form “arcsecond” is also in common usage).

For decimal fractions of an arc second the term milliarcsecond is used, and for convenience the abbreviation mas is used, even though this term and its abbreviation are not defined in NIST 811. Strict compliance with NIST 811 would require the notation 5×10^{-3}" for 5 mas.

This document also adopts the conventions of terminology given in §13.1 of the IEEE Standards Style Manual (2009).

5.3 Test and Verification

Every item in a requirements document must be tested or verified. The format of the requirements document is designed to be easily translated into a compliance matrix that can be used to assess the degree to which the design meets the requirements during the instrument’s design process and is then used to form the basis for acceptance testing at the end of the full scale development phase.

5.4 Overview

The aim of this proposal is to build a new tertiary mirror (M3) and its mount for the 10 m Keck I (K1) telescope at WMKO to make its full observational capabilities available for time-sensitive scientific programs. In contrast to the existing tertiary mirror and mount, the device will rapidly deploy and rotate the mirror to any instrument at a Nasmyth focus or, as desired, stow the mirror out of the light path to permit observations at the Cassegrain focus. In this manner, the K1 deployable tertiary mirror (K1DM3) will enable observations with any of the K1 instruments on any given night, and at any given time. The K1DM3 device will be integrated within the K1 telescope control system and WMKO has committed to a new time-domain operations model that takes full advantage of this new capability.

The 2010 Astronomy Decadal Survey noted the growing primacy of time-domain astronomy (TDA) as a central theme for some of the most challenging modern pursuits. The discovery of the accelerating universe, for example, made use of repeated imaging and spectroscopic observations of distant Type Ia supernovae. The treasure trove of discovery and physical insight into extrasolar planets required high-resolution synoptic spectroscopy. The characterization of the black hole at the center of the Milky Way required repeated adaptive optics imaging of the surrounding stars. All of these are great triumphs for U.S. astronomers, enabled in large part by the Keck telescopes. Time-domain observations will serve as the backbone for 21st century astrophysics. Wide-field imaging at all wavelengths demonstrates that the universe is highly dynamic, with variability on all time-scales. Of great interest are exploding stars, black hole mergers, eclipsing planets, gravitational microlensing events, and flaring sources, all of which stem from a diverse set of astrophysical processes. Central to resolving the astrophysics of these events is high-precision spectroscopy and imaging, ideally at high cadence. Such observations demand the use of large-aperture telescopes; but while a telescope may possess a suite of suitable instrumentation, the scientific returns of TDA are only available if those instruments can be flexibly and rapidly accessed on each observing night. Indeed, the growing demands for precious follow-up time using the world's largest telescopes conflicts with the classical approach of telescope allocation: one night, one instrument. Clearly, a more nimble approach that supports the TDA needs of the observing community is urgently required.

Bringing the routine use of K1DM3 to WMKO will provide immediate access to the unique suite of instrumentation on the Keck I telescope: HIRES - the only echelle spectrograph on a large telescope available to the U.S. community in the northern hemisphere; and LRIS - one of the world's most sensitive optical spectrometers or MOSFIRE - the premier multi-slit infrared spectrograph available to the U.S. community in the northern hemisphere. This will enable the effective and efficient study of time-critical Solar System events, the analysis of stellar atmospheres, the monitoring of stars orbiting the Galactic center, and the discovery of the most distant explosions in the universe. The astrophysical processes explored via these phenomena include the tidal disruption of compact objects, the explosion mechanisms of stars at all masses, gas accretion and planetary dynamics. The installation of K1DM3 will further position the U.S. community to play a leading role in follow-up observations of gravitational wave events.

5.5 The Existing Tertiary on Keck I

The existing Keck I tertiary mirror module is shown in the stored configuration in Figure 1. The tertiary mirror module must be removed from the telescope's tertiary mirror tower in order to allow light to reach the telescope's Cassegrain focus. The existing tertiary mirror module provides fixed detents for the two Nasmyth focal stations and the four bent Cassegrain focal stations on the Keck I telescope.

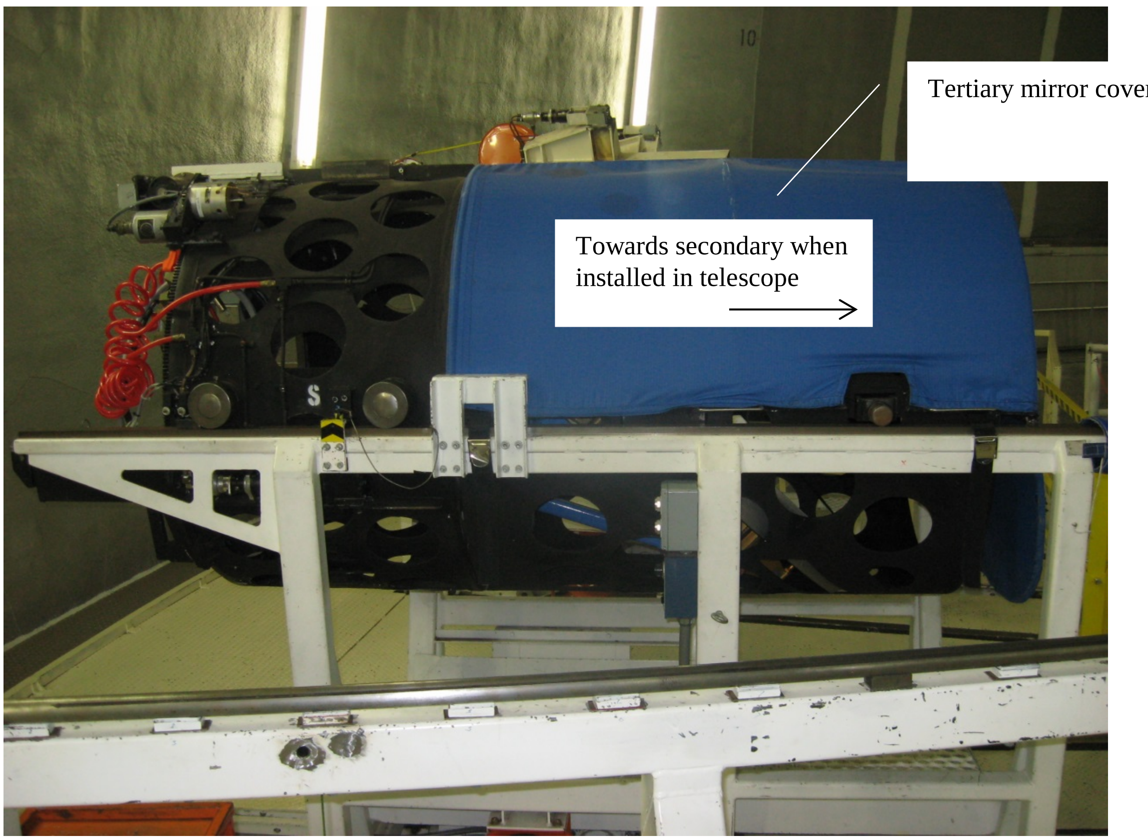

Figure 1: Keck I tertiary module stored on its handler on the Keck I Nasmyth deck

The mirror is supported on an 18 point whiffle tree combined with a center mount, see Figure 2 for a partial view. The mirror supports the full 20' FOV of the Keck telescope. The mirror is fabricated from Schott Zerodur and coated with bare aluminum. The mirror can be removed from the module for recoating when required.

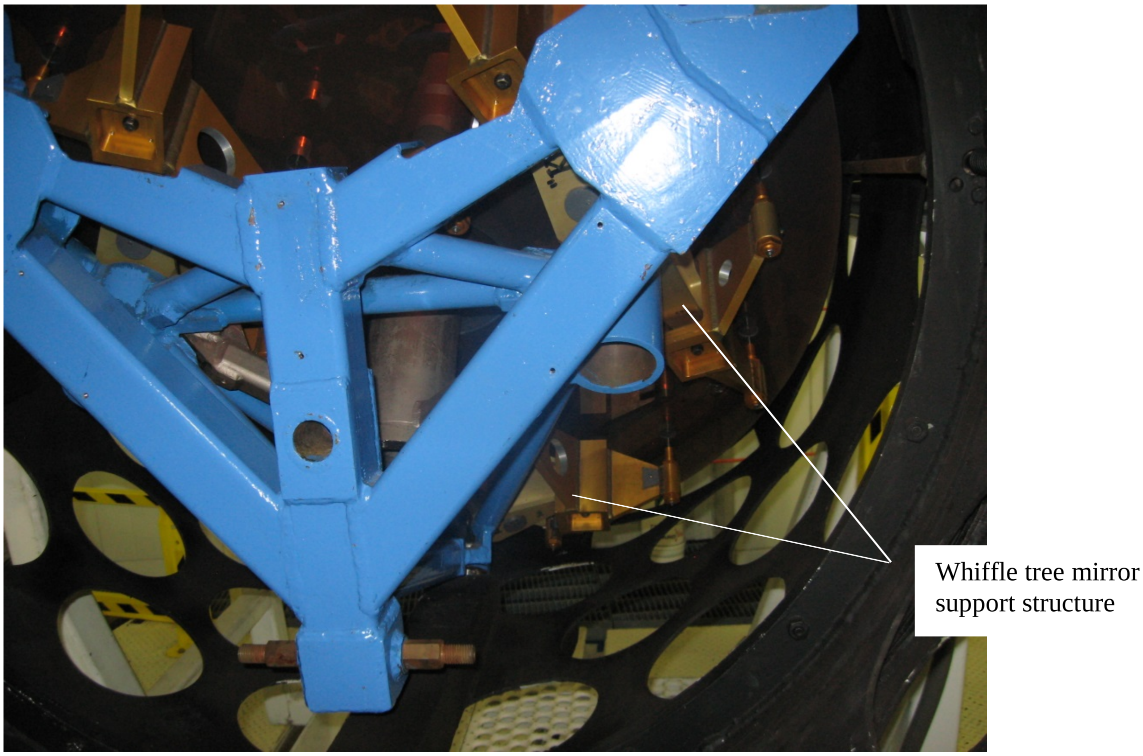

Figure 2: Keck I tertiary module looking at the back of tertiary mirror

The original requirements (Nelson et al., 1985, p. 11-8) for the Keck I tertiary were as follows:

Clear aperture: 1040 mm x 1430 mm
Distance to primary: -4000 mm
Displacement Tolerances

- Tilt < 3"
- Piston normal to surface 1.3 mm (0.15" of defocus)
- In plane of mirror ∞

Anecdotal evidence suggests that performance of the current tertiary is satisfactory, but no routine checking of alignment at each focal station is performed. At present the Keck I AO science instrument OSIRIS has inscribed pupil masks without a center obscuration so the sensitivity to pupil alignment is probably lower than it would be if a matched pupil mask were used.

Nighttime observing procedures are used to collimate the telescope with the result that small night to night tertiary positioning errors are not noticeable because the secondary adjustments made during collimation will compensate for such errors.

The tertiary module is fabricated from steel, and the drive system for rotation of the tertiary is based on the same components used in the Keck I instrument rotator modules. A rear view of the module showing the rotation drive is shown in Figure 3.

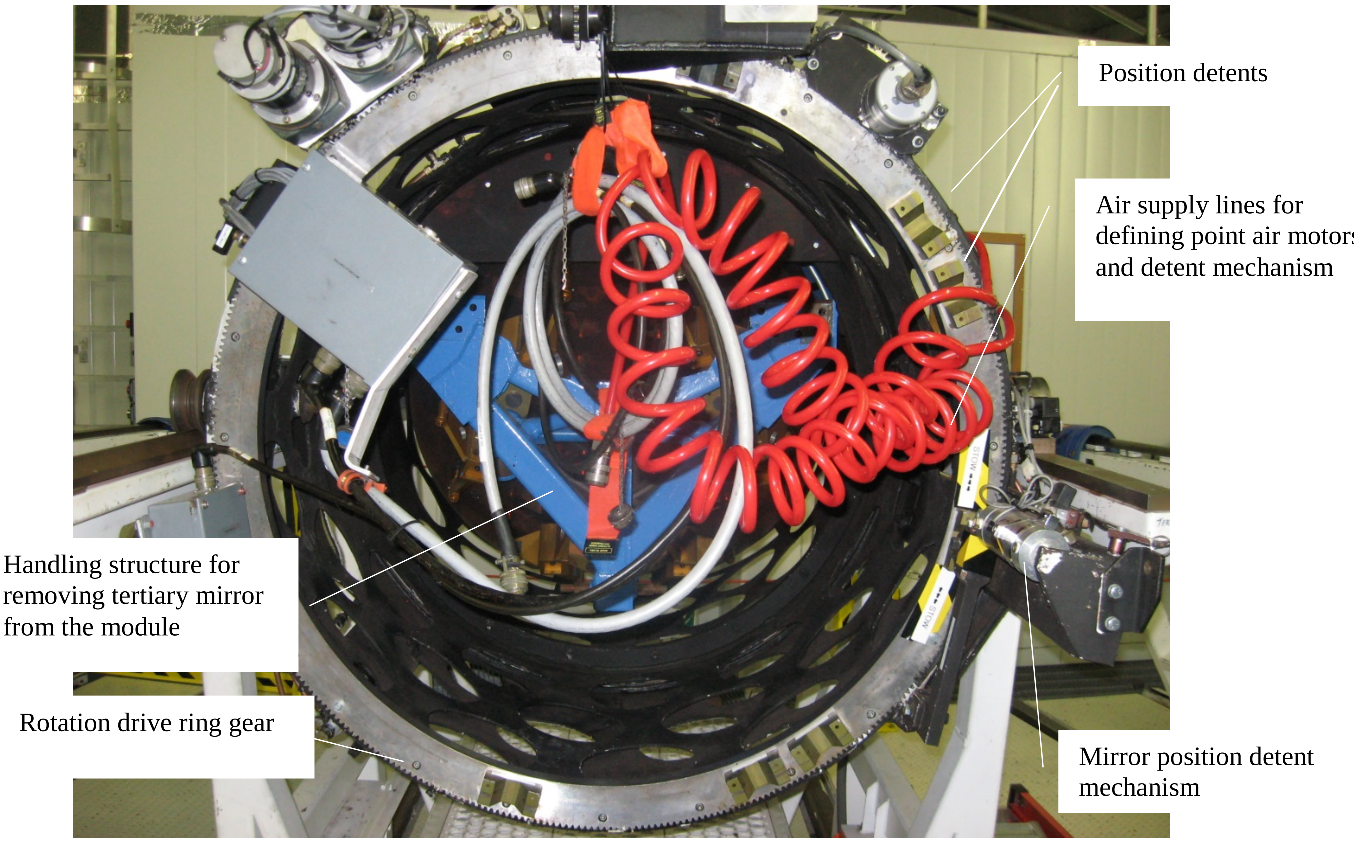

Figure 3: Keck I tertiary module view from end opposite tertiary mirror location ("rear" view)

Further details of the drive components are shown in Figure 3 and Figure 4. The position of the tertiary mirror is defined at each focal station using a v-groove detent engaged by a pneumatic cylinder (see Figure 3). The module is stored on a handler that is parked on the telescope's Nasmyth deck. A rail system is used to move the module from the storage position onto the telescope's Cassegrain platform for transfer into the Cassegrain cage and then on into the tertiary tower. Rails on the module handler, one flat and one v-groove match up with rails extending from the entrance of the Cassegrain cage up to the tertiary module defining position in the tertiary tower.

The Cassegrain portions of the rails are shared with the Cassegrain instruments and the Cassegrain ADC (and formerly with the now retired forward Cassegrain module).

The tertiary mirror module is defined in the telescope using a three point kinematic mount with a sphere, a groove, and a flat. Figure 6 shows the mechanism for the module half of one of the defining points. The telescope mounted half of the defining point uses a pneumatic cylinder to extend an Acme thread lead screw through the center of the telescope half of the kinematic mount. The lead screw is fixed and cannot rotate. The module half of the defining point engages this lead screw with an Acme nut behind a hole in the module half of the kinematic mount. This nut is driven by a reversible air motor. The air motor turns the nut which follows the screw, engaging or disengaging the two halves of the kinematic mount. The three defining points are engaged in sequence, sphere, groove, and flat. A programmable logic controller (PLC) operates solenoid valves on the telescope and the module to control the defining process. Proximity sensors are used to confirm proper definition of the module.

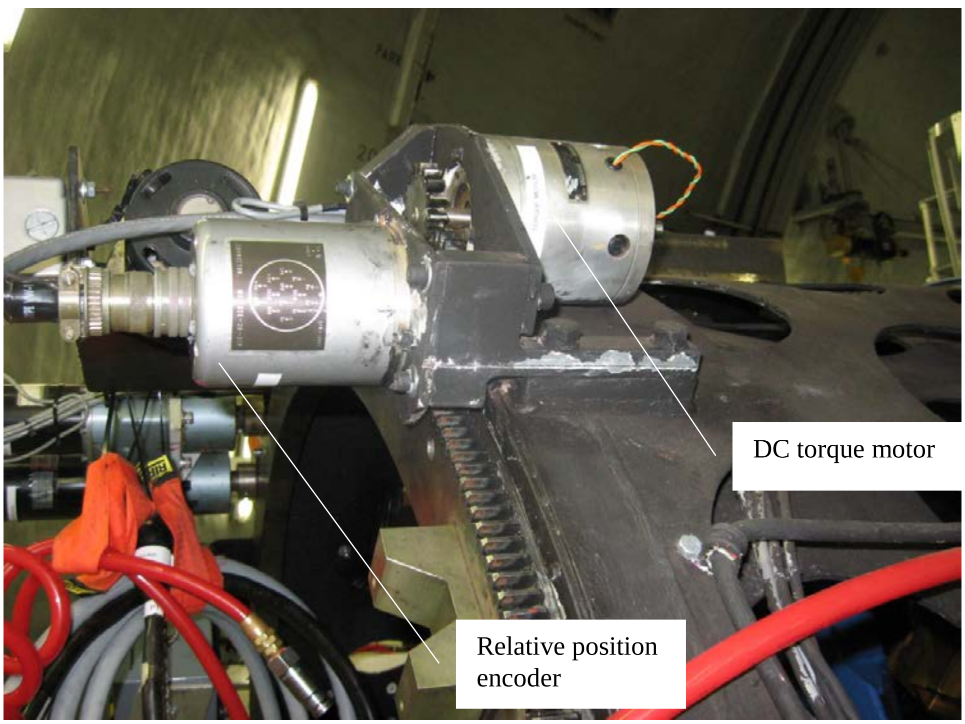

Figure 4: Keck I tertiary module rotator encoder and backlash compensation drive

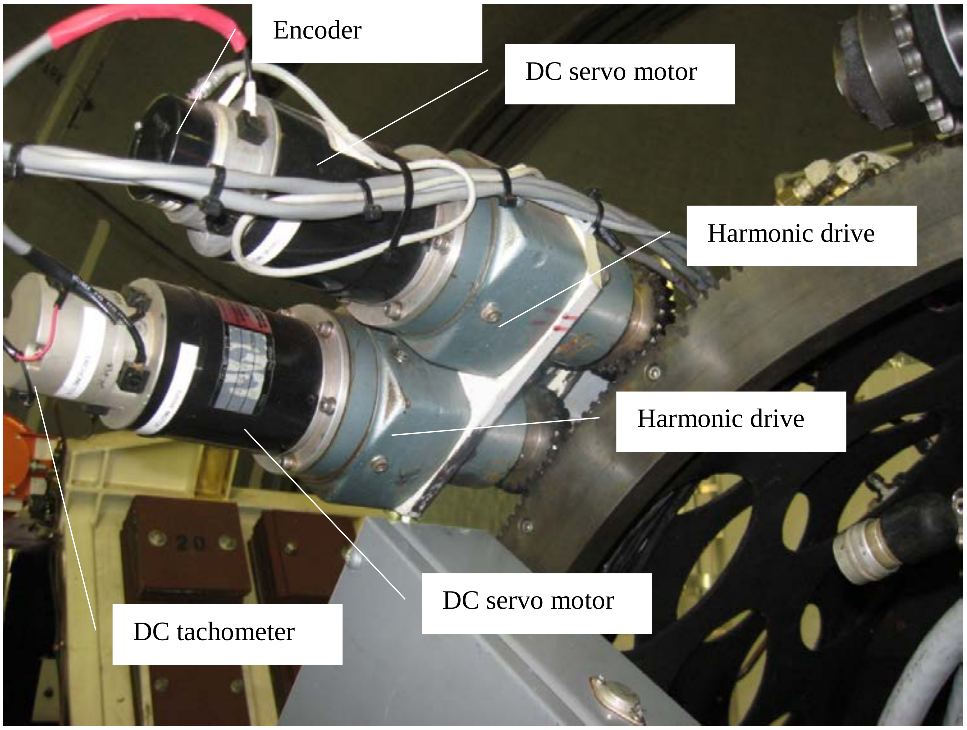

Figure 5: Keck I tertiary module rotator servo motor drives and velocity feedback

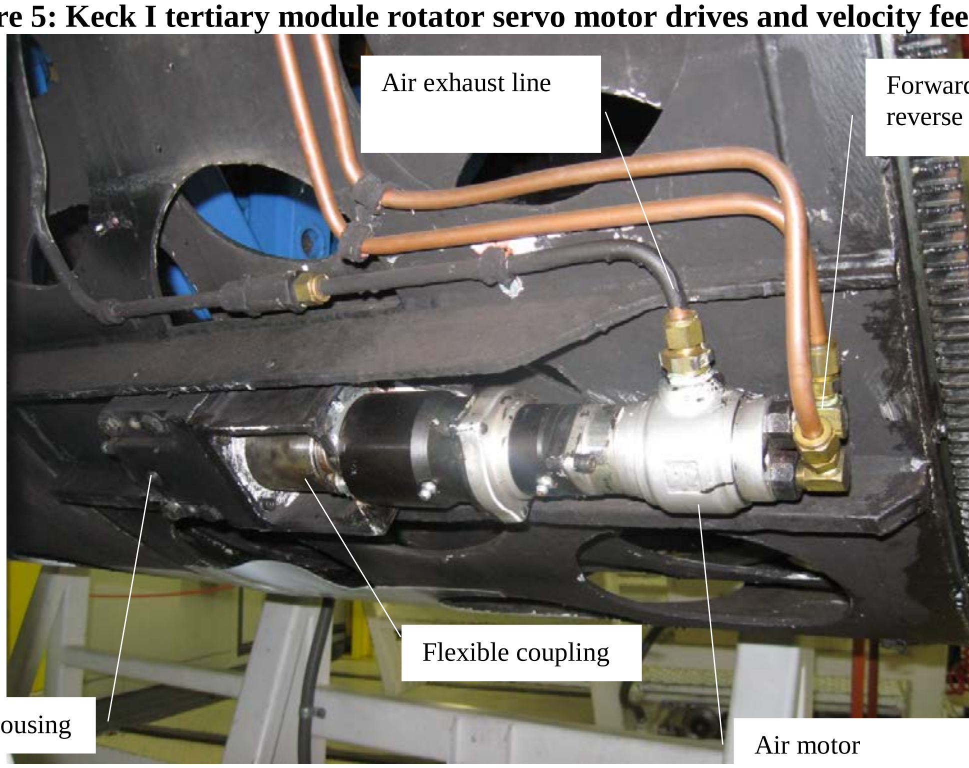

Figure 6: Keck I tertiary module defining point mechanism, rear of module to the right

5.6 K1DM3 Glossary

In the descriptions that follow the following names and definitions for the components of the K1DM3 are used:

K1DM3: the complete system consisting of the K1DM3 module, module handler, control electronics, software and accessories

K1DM3 module: the telescope mounted portion of the K1DM3 containing the tertiary mirror, deployment mechanism, rotation mechanism, defining points and all associated drive motors, air lines, etc.

K1DM3 electronics: the control electronics for the K1DM3 mechanisms.

6 OVERALL REQUIREMENTS

6.1 Purpose and Objectives

The purpose of the overall requirements section is to convey requirements that apply generally to the overall instrument and its accessories.

6.2 Performance Requirements

6.2.1 Parametric Performance Requirements

6.2.1.1.1 Transportation and Shipping Environment

When packaged as required in §6.3.2.1 the K1DM3 shall continue to meet all of the performance requirements without repair after a single shipment to the delivery location by any combination of air or surface transportation. For information, the expected conditions to be encountered during shipping are given in Table 4.

Table 4: Transportation and shipping environment

Parameter	Min.	Typ.	Max.	Units	Notes
Altitude	0	-	4,572	m	1
Temperature	-33	-	71	ºC	2, 3
Temperature shock	-54	-	70	ºC	4
Humidity	0	-	100	%	5
Gravity orientation	-	-	-	NA	6
Vibration	-	-	0.015	g^2/Hz	7, 8
Shock	-	-	15	g	9
Acceleration					
Due to transport	-	-	4	g	10
Due to seismic activity	-	-	2	g	11

Notes:

1. See MIL-STD-810F Method 500 §2.3.1.
2. Maximum is for induced conditions, see MIL-STD-810F Method 501 Table 501.4-I.
3. Minimum is for induced conditions; see MIL-STD-810F Method 502 Table 502.4-II.
4. See MIL-STD-810F Method 503.
5. Relative, condensing.
6. Packaged equipment may be subjected to all possible gravity orientations during transportation and shipping.
7. 10 Hz to 40 Hz, -6dB/oct. drop-off to 500 Hz, all axes.
8. See MIL-STD-810F Method 514.
9. 0.015 second half-sine, all axes.
10. All axes.
11. 0.5 Hz to 100Hz, all axes.

6.2.1.1.2 Non-Operating Environment

The K1DM3 shall meet all of the performance specifications without repair or realignment after being subjected to any number of cycles of any of the non-operating environment conditions defined in Table 5. These represent environments associated with storage and handling within the facility, installation and removal from the telescope, and conditions expected when the telescope is in a non-observing configuration.

For the K1DM3, installation will be performed with the K1DM3 oriented so that the axis of rotation for the tertiary mirror is on a horizontal vector. This means that gravity will act upon the K1DM3 in a vector that is perpendicular to that horizontal vector.

Table 5: Non-operating environment

Parameter	Min.	Typ.	Max.	Units	Notes
Altitude	0	-	4300	m	
Temperature					
Range	-10	1.8	30	ºC	1
Absolute rate of change	0	0.027	1.25	ºC/min	2
Humidity	0	34	100	%	3,4
Gravity orientation	-	-1	-	g	5
Vibration	-	-	$8.0x10^{-4}$	g^2/Hz	6
Shock	-	-	15	g	7
Acceleration					
Due to handling	-	-	-	g	8
Due to seismic activity	-	-	2	g	9

Notes:

1. Based on reference 1, typical is the average annual temperature.
2. Based on reference 1.
3. Relative humidity. Based on reference 1, typical is the average annual humidity.
4. A non-condensing condition is normal when the dome is closed because the dome is air conditioned to control humidity. The dome is not opened unless the dome and outdoor temperatures are above the dew point. Transient conditions can occur that result in condensation.
5. Normal to the earth’s surface.
6. 20 Hz to 1000 Hz, 6db/oct. drop-off to 2000 Hz.
7. 0.015 second half-sine, all axes.
8. 2 g vertical (in the gravity normal direction) 1 g fore/aft (along the direction of motion during handling to move the instrument into or out of the telescope tertiary tower with the telescope pointed at the horizon), 0.5 g perpendicular to the direction of motion or in the direction that is opposite the normal gravity vector.
9. 0.5 Hz to 100Hz, all axes.

6.2.1.1.3 Operating Environment

The operating environment is the ensemble of all conditions experienced under normal telescope operation when the K1DM3 is installed in the Keck I telescope tertiary tower. All performance requirements shall be met while the K1DM3 is subjected to the operating environment conditions given in Table 6.

Table 6: Operating environment

Parameter	Min.	Typ.	Max.	Units	Notes
Altitude	0	-	4300	m	
Atmospheric pressure	607.43	620.71	627.38	mbar	1
Temperature					
Range	-10	1.8	20	ºC	2,3
Absolute rate of change	0	0.027	1.25	ºC/min	4
Humidity	0	34	100	%	5,6
Gravity orientation	-	-1	-	g	7
Vibration	-	-	$0.25x10^{-9}$	g^2/Hz	8
Acceleration	-	-	1	g	9

Notes:

1. Based on reference 1, typical is an average annual value.
2. Based on reference 1, typical is the average annual temperature.
3. Maximum temperature at the summit based on reference 1 is 14 ºC; laboratory operation requires a maximum of at least 20 ºC.
4. Based on reference 1.
5. Relative humidity. Based on reference 1, typical is the average annual humidity.
6. A non-condensing condition is normal when the dome is closed because the dome is air conditioned to control humidity. The dome is not opened unless the dome and outdoor temperatures are above the dew point. Transient conditions can occur that result in condensation.
7. Normal to the earth's surface. Cassegrain instruments and tertiary tower mounted equipment experience a variable gravity vector.
8. 8 Hz to 80 Hz
9. All axes, due to telescope drive system fault conditions.

6.2.2 Operational Performance Requirements

6.2.2.1 Air Borne Contaminants

The weather conditions at the summit of Mauna Kea include frequent high winds resulting in some air borne contaminants, particularly dust and insects. Instruments shall be protected during installation and handling against the entry of these contaminants, in particular care shall be taken with optical surfaces, precision mechanisms, fine pitch connectors and fiber optic connectors.

6.2.2.2 Audible Noise

Unless otherwise specified or accepted the K1DM3 and any pumps, motors, outboard electronics or computers shall not at any time produce audible noise in excess of 50 dBA at a distance of 1 meter. This is a standard office operating environment maximum noise level. This includes intermittent noises from pumps and variable speed cooling fans. Audible warning signals for emergency or fault conditions are exempt from this requirement, but they shall be provided with a silence after delay feature or a manual silencing switch.

6.2.2.3 Telescope Reconfiguration

The K1DM3 shall be designed to facilitate telescope reconfigurations by allowing complete disconnection of all services when the K1DM3 module is to be moved during telescope reconfigurations. This includes all power and control signals, glycol and air lines. It is essential that the K1DM3 be able to return to operation without requiring special procedures or maintenance after reconnection. The K1DM3 shall be capable of being stored indefinitely without requiring connection to services.

6.2.2.4 Power Failure Tolerance

The observatory summit facilities provide backup power to the instrument electronics. The first level of backup is the Keck I dome UPS, an industrial uninterruptible power supply (UPS) shared with the other instruments on Keck I. This UPS has a hold up time of 30 minutes. A separate UPS is provided for the Keck I computer room, and this UPS provides backup power for the instrument computers. The Keck I computer room UPS also has a hold up time of 30 minutes.

Under normal conditions the Observatory summit standby generator will start within 1 minute of the power failure and begin supplying primary power to the Keck I dome UPS, Keck I computer room UPS and the other UPS units at the summit.

During a power failure the glycol cooling system pumps and chiller will be inoperative, so any K1DM3 electronics dependent on glycol cooling require either flow switches or temperature sensors to ensure that the electronics are shut down even though the electronics will be powered from the Keck I dome UPS and the Observatory summit standby generator.

Under normal conditions the Observatory summit standby generator has sufficient fuel for 18 hours of continuous operation at full load. With only two exceptions in over 10 years of operation, the longest power failures to date that WMKO has experienced at the summit have been less than 1 hour in duration.

The worst-case conditions to be experienced by the instrument can be understood to occur under conditions where the Observatory summit standby generator fails to start. In this case within 30 minutes the dome UPS and computer room UPS will be exhausted resulting in a total instrument power failure for a further 30 minutes based on the majority of the worst case power failures to date.

Because of the possibility of power failures, and also the necessity of disconnecting instruments from services during telescope reconfiguration, the K1DM3 shall be designed so that power failures will not degrade the performance of the K1DM3 or damage any components.

6.3 Implementation Requirements

6.3.1 Common Practice Implementation Requirements

None.

6.3.2 Standards Implementation Requirements

6.3.2.1 Shipping Containers

All shipping containers shall be designed to provide adequate protection for the equipment during transport. Unless otherwise specified single use containers suitable for the size, weight and shipment method to be employed are acceptable. For guidance in the design of suitable containers consult Air Transport Association (ATA) Spec 300, 2001.1 edition, “Specification for Packaging of Airline Supplies”.

6.3.3 Regulatory Implementation Requirements

6.3.3.1 OSHA Requirements

The K1DM3 shall comply in all respects with the applicable requirements of the Occupational Safety and Health Administration (OSHA) as established by Code of Federal Regulations (CFR) 29 Part 1910 “Occupational Safety And Health Standards”, particularly subpart O, section 1910.212 and subpart S sections 1910.302 through 1910.304.

The requirements of Subpart O, section 1910.212 that are applicable to the K1DM3 are summarized as follows:

1. *Machine guarding must be provided to protect the operator and other employees from hazards such as those created by ingoing nip points or rotating parts.*
2. *Guards shall be affixed to the machine.*
3. *Revolving barrels and drums shall be guarded by an enclosure that is interlocked with the drive mechanism so that the barrel or drum cannot revolve unless the guard is in place.*

The requirements of Subpart S, sections 1910.302 through 1910.304 that are applicable to the K1DM3 may be summarized as follows:

1. *Listed or labeled equipment shall be used or installed in accordance with any instructions included in the listing or labeling.*
2. *Conductors shall be spliced or joined with splicing devices suitable for the use or by brazing, welding, or soldering with a fusible metal or alloy. Soldered splices shall first be so spliced or joined as to be mechanically and electrically secure without solder and then soldered. All splices and joints and the free ends of conductors shall be covered with insulation equivalent to that of the conductors or with an insulating device suitable for the purpose.*
3. *Parts of electric equipment which in ordinary operation produce arcs, sparks, flames, or molten metal shall be enclosed or separated and isolated from all combustible material.*
4. *Electrical equipment may not be used unless the manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product may be identified is placed on the equipment. Other markings shall be provided giving voltage, current, wattage, or other ratings as necessary. The marking shall be of sufficient durability to withstand the environment involved.*
5. *Each disconnecting means for motors and appliances shall be legibly marked to indicate its purpose, unless located and arranged so the purpose is evident.*
6. *Live parts of electric equipment operating at 50 volts or more shall be guarded against accidental contact by approved cabinets or other forms of approved enclosures.*
7. *A conductor used as a grounded conductor shall be identifiable and distinguishable from all other conductors. A conductor used as an equipment grounding conductor shall be identifiable and distinguishable from all other conductors.*
8. *No grounded conductor may be attached to any terminal or lead so as to reverse designated polarity.*
9. *A grounding terminal or grounding-type device on a receptacle, cord connector, or attachment plug may not be used for purposes other than grounding.*
10. *Conductors and equipment shall be protected from overcurrent in accordance with their ability to safely conduct current.*
11. *Overcurrent devices may not interrupt the continuity of the grounded conductor unless all conductors of the circuit are opened simultaneously.*
12. *Overcurrent devices shall be readily accessible to each employee or authorized building management personnel. These overcurrent devices may not be located where they will be exposed neither to physical damage nor in the vicinity of easily ignitable material.*
13. *Fuses and circuit breakers shall be so located or shielded that employees will not be burned or otherwise injured by their operation due to arcing or suddenly moving parts.*
14. *Circuit breakers shall clearly indicate whether they are in the open (off) or closed (on) position.*
15. *The path to ground from circuits, equipment, and enclosures shall be permanent and continuous.*
16. *Metal enclosures for conductors shall be grounded.*
17. *Exposed, non-current-carrying metal parts of fixed equipment, which may become energized, shall be grounded.*
18. *Exposed non-current-carrying metal parts of cord and plug connected equipment, which may become energized, shall be grounded.*
19. *Non-current-carrying metal parts of fixed equipment, if required to be grounded, shall be grounded by an equipment grounding conductor, which is contained within the same raceway, cable, or cord,*

or runs with or encloses the circuit conductors. For DC circuits only, the equipment grounding conductor may be run separately from the circuit conductors.

For the purposes of the foregoing approved means acceptable to the authority enforcing the applicable subpart. The authority enforcing the applicable subpart is the Assistant Secretary of Labor for Occupational Safety and Health. The definition of ''acceptable'' indicates what is acceptable to the Assistant Secretary of Labor, and therefore approved within the meaning of the applicable subpart. Approved for the purpose means approved a specific purpose, environment, or application described in a particular standard requirement. Suitability of equipment or materials for a specific purpose, environment or application may be determined by a nationally recognized testing laboratory, inspection agency or other organization concerned with product evaluation as part of its listing and labeling program.

Note that the preceding text is reproduced verbatim from the referenced CFR and any grammatical errors or typographical errors are part of that text.

6.3.3.2 Electrical Safety

The K1DM3 shall conform to the requirements of the National Electric Code (NEC), publication 70 of the National Fire Protection Association (NFPA). The applicable local electric code is the Hawaii County Code 1983, 1995 Edition. This code adopts the National Electric Code in its entirety and there are no additional special requirements applicable to the locations where the instrument will be installed or operated. Vendor's attention is specifically directed to the following articles of the NEC:

Article 110 Requirements for Electrical Insulation
Article 200 Use and Identification of Grounded Conductors
Article 250 Grounding
Article 300 Wiring Methods
Article 310 Conductors for General Wiring
Article 312 Cabinets, Cutout Boxes, and Meter Socket Enclosures
Article 400 Flexible Cords and Cables
Article 404 Switches
Article 647 Sensitive Electronic Equipment

6.4 Design Requirements

6.4.1 Technological Design Requirements

6.4.1.1 Materials Suitability and Safety

Certain environmental conditions (low temperature and pressure) at the summit of Mauna Kea make certain materials unsuitable for use in instrument construction. Materials used in the construction, lubrication or packaging of instruments shall not produce hazardous by-products such as gases or other contaminants under the conditions of operation and use at the summit of Mauna Kea. No mercury may be used in any component of the K1DM3.

Table 7 lists specific materials that shall not be used. Note that this table applies to components normally exposed to the atmosphere during operation or servicing.

Table 7: Materials not suitable for use in equipment at the summit of Mauna Kea

Material Type	Common Name	Reason(s) for Unsuitability
Adhesive, insulator	RTV silicone rubber[1]	Outgases during curing
Adhesive	Cyanoacrylates	Outgases during curing, subject to hydrolytic degradation
Conductor	Mercury[2]	Reactive, salts formed are toxic
Insulator	Acrylic[4]	Outgases, hygroscopic, brittle at low temperatures
Plated finish	Cadmium[2]	Outgases, reactive, hazardous
Insulator	Cellulose Acetate Butyrate	Hygroscopic
Insulator	Glass-Reinforced Extruded Nylon	Outgases, hygroscopic
Insulator	Kapton	Subject to hydrolytic degradation
Insulator	Neoprene	Outgases, subject to degradation by ozone and UV exposure
Insulator	Nylon[5]	Outgases, subject to degradation by ozone and UV exposure
Insulator	Phenolic[3]	Hygroscopic
Insulator	Polychlorinated Biphenyls[2]	Combustion produces highly toxic gases

Notes:

1. Neutral cure RTV silicones may be acceptable provided that the cured silicone and the surrounding area are cleaned after assembly.
2. Use is or soon will be highly regulated.
3. Electrical grade phenolic is not hygroscopic.
4. Cast acrylic resin
5. Cable ties of weather resistant Nylon 6/6 (carbon black additive) are acceptable.

6.4.2 Regulatory Design Requirements

None.

6.4.3 Standards Related Design Requirements

None.

6.4.4 Integration Related Design Requirements

None.

7 OPTICAL REQUIREMENTS

7.1 Purpose and Objectives

The purpose of this section is to describe requirements for the performance, implementation and design of the K1DM3 optical system. Unless noted otherwise all optical requirements apply over the full range of environmental conditions given in Table 6.

7.2 Performance Requirements

7.2.1 Parametric Performance Requirements

7.2.1.1 Typical Parameters

The K1DM3 shall provide the optical performance described in Table 8.

Table 8: K1DM3 typical optical performance requirements

Parameter	*Min.*	*Typ.*	*Max.*	*Units*	*Notes*
FOV (diameter)					
Deployed	5	-	-	'	1
Retracted	20	-	-	'	2
Vignetting					
Deployed	-	-	0%	n/a	3
Retracted	-	-	0%	n/a	4,5
Tertiary Mirror					
Optical surface flatness					
Slope error	-	-	9.7×10^{-7}	rms	6
Surface error	-	-	26	nm, rms	7
Reflectivity	-	93	-	%	8
Non-optical surface finish	-	-	-	-	9,10

Notes:
1. FOV to each Nasmyth or bent Cassegrain focal station with the tertiary mirror deployed
2. FOV to the Cassegrain focal station with the tertiary mirror retracted
3. When deployed the tertiary mirror shall support the full deployed field at both Nasmyth focal stations and the bent Cassegrain focal stations without vignetting the light path from the sky to the primary mirror, from the primary mirror to the secondary mirror, and from the secondary mirror to the tertiary mirror.
4. When retracted the tertiary mirror and any associated structure shall not vignette light path from the telescope secondary mirror to the Cassegrain science or guider fields of the LRIS and MOSFIRE instruments.
5. When retracted the tertiary mirror and any associated structure shall not vignette the light path from the sky to the telescope primary mirror, and the light path from the telescope primary mirror to the secondary mirror.
6. Where 0 is a perfectly flat surface
7. Over any 44 mm subaperture on the tertiary mirror
8. Bare aluminum coating average reflectivity from 400 nm to 2000 nm
9. Grind smooth with #320 abrasive
10. Chamfer all edges at 45° to 3 mm maximum face width

7.2.2 Operational Performance Requirements

7.2.2.1 Operating modes

The K1DM3 shall provide two operating modes, deployed and retracted. In the deployed mode the tertiary mirror shall be positioned to fold the light from the telescope optical axis through 90 degrees and allow, by rotation of the tertiary mirror, the reflected light to be directed to either of the Keck I Nasmyth focal stations, or to any one of the four bent Cassegrain focal stations.

In the retracted mode the K1DM3 shall move to a position that minimizes the impact on the FOV of the Keck I Cassegrain instruments, currently LRIS and MOSFIRE. Since both instruments have irregularly shaped FOVs an acceptable solution is for the retracted K1DM3 to track the position angle of each instrument to ensure that the retracted tertiary remains out of the FOV of the current Cassegrain instrument.

7.3 Implementation Requirements

7.3.1 Feature Implementation Requirements

The mirror should employ a multi-point support “whiffle tree” structure similar to the design of the support structure for the existing Keck I tertiary mirror. The interface between the tertiary mirror and the whiffle tree structure shall incorporate the most current knowledge of how to design and install the required interface pads between the mirror and the support structure.

7.3.2 Common Practice Implementation Requirements

7.3.2.1 Optical Materials

Optical glass shall conform to the requirements of MIL-G-174B. The class, grade, and form of the glass shall be suitable for the application.

The tertiary mirror shall be made of Ohara Clearceram-Z or equivalent.

7.3.2.2 Coatings

The mirror shall be supplied uncoated and shall be coated with bare aluminum by WMKO.

7.3.3 Standards Implementation Requirements

None.

7.3.4 Regulatory Implementation Requirements

None.

7.4 Design Requirements

7.4.1 Technological Design Requirements

7.4.1.1 Optical Component Mountings

7.4.1.1.1 General

All optical components shall be mounted so that alignment is maintained during thermal cycling due to environmental conditions encountered during shipping, handling, and operations. Mountings shall ensure that excessive stress is not placed on the optical components due to thermal differentials between the optical component and the mount. Mountings shall also ensure that alignment of optical components is maintained without excessive stress at all module rotator angles and telescope elevations.

7.4.1.1.2 Elastomers and Adhesives

Materials used in optical component mountings, particularly elastomers and adhesives shall be compatible with the coatings on the associated optical components. Such materials when used on the tertiary mirror mounting shall be able to be placed in the evaporative coating chamber at WMKO and tolerate the vacuum and thermal conditions encountered in the coating process without deterioration or outgassing.

7.4.1.2 Alignment Tolerancing

Before assembly, all optical components and systems shall have a documented optical alignment tolerance budget. During assembly measurements shall be made as required to ensure that the stack-up of tolerances does not exceed the tolerance budget.

7.4.2 Regulatory Design Requirements

None.

7.4.3 Standards Related Design Requirements

Drawings for optical components shall conform to American National Standards Institute (ANSI) / American Society of Mechanical Engineers International (ASME) standard Y14.18M-1986 "Optical Parts (Engineering Drawings and Related Documentation Practices)".

7.4.4 Integration Related Design Requirements

None.

8 MECHANICAL REQUIREMENTS

8.1 Purpose and Objectives

The purpose of this section is to describe requirements for the mechanical performance, implementation and design of the K1DM3.

The mechanical requirements address issues of design, reliability and maintainability. Based on experience with previous instruments the observatory is sensitive to certain aspects of performance, implementation and design that have proven to be important factors in the up time of its instruments. The mechanical requirements section has as a main objective the description of the expected performance, features and configuration of the instrument's mechanical systems. A secondary objective is to identify specific areas where experience indicates particular attention is required with respect to performance, implementation or design.

Unless noted otherwise all mechanical requirements apply over the full range of environmental conditions given in Table 6.

8.2 Performance Requirements

8.2.1 Parametric Performance Requirements

The mechanical performance requirements for the K1DM3 shall be as given in Table 9.

Note that the mirror in beam positioning requirements are given in terms of the mirror plane for decenter and about an axis normal to the mirror plane for rotation of the mirror. Tip is given in terms of motion around the telescope Z axis, and Tilt is given in terms of motion around the telescope Y axis. In other words, Tip corresponds to rotation of the deployed mirror to select either of the Nasmyth focal stations or one of the four bent Cassegrain ports. Tilt corresponds to the folding of the light from the telescope secondary through 90° to direct the light towards the telescope elevation axis.

The module defining error requirements apply to initial positioning each time the K1DM3 is installed in the telescope. The repeatability requirements apply to each positioning of the K1DM3 when it is installed in the telescope.

The total tertiary mirror positioning error due to module defining error and the error allowed by the mirror in beam positioning accuracy and repeatability requirements may not exceed the maximum error allowed due to module defining error alone.

The in beam stability requirements are directed at controlling random motion of the mirror in response to vibration when the telescope is moving or stationary. It is possible for a systematic drift of position to occur due to monotonic changes in mirror position, for example a change in the position of the telescope secondary with changes in telescope elevation. Any such drift will be removed by the guiding process, although changes in position of either the secondary or tertiary of sufficient magnitude may result in a reduction in image quality and possibly, due to the curved telescope focal plane, a change in focus. However, the guiding process has a limited bandwidth (1 to 2 Hz. maximum) and cannot compensate for motions corresponding to higher frequencies. Also, the image position sensors (guide cameras) have finite resolution and provide limited detection of small motions that appear to simply make the seeing worse.

To determine the limit for motion of the K1DM3 tertiary mirror in response to vibrations we follow established convention which allows uncorrelated effects on image quality at the level of 10% of the seeing disk. Based on this convention, for 0.4" seeing, translation of the mirror along the telescope X or Z axes should be no more than 29 microns. We adopt this as an rms constraint on movement due to vibration. Confining the motion to ±29 microns (rms) places a requirement that motion due to vibration be less than 0.92" and 0.46" (rms) for tip and tilt respectively.

The requirement for tracking by the K1DM3 rotator assumes that the required clear FOV in the retracted position (see Table 8) is achieved at only a finite number of positions relative to the science and guider FOVs of the Keck I Cassegrain instruments. It also assumes that these instruments rotate to compensate for the image rotation produced by the telescope as it follows the sidereal motion of the sky. The combination of these two assumptions makes it is necessary to rotate the retracted tertiary mirror to meet the requirement to not vignette the light path to the FOVs of the Cassegrain instruments (see Table 8, notes 4 and 5).

Table 9: K1DM3 mechanical performance requirements

Parameter	***Min.***	***Typ.***	***Max.***	***Units***	***Notes***
K1DM3 module weight	-	-	1000	Kg	1
KIDM3 handler weight	-	-	1000	Kg	
K1DM3 module overall dimensions					
Diameter	-	-	1240	mm	2
Length	-	-	2120	mm	2
Operating elevation angle	-0.5	-	93.5	º	3
Operating ambient temperature	-10	0	20	ºC	
K1DM3 module power dissipation					
To ambient	-	-	5	Watts	4
To glycol supply	-	-	1800	Watts	
Glycol cooling					
Temperature rise	-	-	3	ºC	5
Operating pressure	-	30	100	Psig	6
Pressure drop	-	-	20	Psi	
Flow rate	-	-	9.8	l/min	
Module defining error					
Decenter from the telescope X and Z axes	-	-	0.725	mm, rms	7,8,10
Decenter from the telescope Y axis	-	-	0.725	mm, rms	7,8
Rotation about the X axis	-	-	1	º	7,8
Rotation about the Y axis	-	-	23	", rms	7,8,11
Rotation about the Z axis	-	-	11.5	", rms	7,8,12
Mirror in beam positioning					
Accuracy					
Decenter in the mirror plane	-	-	2.5	mm	
Decenter from the telescope X and Z axes	-	-	0.725	mm, rms	7,10
Tip	-	-	11.5	", rms	9,12
Tilt	-	-	23	", rms	9,11
Rotation about mirror surface normal	-	-	1	°	
Repeatability					
Decenter in the mirror plane	-	-	2.5	mm	13,14
Decenter from the telescope X and Z axes	-	-	0.725	mm, rms	7,10,13,14
Tip	-	-	11.5	", rms	9,12,13,14
Tilt	-	-	23	", rms	9,11,13,14
-	-	-	1	°	13,14
Stability					
Decenter in the mirror plane	-	-	1	mm	14,15
Decenter from the telescope X and Z axes	-	-	0.029	mm	7,14
Tip	-	-	0.92	", rms	9,14
Tilt	-	-	0.46	", rms	9,14
Rotation about mirror surface normal	-	-	1	°	14,15

Table 9, cont'd: K1DM3 mechanical performance requirements

Mirror retracted positioning					
Repeatability					
Decenter from the telescope Z axis	-	-	2	mm	7,20
Rotation on either axis perpendicular to the telescope Z axis	-	-	1	°	7,20
Rotation about the telescope Z axis	-	-	15	"	7,20
Mirror deploy/retract time	-	-	120	s	16
Retracted/deployed balance change	-	-	0.5	A	17
Rotation about the telescope Z axis					
Slew speed	2	6	-	°/s	
Tracking speed	-	-	0.7	°/s	18
Range	360	-	-	°	19
Tracking error	-	-	TBD	", rms	20

Notes:

1. Goal maximum. The current Keck I tertiary mirror module weighs 1,256 kg. In no event may the K1DM3 exceed this weight.
2. The overall dimensions of the existing Keck I tertiary module are given in referenced drawing 1. The dimensions quoted here are identical. Note however that the actual envelope must clear the module tracks and other features in the tower as shown referenced drawing 3.
3. Maximum range of telescope elevation change. 90° elevation corresponds to the telescope pointed straight up (at the Zenith). See referenced drawing 4 for limit definitions.
4. Thermal radiation from the K1DM3 module due to power dissipation of components on the K1DM3 associated with the deploy/retract mechanism and the rotation mechanism must not exceed a value that by analysis can be shown to contribute no more than 1% of the average sky background at 2.4 µm wavelength.
5. Normal coolant supply temperature is 3 ºC below dome ambient. The coolant is a 50/50 mix of Dowtherm SR-1 and water.
6. All cooling system plumbing shall be able to withstand a maximum pressure of 100 psig in the event of system pressure regulation failure
7. With the telescope pointed at the horizon the x axis is the direction parallel to the telescope elevation axis (horizontal), the y axis is perpendicular to this (vertical), and the z axis corresponds to the telescope optical axis. The positive signs for each axis are defined by the right hand rule when standing behind the telescope (at the Cassegrain focus).
8. Module defining error is the residual position error of the K1DM3 module after it is defined in the telescope tertiary tower
9. Tip refers to motion around the telescope Z axis and tilt refers to the motion around the telescope Y axis
10. The sum for decenter from the telescope X and Z axes due to defining error and mirror in beam positioning accuracy and repeatability may not exceed the value given for defining error alone
11. The sum for rotation about the Y axis due to defining error and mirror in beam tilt accuracy and repeatability may not exceed the value given for defining error alone
12. The sum for rotation about the Z axis due to defining error and mirror in beam tip accuracy and repeatability may not exceed the value given for defining error alone
13. Repeatability requirements apply over a temperature range of ±5 °C with an average rate of change of 1.6 °C/hour
14. Repeatability and stability requirements apply only when the mirror is defined in beam
15. The stability of decenter in the mirror plane and rotation about the mirror surface normal should be determined by the constraint of the mirror mass needed to achieve the other stability requirements

16. Time required to move to a selected deploy position or to fully retract and become ready to begin rotator slewing or tracking
17. The average of the elevation drive current required to move to higher and lower elevations shall not exceed 0.5 A (where an average of 0 A indicates a perfectly balanced telescope) when the balance of the K1DM3 module changes due to moving the tertiary mirror between the retracted and stored positions. The torque constant for the elevation drive is 100 kg m/A.
18. Tracking means that the K1DM3 rotator is moving at the variable rate required to match the rotator motion of a Keck I Cassegrain instrument when that instrument's rotator is compensating for the image rotation produced by the telescope as it follows the sidereal motion of the sky
19. The rotator shall be capable of continuous clockwise or counter-clockwise rotation about the telescope z axis.
20. If continuous or intermittent rotation is required when the mirror is retracted to avoid vignetting the light path from the telescope secondary mirror to the Cassegrain focal station, the mirror must not vignette this light path at any time.

8.2.1.1 Elevation Range

The K1DM3 is expected to meet all of the performance requirements given in Table 9 over the full elevation range of the Keck I telescope.

8.2.1.2 K1DM3 Module Power Dissipation

The K1DM3 module shall not radiate more than 5 watts of heat into the telescope dome ambient environment. All heat generated by the K1DM3 module in excess of this amount shall be carried away by a liquid cooled heat exchanger system.

8.2.1.3 K1DM3 Electronics Power Dissipation

The K1DM3 electronics shall be located remotely from the K1DM3 module in a location where either room air conditioning or a liquid to air heat exchanger system can carry away the heat generated by the electronics. If a standalone enclosure is provided for the K1DM3 electronics the enclosure shall be cooled with a liquid to air heat exchanger and insulated so that no more than 50 watts is dissipated into the dome environment.

8.2.2 Operational Performance Requirements

8.2.2.1 Rotator

The K1DM3 module shall be provided with a rotator mechanism that serves to point the deployed tertiary mirror at the desired Keck I Nasmyth or bent Cassegrain focal position. When the deployed mirror is positioned at one of the six focal station positions it shall be locked in place by a detent or other means.

When the tertiary mirror is retracted the rotator shall be able to rotate to any position at any telescope elevation angle. If required the rotator shall be able to rotate continuously at any telescope elevation angle in order to maintain the retracted tertiary mirror in a position that does not vignette the light path to the science and guider FOVs of the Cassegrain instruments LRIS and MOSFIRE.

8.2.2.2 Operating Temperature Range

The K1DM3 shall be designed for operation over the ambient temperature range given in §6.2.1.1.3.

8.2.2.3 Vibration

Vibration isolation shall be employed as required to isolate sources of vibration within the K1DM3 due to moving components such as fans, pumps and motors.

The K1DM3 shall meet all performance and operating requirements when installed in a vibration environment that conforms to the Generic Vibration Criteria[1] Curve "D" as shown in Figure 7. The K1DM3 shall not produce vibrations that result in rms velocities in excess of those given in curve "D" of Figure 7.

[1] Gordon, Colin G. *Generic Criteria for Vibration-Sensitive Equipment*. Proceedings of the SPIE Vol. 1619, pp. 71-85, Vibration Control in Microelectronics, Optics, and Metrology. Gordon, Colin G. editor. SPIE 1992.

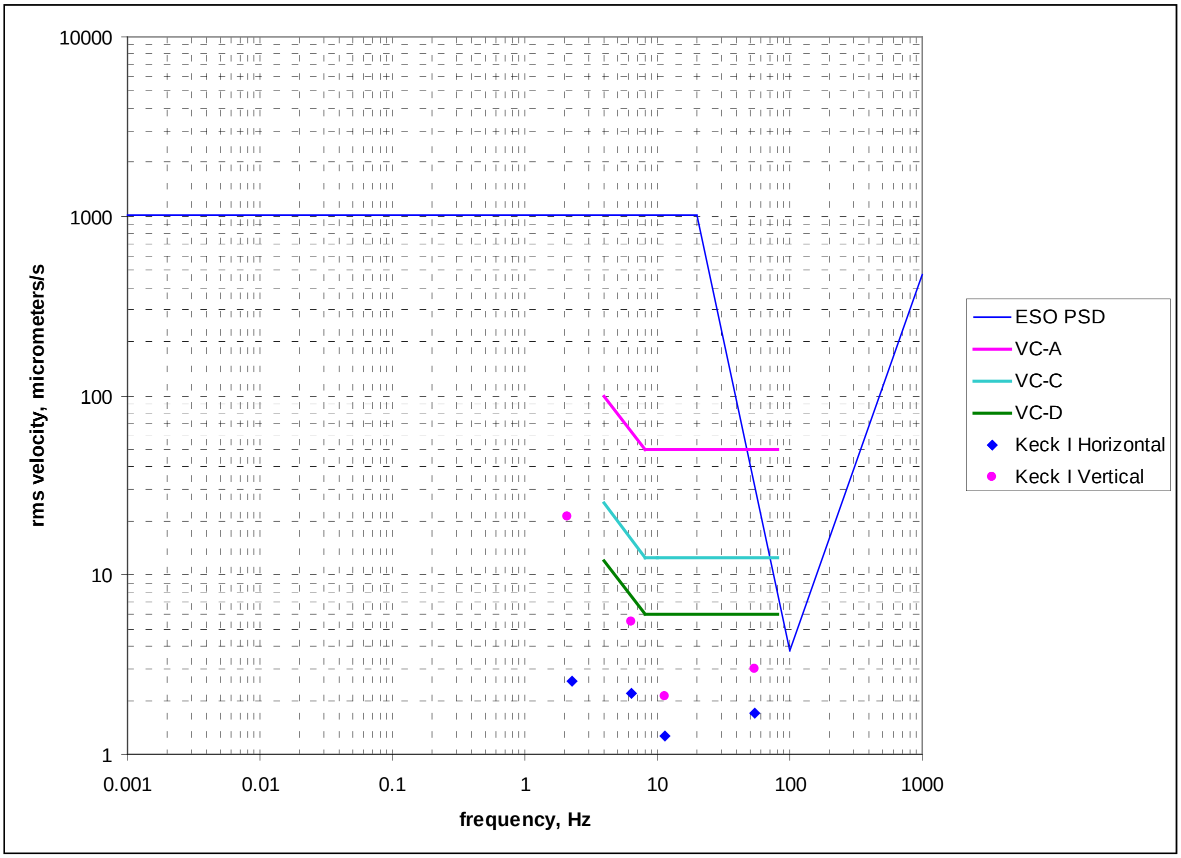

Figure 7: Keck I & II telescope equipment vibration limits

Vibration measurements made to confirm compliance with these vibration limits shall be made in accordance with the presentation shown in Figure 7 and the methods of reference 4.

8.3 Implementation Requirements

8.3.1 Feature Implementation Requirements

8.3.1.1 K1DM3 Module

The K1DM3 module shall be designed for installation in the Keck I tertiary tower using the same defining points provided for the existing Keck I tertiary mirror module. All adjustments to align the K1DM3 module in the telescope shall be made by adjusting the defining point halves located on the K1DM3 module.

The K1DM3 module shall be compatible with the module insertion and removal rails provided in the Keck I tertiary tower.

8.3.1.2 Tertiary Mirror Mounting

The tertiary mirror mounting shall provide for removal and replacement of the mirror for recoating. Any permanently attached fittings or supports and their means of attachment must be compatible with the vacuum and thermal environment of the WMKO evaporative coating chamber.

The following procedure shall be used to remove the mirror for recoating:

1. Remove the K1DM3 module from the telescope using the K1DM3 handler.
2. Rotate the mirror to place the mirror surface in the upward facing position.
3. Retract the mirror. This will place the mirror essentially parallel to the ground.
4. Using the Keck I jib crane grasp the mirror with a custom made talon assembly.
5. Disengage the mirror from the K1DM3 module and lift it off with the crane.
6. Place the mirror on a modified version of the existing tertiary mirror coating cart and transport the mirror to the coating room.

The above procedure is reversed to replace the mirror in K1DM3 after recoating.

8.3.1.3 K1DM3 Mechanisms

All K1DM3 instrument mechanisms shall provide a positive indication that the requested move(s) have been completed. The use of a relative or absolute position indicating means in conjunction with limit switches is preferred.

The tertiary mirror shall be securely held in place in both the deployed and retracted positions to designed to ensure that the mirror does not become loose or free to swing about during a zone 4 earthquake (see §8.3.3.1 below).

Mechanisms shall operate properly over the full ambient temperature range given in §6.2.1.1.3.

8.3.1.4 Handler

The K1DM3 module handler shall be based on the design of the existing K1DM3 tertiary mirror module handler and shall be as identical to that existing handler as possible.

The K1DM3 module handler shall incorporate structural components that shall maintain its integrity during a zone 4 earthquake (see §8.3.3.1 below).

The handler shall incorporate seismic restraint provisions for the K1DM3 module when the handler is parked at the storage position.

The handler shall be equipped with a removable tractor drive assembly compatible with the existing Keck I tertiary mirror module tractor drive assembly and drive method to move the handler on the Keck I Cassegrain platform and Nasmyth deck rail system.

A dust cover shall be provided to protect the tertiary mirror when the K1DM3 module is stored on the handler.

8.3.1.5 Access and Covers

Components requiring routine service or maintenance shall be accessible by removing a single cover secured by no more than 8 fasteners. Covers that may be removed in a location where fasteners could fall into the interior of the enclosure shall be equipped with captive fasteners. Captive fasteners shall be of the threaded type and shall not be held captive by swaged sleeve fittings. Quarter turn fasteners engaging spring hooks are specifically discouraged for reasons of fit and reliability.

Whenever possible service access provisions shall be provided that do not require disassembly of the entire instrument to access motors or switches for replacement.

8.3.1.6 Glycol Cooling

All glycol cooling circuits shall be compatible with a 50/50 mix of Dowtherm SR-1 and water.

All glycol cooling circuits shall be plumbed with braided stainless steel hose and stainless steel fittings. Custom manifolds shall be used rather than arrangements of “T” fittings and hose. Permanent connections shall be made with JIC 37º flare compression fittings or SAE straight thread O-ring fittings. Teflon tape shall not be used to seal threaded connections.

Removable connections shall be made with ½ inch Parker Hannifin series FS quick disconnect fittings. The instrument supply coupler is male and the return coupler is female.

Where required King Instrument Company flow meters and needle valves are preferred for flow metering and control applications. Where variable gravity orientations are encountered a spring loaded variable area flow meter, such as the in-line flow meters manufactured by the Hedland Division of Racine Federated Inc. shall be employed. The Hedland T303 stainless steel models are preferred.

All glycol cooling systems shall be provided with a flow switch, Proteus Industries Inc. type 100B110 is preferred, to generate a loss of coolant alarm. This flow switch shall interrupt power to the affected system unless a separate over-temperature detection system is provided to remove power from the affected system.

8.3.2 Common Practices Implementation Requirements

8.3.2.1 Fit and Finish

All steel or iron components shall be plated or painted to prevent rust. This includes fasteners and rivets. Welds not ground to the surface or joint profile shall be of dress quality. All welds and castings shall be stress relieved prior to painting and assembly.

Machined components shall be free of tool marks, scratches and material flaws such as inclusions or voids.

Unless otherwise specified all external enclosure and exposed structural elements shall be finished in epoxy paint applied in accord with the manufacturer's instructions.

All burrs and sharp edges shall be removed from all fabricated components unless the function of the component requires a sharp edge.

Mild steel surfaces that cannot be painted for functional reasons (such as accurate interface surfaces) shall be protected by a non-tracking anti-corrosion dry film lubricant.

8.3.2.2 Continuity of Shielding and Grounding

Dissimilar metals in contact under conditions where electrolytic corrosion may occur shall be isolated by a dielectric finish or insulating spacers. Notwithstanding this requirement all components of enclosures that are required to provide protective grounding or EMI shielding shall be electrically bonded at multiple points by threaded fasteners, finger stock, or a continuous conductive elastomeric gasket. If grounding straps are used they shall be tin plated copper braids not less than 6 mm in width. Anodized aluminum parts shall be free of anodizing at the points where electrical contact is required. Painted metal parts shall be free of paint at the points where electrical contact is required.

8.3.2.3 Corrosion resistance

All metal components shall be finished to prevent corrosion in the operating environment (see Table 6) over a normal 10 year operating lifetime including handling, maintenance and repair.

All removable fasteners shall be plated or treated to prevent corrosion.

Internal components may be plated or paint finished. A contractor who can show conformance to the requirements of MIL-STD-171E "Finishing of Metal and Wood Surfaces" or equivalent shall perform any required painting, plating or anodizing.

8.3.2.4 Fasteners

Metric sizes shall be used whenever available for threaded fasteners.

Press fit studs or threaded inserts shall be installed in the correct material (i.e. no aluminum inserts in steel) according to the manufacturer's instructions. Samples of such fasteners installed in the actual material shall be obtained and subjected to pull out tests prior to use in an actual design. Self-tapping screws shall not be used for removable covers or to secure components that shall have to be removed for repair or replacement.

Fasteners shall have either Phillips or hex socket heads. Hex socket button head fasteners shall not be used except where space or specific function requires them. Undercut machine screws shall not be used except in special cases where there is no other appropriate design alternative.

Prevailing torque locknuts or lock washers are preferred to thread locking compounds. Soft insert locknuts shall have Kel-F or Vespel inserts, and shall only be used where subsequent removal is not anticipated.

8.3.2.5 Lubricants

Lubricants shall be suited for the low temperature environment encountered at the summit. The base oil in a grease lubricant shall have a high viscosity index, a low pour point temperature and a low viscosity at the average operating temperature (based on a 0 ˚C ambient). Greases using synthetic base oils such as Fluoroether or Silicone are preferred.

Where appropriate bearings and gears shall be lubricated using the preferred WMKO grease, Kuberplex Isoflex NB 5051. Closed raceways shall be filled only with the volume required for proper lubrication. Closed raceways shall be provided with stainless steel Zerk fittings or equal to allow for periodic maintenance. These fittings shall be accessible by removing an access cover but without requiring disassembly of the instrument.

8.3.2.6 Lubricated Components

Exposed lubricated components such as gear trains or lead screws shall be enclosed in a shroud or boot to prevent the collection of dust and dirt and also to prevent accidental contact that may result in the transfer of the lubricant to other surfaces.

8.3.3 Standards Implementation Requirements

8.3.3.1 Structural

The structure of the K1DM3 module shall meet the zone 4 earthquake survival requirements of Telcordia Standard GR-63-CORE, "NEBS™ Requirements".

8.3.4 Regulatory Implementation Requirements

None.

8.4 Design Requirements

8.4.1 Technological Design Requirements

8.4.1.1 Opto-Mechanical Assemblies

Optical and mechanical assemblies, modules or components that shall be removed for service shall be provided with locating pins or other features as required to permit repeatable removal and replacement.

Handling features shall be provided on all components unless they are inherently easy to handle without risk of damage. Handles shall be provided (preferably fixed) for components with weights greater than 1 kg up to 25 kg. Heavier components and subassemblies shall be provided with lifting eyes or ‘A’ brackets.

8.4.1.2 Electrical/Electronic Assemblies and Enclosures

Service access and regulatory compliance in electronic assemblies and enclosures requires attention to the dimensions of components and the space provided for terminal access, wire bending and component mounting.
The mechanical arrangement of the electronic assemblies within enclosures shall be designed using techniques that document the proposed arrangement and permit the verification of accessibility, wire bend radii and electrical spacings. Computer aided design techniques including solid modeling may be of value in achieving these objectives.

Where possible electrical and electronic subsystems shall consist of rack mounted modules conforming to the 19 inch (482.6 mm) width pattern of Electronic Industries Association (EIA) standard 310-D, “Cabinets, Racks, Panels, and Associated Equipment”, section 1. Where rack mounted modules are used each module shall be installed using rack slides.

Where rack mounted equipment can be accessed only from the front all rack slides shall extend far enough to permit disconnection of any rear panel connections prior to removal of the rack module from the slides.

In systems that consist predominantly of rack mounted modules, all commercial off the shelf (COTS) modules, components and subsystems that are not available in rack mount configurations shall be mounted in suitable rack module chassis or on rack mount shelves. All rack module chassis and shelves shall be mounted on slides. Components or modules mounted on shelves shall be fully enclosed as required to meet all other requirements for grounding, shielding and electrical safety.

Components or modules weighing less than 0.5 kg may be mounted on hinged or screw mounted rack panels provided that all other requirements for grounding, shielding and electrical safety are met.

Rails in 19 inch rack cabinets shall be tapped or equipped with captive tapped inserts. Clip nuts shall not be used.

Enclosures for electrical and electronic components shall provide a continuous shield to prevent the entry or emission of electromagnetic energy. No openings greater than 3 mm in diameter or 3 mm in width and 15 cm in length shall be permitted on the exterior of any enclosure for electrical and electronic components. This includes gaps due to access covers, hinges or other enclosure components. Removable covers that do not make continuous contact with the enclosure shall be provided with a fastener every 15 cm or with conductive gaskets or finger stock as described in §8.3.2.2.

Thermal analysis shall be performed to ensure that all components operate within their temperature limits and to ensure that excess heat is not transmitted to other components or sub-systems of the instrument.

8.4.1.3 Drive Couplings

Shaft couplings for motors, encoders and other drive components shall be pinned or locked so that the shaft and coupling cannot slip. Separable couplings shall be used whenever possible for motors to facilitate motor replacement.

8.4.1.4 Component Ratings

Structural elements and fasteners whose failure could cause injury to personnel or equipment shall be selected for a safety factor of 10 over ultimate strength of the material. All other structures and fasteners shall be designed with a safety factor of at least 5.

All mechanical moving parts shall be selected for a 10 year operating lifetime in the operating environment specified in Table 6.

8.4.2 Regulatory Design Requirements

None.

8.4.3 Standards Related Design Requirements

Enclosures for electrical/electronic components and wiring shall conform to the requirements of the Underwriters Laboratories Inc. (UL) Standard for Safety 508 "Industrial Control Equipment". See §9.3.3.1 for references to the relevant requirements.

All electrical and electronic components shall be enclosed in a manner that meets the requirements for a NEMA type 4 or better enclosure. The requirements for a NEMA type 4 enclosure are given in the National Electric Manufacturers Association (NEMA) standards publication 250-1997, "Enclosures for Electrical Equipment (1000 Volts Maximum)".

Mechanical drawings shall conform to ANSI standard Y14.5M-19994 (R1999) "Dimensioning and Tolerancing" and ASME standard Y14.100-2000 "Engineering Drawing Practices".

8.4.4 Integration Related Design Requirements

8.4.4.1 K1DM3 Module

The K1DM3 module shall be designed for installation in the Keck I telescope tertiary mirror tower and for storage at the Keck I telescope RT3 position.

Positioning of the K1DM3 for storage or observing shall not require changes to the mechanical configurations of existing instruments on Keck I.

8.4.4.2 K1DM3 Electronics

The K1DM3 electronics shall be located in an existing EIA 19 inch rack in the Keck I computer room or mounted in an insulated, glycol cooled enclosure in the dome in a location below the level of the telescope primary mirror.

8.4.4.3 Servicing

The K1DM3 module shall be provided with all fixtures and equipment needed to disassemble the module for service. If required a crane shall be provided by the observatory. The footprint of service fixtures or stands shall be minimized because storage and working space on the summit is at a premium.

The K1DM3 tertiary mirror shall be removable for recoating and shall be provided with an adapter as required to permit the use of the existing Keck I tertiary mirror handling fixture when the mirror is removed for recoating (see §8.3.1.2).

The profile of all service fixtures or stands shall be designed with as low of a center of gravity as possible to resist tipping. Seismic restraints may also be required.

Handling provisions, fixtures and stands shall be designed for safe operation and with consideration for ergonomic factors such as range of motion and working posture.

9 ELECTRONIC/ELECTRICAL REQUIREMENTS

9.1 Purpose and Objectives

The purpose of this section is to describe requirements for the performance, implementation and design of the K1DM3 electronics.

The electronic/electrical requirements address issues of safety, design, reliability and maintainability. Based on experience with previous instruments the observatory is sensitive to certain aspects of performance, implementation and design that have proven to be important factors in the up time of its instruments. The electronic/electrical requirements section has as a main objective the description of specific requirements for implementation and design.

A key consideration is the safety of personnel and equipment, and proper electrical design and implementation practices in compliance with recognized standards are an essential aspect of electrical safety. A second consideration is the electromagnetic compatibility of the instrument with the observatory systems, and specific implementation and design requirements are given to aid in achieving the required electromagnetic emissions and susceptibility performance.

Unless noted otherwise all electronic/electrical requirements apply over the full range of environmental conditions given in Table 6.

9.2 Performance Requirements

9.2.1 Parametric Performance Requirements

9.2.1.1 Electrical Power

The electrical power requirements for the K1DM3 are given in Table 10.

Table 10: K1DM3 electrical performance requirements

Parameter	*Min.*	*Typ.*	*Max.*	*Units*	*Notes*
K1DM3 Power					
Voltage	108	120	132	Volts AC	1
Current	-	-	15	A	1
Frequency	57	60	63	Hz	1
Tractor Power					
Voltage	187	208	229	Volts AC	2
Current	-	-	20	A	
Frequency	57	60	63	Hz	
Wire and cable ratings	-30	-	100	°C	

Notes:

1. Power for all K1DM3 electronics and drive motors including the deploy/retract and rotator drives, but excluding the tractor drive for moving the handler.
2. Power for the handler tractor drive.

9.2.1.2 Power Dissipation

See §8.2.1.1.

9.2.1.3 Compatibility

The K1DM3 shall be electrically compatible with the telescope environment.

9.2.1.4 Temperature and Humidity

Unless otherwise agreed to by WMKO all electronics in K1DM3 shall at a minimum meet the requirements for commercial temperature range operation from 0 °C to 50 °C and shall be enclosed in an air conditioned location in the observatory computer room or in an insulated enclosure cooled with a liquid to air heat exchanger and providing a controlled environment with an operating temperature range suitable for the enclosed electronics. All electronics not so enclosed shall be designed for operation in an ambient temperature range of -10 °C to 30 °C

All K1DM3 electronics shall be designed for operation from 0% to 95% relative humidity, non-condensing.

9.2.1.5 Cable and Wire Ratings

All wire and cable shall be rated for an ambient temperature range of -30 °C to 100 °C.

9.2.2 Operational Performance Requirements

None.

9.3 Implementation Requirements

9.3.1 Feature Implementation Requirements

9.3.1.1 Emergency Stop Input

The K1DM3 shall be provided with an emergency stop input that stops all K1DM3 module motion (including the rotator) when the observatory emergency stop signal is activated.

9.3.1.2 Local Control and Remote Lockout

The K1DM3 module shall be provided with local controls for tertiary mirror deploy/retract and speed and direction of rotation. A key lock operated remote lockout switch shall also be provided on the module to defeat remote control of the module.

9.3.1.3 Host Computer

If a dedicated host computer is required for the K1DM3 it shall be an industrial grade high reliability server using the Intel 64 bit architecture and running a WMKO approved operating system.

Connections to the observatory wide "public" network and any required K1DM3 private network shall be made using two separate network interfaces in the host computer. This will isolate the time critical K1DM3 control communications from the Observatory wide network traffic. The host computer shall be configured to ensure that there are no routes or bridges between the Observatory wide network and the K1DM3 private network.

9.3.1.4 K1DM3 Module Connection Panel

All interconnections to the K1DM3 module shall be made at a single location on the stationary portion of the module frame.

9.3.1.5 Printed Circuit Boards

All removable plug-in printed circuit boards shall be equipped with positive retention features. Extractors shall be provided for all circuit boards where high insertion and withdrawal forces are expected.

9.3.2 Common Practices Implementation Requirements

9.3.2.1 Stray Light

The K1DM3 module shall not produce stray light from LED or lamp indicators, optical switches or optical shaft encoders over the wavelength range of 320 nm to 20,000 nm.

LED or lamp indicators shall not be used on the exterior of the K1DM3 module. Any indicators required for service shall be concealed behind a cover or access door. Optical switches or shaft encoders shall be optically baffled or enclosed so that no stray visible or infrared light is emitted into the telescope optical path or dome environment.

All exterior parts of the K1DM3 module shall be examined for stray light emissions with a night vision device with a light gain of at least 50,000[2]. A person known to have normal photopic and scotopic visual sensitivity shall conduct the examination under dark adapted conditions.

9.3.2.2 Digital Control and Status Communications

Where ever possible digital communications for control and status information between subsystems and modules shall be implemented using the TCP/IP protocol over a 100Base-TX Ethernet interface. Purpose built or custom designed electronic modules and circuits that require such communication shall be designed with these protocols.

Where legacy or COTS hardware is used and only serial communications is available, RS-232 signal levels with an asynchronous 8 bit format may be used. RS-232 data rates shall be the maximum practical for the required cable length, and RS-485 levels with electrical isolation (to prevent common mode problems and ground loops) shall be used for cable runs longer than 3 meters.

All RS-232 controlled devices shall be interfaced to the instrument computers using a terminal server. The Lantronix EDS32PR is the preferred terminal server at WMKO.

[2] This is a typical specification for generation III night vision monocular such as the ITT 160 Night Mariner.

9.3.3 Standards Implementation Requirements

9.3.3.1 Electrical Safety

The design and construction of the K1DM3 shall conform to the requirements of UL Standard for Safety 508 “Industrial Control Equipment”. The relevant portions of UL 508 may be summarized as follows:

1. Specific metal gauge requirements are given in tables 6.1 (page 22) and 6.2 (page 23).
2. Specific details for doors and covers are given in section 6.4 (pages 24 through 27).
3. Specific requirements for the design of ventilation openings are given in section 6.9 (pages 31 through 33).
4. Specific details for controlling the accessibility of live parts are given in section 6.17 (pages 36 through 37 and figures on pages 38 and 39).
5. Requirements for insulating material that directly supports live parts are given in section 15 (pages 42B through 43). This includes printed circuit boards.
6. Specific requirements for the protection of control circuits are given in section 18.2 (pages 47 through 48B).
7. Specific requirements for internal wiring are given in section 21 (pages 50 through 56A).
8. Section 34 (page 68) gives specific requirements for the separation of circuits.
9. Section 35 (page 68A) gives specific requirements for optical isolators.
10. Specific details for required electrical spacings are given in section 36 (pages 68A through 73).
11. Specific details for grounding are given in section 40 (pages 79 through 82).
12. Table 43.1 (pages 84C through 84E and explanations on pages 84E and 84F) indicates the maximum permissible temperature rises for specific materials and components.
13. Table 43.2 (page 86) indicates the ampacity of various insulated conductors.
14. Section 49 (pages 99 through 100A) gives the requirements for dielectric voltage-withstand testing.
15. Section 62 (pages 128B and 128C) gives specific requirements for device ratings.
16. Section 63 (pages 128E through 133) gives specific requirements for markings. These are summarized in table 67.1 (pages 134A through 136B).
17. Additional requirements for programmable controllers are given in sections 177 through 193 (pages 196B through 201)

The design and construction of the wiring of the K1DM3 shall conform to the requirements of the National Electric Code. The applicable local electric code is the Hawaii County Code 1983, 1995 Edition. This code adopts the National Electric Code in its entirety and there are no additional special requirements applicable to the locations where the K1DM3 will be installed or operated. The requirements given in §9.3.3.1 are consistent with the applicable portions of the National Electric Code.

9.3.3.2 Electromagnetic Compatibility

Standards exist that specify the test conditions and limits for electromagnetic emissions and electromagnetic immunity. They do not give information on how to achieve compliance. In the absence of such information WMKO asserts that a satisfactory level of electromagnetic emission and immunity compliance can be achieved by following the requirements given in sections 8.3.2.2, 8.4.1.2 and 9.3.4.5 of this document.

For information on the permitted level of emissions and the required level of immunity the following standards may be consulted:

1. The conducted and radiated emissions limits for unintentional radiators are specified in Title 47 CFR Part 15, sections 15.107 and 15.109 for class B devices.

2. Electromagnetic immunity requirements are given in the Council of the European Communities Directive EMC 89/336/EEC, and the reference standard of the European Committee for Electrotechnical Standardization (CENELEC) EN 50082-1:1997 "Electromagnetic compatibility-Generic immunity standard-Part 1: Residential, commercial and light industry" published in the Official Journal of the European Community on March 1, 1998.

9.3.4 Regulatory Implementation Requirements

9.3.4.1 AC Line Connections

All ac line connected parts shall be fully enclosed so as to prevent accidental contact with live parts. All ac line connections shall utilize UL listed connectors and cables.

All power input connectors shall have an adjacent label indicating the voltage, frequency and current rating for which the equipment is designed.

9.3.4.2 Covers

Removable covers that permit access to circuits with voltages in excess of 36 volts RMS ac or 30 volts dc shall be marked with a warning label.

Removable covers that permit access to circuits of less than 36 volts RMS ac or 30 volts dc that are capable of fault currents in excess of 2 amperes shall be marked with a warning label.

9.3.4.3 Wiring

Internal wiring of 120/208/240 volts ac circuits shall use UL type AWM stranded wire with an insulation thickness of at least 0.8 mm.

The insulation color of internal wiring and the conductors of multi-conductor cable for ac power wiring shall conform to the requirements of the National Electric Code. The insulation of neutral (grounded) conductors shall be white or gray in color. Neutral conductors shall be the same size as phase conductors except in cases where two or more phases are provided and harmonic currents are expected, in which case the neutral conductors shall be 125% of the size of the phase conductors.

The insulation of grounding conductors (protective or earth ground) shall be green or green with a yellow stripe.

Grounding conductors shall be the same size as the phase conductors.

Phase, neutral and ground conductors shall be sized using table 43.2 of UL 508.

9.3.4.4 Overcurrent Protection

A fuse or circuit breaker shall internally protect all ac line connected equipment. When a time delay fuse or time delay breaker is used the rating of the breaker shall not exceed 150% of the continuous full load current of the connected load. Where a non-time delay fuse is used the rating of the fuse shall not exceed 150% of the continuous full load current of the connected load. Where an instantaneous trip breaker is used the rating of the breaker shall not exceed 250% of the continuous full load current of the connected load.

The panel where the fuse or circuit breaker is located shall be clearly marked with the type and rating of the protective device.

9.3.4.5 Grounding and Shielding

The enclosures of ac line connected components shall be grounded in conformance with the requirements of the National Electric Code and any local codes. Grounding conductors shall be continuous and bonded to the enclosure in at least one point. The grounding point shall be specifically provided for the purpose and shall not be a screw or nut used for mounting components or covers. Any paint or surface treatment that acts as an insulator shall be removed in order to ensure a good electrical contact for the ground connection.

All components capable of generating electromagnetic emissions in excess of the limits established in the standards referenced in 9.3.3.2 above shall be shielded and the shielding grounded to limit electromagnetic emissions to the levels allowed by the standards referenced in 9.3.3.2. All components susceptible to externally generated electromagnetic emissions in excess of the limits established in the standards referenced in 9.3.3.2 above shall be shielded and the shielding grounded to protect those components from unintended operation due to external electromagnetic emissions of the levels established in the standards referenced in 9.3.3.2.

9.3.4.6 Terminations

Crimp terminals and compression screw terminals shall not be used to terminate more than the number of conductors specifically approved for the terminal. All crimp terminals and screw terminals used for ac line connected wiring shall be UL recognized components. All crimp terminations shall be performed using the manufacturer's tooling in accord with the manufacturer's instructions.

9.3.4.7 Altitude Derating

The voltage ratings of relays, switches and insulated cables shall be reduced to 80% of their rated value due to the altitude at the summit of Mauna Kea. Electrical spacings shall also be increased by a factor of 1.25 to compensate for the increased altitude.

The normal dielectric withstand test specification for UL approved or listed components for use in ac line connected equipment operating from 120/240 volts ac is 2500 volts AC/60 Hz for one minute. Voltage ratings for all components shall be checked for safety margin with respect to this rating using the following equation:

$$VI = \frac{2*V+1000}{AF}$$

where :

VI is the voltage isolation required for the altitude

AF is the altitude factor of 0.8 for 15,000 feet

V is the sea level rated working voltage

The resulting value for VI shall be less than the dielectric withstand test specification voltage (2500 volts AC) or a dielectric withstand test at altitude shall be performed to ensure that the system is safe for the intended application.

9.4 Design Requirements

9.4.1 Technological Design Requirements

9.4.1.1 Motion Control Systems

The preferred motion controllers for stepper and servomotors are Galil or Pacific Scientific programmable motion controllers. The preferred motion controller for piezo devices (tip/tilt and focus) is the 500 series from Physik Instrumente.

9.4.1.2 Power Ratings

All power dissipating components to be cooled by free air convection shall be derated to 80% of their sea level absolute maximum average power dissipation ratings.

9.4.1.3 Wiring and Interconnections

9.4.1.3.1 Connector and Cable Mounting

Cable and wiring strain relieves shall be designed so that strain relief and wiring integrity is not compromised by opening access doors or removing service access covers.

Connectors shall not be mounted on service access covers or on access doors.

9.4.1.3.2 Cable and Wire Routing

Cables and wiring shall be routed so that they do not interfere with the optical path of the instrument. Cables and wiring shall be routed so that full travel of moving or adjustable parts is not affected and does not place a strain on the mounting or connections of any cables or wiring. Service loops shall be provided when necessary, but all cables shall be routed neatly and secured at regular intervals with wire ties or lacing cord.

9.4.1.3.3 Labeling of Interconnections

All external, interconnecting cables and any corresponding panel mounted connectors shall be uniquely identified and labeled. The labeling and identification shall be in a clearly visible and non-removable form. This identification scheme shall be identical to that used in the system documentation. Identification of cables by color-coding is not a substitute for clear labeling.

9.4.1.3.4 Interconnections

External interconnections of low voltage ac and dc circuits shall be shielded whenever there is a reasonable possibility that those interconnections will be subject to electromagnetic interference or unwanted coupling.

Cable shields shall be terminated to the connector housings and not via a wire to a connector pin. Where it may be necessary to isolate shields due to common mode noise problems, cable shield terminations shall be made at one end of the cable only, with the end selected for termination being the one that is closest to the point in the system where the zero signal reference potential is grounded. This is normally the location of the terminating load resistance for signal inputs and the location of the signal source for outputs.

Cable shields shall be electrically continuous with the connector housing, and WMKO prefers that no ground pigtails or other wire connections separate from the connector housing be used. In cases where the design requires different practices those design requirements shall be discussed with WMKO.

Where multiple connector pairs of identical type are used each connector pair shall be uniquely keyed to prevent accidental interchange of the connections.

All connectors shall include pre-grounding pins that make circuit common connections (dc reference or ac protective ground) before all other connections during connector insertion and break circuit common connections (dc reference or ac protective ground) after all other connections during connector removal.

9.4.1.3.5 Data Communications

9.4.1.3.5.1 Control and Status Communications

Where ever possible digital communications for control and status information between subsystems and modules shall be implemented using the TCP/IP protocol over a 100Base-TX Ethernet interface. Purpose built or custom designed electronic modules and circuits that require such communication shall be designed with these protocols.

Where legacy or COTS hardware is used and only serial communications is available, RS-232 signal levels with an asynchronous 8-bit format may be used. RS-232 data rates shall be the maximum practical for the required cable length, and RS-485 levels with electrical isolation (to prevent common mode problems and ground loops) shall be used for cable runs longer than 3 meters.

9.4.1.3.5.2 Network Communications

Control communications between the K1DM3 and the K1DM3 host computer shall employ the TCP/IP protocol over a private 100Base-TX network (the K1DM3 private network) conforming to the Institute of Electrical and Electronics Engineers (IEEE) Standard 802.3U revision 95 “Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method & Physical Layer Specifications: Mac Parameters, Physical Layer, Medium Attachment Units and Repeater for 100 Mb/S Operation (Version 5.0)”. Cabling and terminations shall conform to Telecommunications Industry Association and Electronics Industry Alliance (TIA/EIA) standard TIA/EIA-568-B “Commercial Building Telecommunications Cabling Standards”.

9.4.2 Regulatory Design Requirements

See §9.3.3.1.

9.4.3 Standards Related Design Requirements

Connectors used for low voltage ac and dc circuits shall be types equivalent in performance to connectors that conform to military specification MIL-C-38999 series IV.

9.4.4 Integration Related Design Requirements

None.

10 Safety Requirements

10.1 Purpose and Objectives

Safety is the paramount concern for all activities at the observatory. Specific regulations apply to health and safety as described in §6.3.3, §9.3.3 and §9.3.4. The purpose of this section is to provide requirements related to specific safety concerns during the operation and handling of the K1DM3. This section is not the first section in the requirements because understanding of it requires prior knowledge of, and depends on references to the mechanical and electrical/electronic requirements of the instrument.

10.2 Scope

Unless otherwise indicated all of the requirements of this section apply to all components of the K1DM3.

10.3 Performance Requirements

10.3.1 Parametric Performance Requirements

None.

10.3.2 Operational Performance Requirements

The normal operation of the K1DM3 shall not produce any safety hazard to personnel or equipment. Interlocks, labeling and procedures shall be provided to ensure the safety of personnel and equipment during maintenance and repair.

As part of the processes for the detailed design review and the pre-shipment review the safety of the system shall be reviewed. In general it is expected that conformance to the requirements of this document and the referenced regulatory standards will ensure a safe system.

10.4 Implementation Requirements

10.4.1 Feature Implementation Requirements

10.4.1.1 Local Control

During servicing a means shall be provided to ensure that all K1DM3 mechanisms are under local control and remote control is locked out. See §9.3.1.2.

10.4.1.2 Emergency Stop

See §9.3.1.1.

10.4.1.3 Mechanical

All areas of the K1DM3 module where exposed moving parts can create a pinch hazard shall be clearly marked with a hazard warning label or equipped with shrouds to prevent accidental contact.

The tertiary mirror rotator shall incorporate a mechanical lockout feature that locks the rotator in place so that it cannot rotate. This feature shall ensure that the tertiary mirror rotator will not move due to an imbalance caused by removal of a component for service. Mechanical lockout features shall activate an electrical lockout consisting of one or more non-defeatable switches that disable the drive system when the mechanical lockout is active and provide a remote indication that the mechanical lockout is active. The electrical lockout will protect the rotator drive system components as well as prevent unintended drive activation.

10.4.1.4 Electrical

Removable panels that expose voltages in excess of 230 Vac or 500 volts dc shall be equipped with defeatable interlock switches that remove all voltages in excess of 36 volts ac or dc from all exposed connections and terminals.

See §9.3.3.1 for additional electrical safety requirements.

10.4.2 Common Practice Implementation Requirements

None.

10.4.3 Standards Implementation Requirements

None.

10.4.4 Regulatory Implementation Requirements

See §6.3.3, §9.3.3 and §9.3.4.

10.5 Design Requirements

10.5.1 Technological Design Requirements

10.5.1.1 K1DM3 Instrument Mechanisms

No part of any K1DM3 mechanism shall move when ac mains power is applied to or removed from the K1DM3 electronics. The K1DM3 motion control hardware shall inhibit all motion during a power on/reset.

If closed loop or servo systems are used in the K1DM3 motion control systems these servo loops shall be designed so that loss of the encoder signal or disconnection of the motor cannot result in a “wind up” of the servo position command. Software features shall be implemented to inhibit motion when the position error measured by the servo controller exceeds the smallest reasonable margin that reflects all of the expected operating conditions.

Limit switches shall be closed when not actuated (N.C. contacts). Motion control software shall be designed so that a disconnected limit switch shall appear to be active, inhibiting further motion towards that limit. Motion control software shall also be designed so that movement away from an active limit switch is restricted to a reasonable distance past the limit switch actuation point after which motion is stopped and an error indicated due to the apparent failure of the limit switch to open.

If used, position encoders shall include a status loop through the connections to the encoder so that in the event of loss of the encoder connection (or intentional disconnection) all motion on the associated axis is inhibited.

10.5.2 Regulatory Design Requirements

As indicated in the sections for overall, mechanical and electrical requirements the design of the K1DM3 shall conform to all applicable regulatory requirements.

10.5.3 Standards Related Design Requirements

None.

10.5.4 Integration Related Design Requirements

None.

11 SOFTWARE REQUIREMENTS

11.1 Purpose and Objectives

The software requirements section describes requirements for performance, implementation and design. Based on experience with previous instruments the observatory is sensitive to certain aspects of performance, implementation and design that have proven to be important factors in the up time of its instruments. The software requirements section has as a main objective ensuring compatibility of the K1DM3 software with existing observatory software systems. A secondary objective is guiding the selection of software architecture and implementation decisions towards reuse of prior successful instrument software and towards implementations that fit within the software skill sets at the observatory in order to maximize the ability of the observatory to support and maintain the K1DM3 software.

WMKO has established a number of standards for software and these standards form an integral part of the software requirements for the K1DM3.

Specific requirements are given in areas where repeated problems have affected the availability of instruments. Among these are issues of network reliability, reliability of fiber optic data connections to detector controllers, and problems with handling errors in a manner that minimizes the loss of observing time by providing useful error messages and avoids total system resets or power cycling to restore proper operation.

11.2 Scope

Unless otherwise indicated all of the requirements of this section apply to all software components of the K1DM3.

11.3 Performance Requirements

11.3.1 Parametric Performance Requirements

11.3.1.1 Reliability

All software components of K1DM3 shall be tested under simulated operating conditions and shall achieve at least 150 hours of continuous operation without a fault. The reliability of the following software components shall be tested and confirmed:

a. Host OS
b. Host application
c. Motion controller code

11.3.1.2 Fiber Optic Data Links

Fiber optic data links shall tolerate up to 10 db of attenuation due to interconnection losses without impairment of performance or reliability.

11.3.2 Operational Performance Requirements

11.3.2.1 Overhead

Software shall permit simultaneous motion of multiple mechanisms in order to minimize the time required to complete each instrument set-up between observations. When multiple axis of motion control is used for reconfigurations it shall be possible to simultaneously move all axis of motion that does not otherwise require sequencing because of mechanical design constraints.

11.3.2.2 Error Recovery

11.3.2.2.1 Loss of Network Connections

All K1DM3 software shall gracefully recover from the interruption of TCP/IP network connections, fiber optic connections, USB connections, and RS-232 connections any time. This disconnection may occur due to physical interruption of the network connection, or the power cycling or hardware reset/reboot of the device at the other end of the network connection. Software shall implement reasonable timeouts and handle all TCP/IP network errors so that recovery from a network fault is as automatic as possible. Specifically, the components that have not experienced power cycling or a hardware reset/reboot shall recover from the loss of the network connection without requiring that they be reset or rebooted.

Whenever possible it is expected that the system shall perform in a manner that permits recovery from any of the following conditions without requiring manual resetting of any hardware component:

1. Loss of network or data connections:
    a. Host to public network
    b. Host to motion controller(s)
2. Power cycling:
    a. Host
    b. Motion controller(s)
3. Hardware resets:
    a. Host
    b. Motion controller(s)

When recovery is not possible, and for the cases where the host computer is not the system being reset or power cycled, it is expected that the user interface software in the system shall provide a useful diagnostic message or warning to the operator without crashing or locking up.

11.3.2.3 Execution Speed and Command Latency

The response time requirements for the K1DM3 software shall be as given in Table 11.

Table 11: Software Latencies

Software Function	*Goal*	*Min.*	*Max.*	*Units*	*Notes*
Status requests	0.1	-	0.2	s	
Motion commands	0.1	-	0.2	s	
Observatory E-stop	0.01	-	0.05	s	
Application software startup and initialization	> 10	-	30	s	1

Notes:

1. Not including the actual time required to perform the operating system re-boot and associated initializations.

11.4 Implementation Requirements

11.4.1 Feature Implementation Requirements

11.4.1.1 User interfaces

WMKO shall implement the user interface for K1DM3 as a DCS control row or other user interface paradigm. The user interface shall command the K1DM3 software via keywords.

For engineering test purposes graphical user interfaces (GUIs) written in Java shall be provided for control of the K1DM3. These interfaces shall be implemented in a manner consistent with other WMKO instruments and in conformance with KSD 210. User interfaces based on the MOSFIRE heritage are preferred.

11.4.1.2 Software Licenses

Any licensed software required for operation of the K1DM3 software shall be supplied with an adequate number of fully paid licenses to permit operation of all K1DM3 software. Software using IDL or other licensed development packages shall be designed to operate using a virtual machine or other software package that is free of royalty or license fee costs. Where this is not possible node locked licenses shall be required for each host computer (where applicable).

11.4.2 Common Practice Implementation Requirements

K1DM3 control software shall be written to run under a WMKO approved operating system. All communications between the instrument software components and the user interfaces and the telescope systems shall be based on keywords conforming to WMKO standards. The K1DM3 control software shall reuse the TCL application "galildisp" currently in use for the ADC.

Java shall be used for user interfaces the implementation and shall be consistent with the MOSFIRE implementations. Java user interfaces shall run under the current versions of the Linux operating systems and remote window managers in use at WMKO.

11.4.3 Standards Implementation Requirements

K1DM3 software shall conform to the requirements of KSD 201 and KSD 210. All communications between the K1DM3 host software and other observatory systems shall be via keywords conforming to the requirements of the Keck Task Library (KSD 8).

11.4.4 Regulatory Implementation Requirements

None.

11.5 Design Requirements

11.5.1 Technological Design Requirements

11.5.1.1 Client-Server Architecture

The basic architecture of the K1DM3 software shall be based on client-server architecture. The server components of the system shall provide keyword services compliant with the Keck Keyword Interface standards.

11.5.1.2 Communications Protocols

Client-server communications shall be via TCP/IP using a WMKO approved protocol. It is not required that existing message formats or services be used, provided that they are capable of supporting the Keck Task Library (KTL) as described in KSD 8.

Standard implementations of RS-232 serial communications may be used for communication with COTS hardware that does not support TCP/IP network communications.

11.5.1.3 Keywords

Keywords shall be defined in collaboration with WMKO software staff. The action of keywords or acceptable ranges of values shall not be dependent on previous values of the keyword. Keywords shall conform to the formats described in KSD 8, 28, and 46.

11.5.1.4 Host Software

Keyword level access shall be provided for all mechanism control and status monitoring.

11.5.2 Use Cases

The K1DM3 implementation does not depend on the existence of the WMKO Telescope Control System Upgrade (TCSU) but it is expected that the K1DM3 will be delivered after completion of the TCSU project. This means that TCSU specific functionality should be provided in the K1DM3 software implementation.

11.5.2.1 Legacy Tertiary Use Case

Fallback capability shall be maintained to use the legacy Keck I tertiary and to allow the use of a facility forward Cassegrain rotator.

11.5.2.2 KIDM3 Tertiary – Extended Position Use Case

In this use, the tertiary is guiding the beam to one of the focal locations on the elevations ring. The beam guiding shall be initiated by the TCSU system which will command the KIDM3 module using enumerated location ID’s.

11.5.2.3 KIDM3 Tertiary – Retracted Position Use Case

In this use, the KIDM3 module allows use of the Cassegrain instrument. As the Cassegrain instrument rotator changes position, the rotator on KIDM3 must rotate to a position that does not vignette the field of view.

11.5.3 Requirements Based on Design Use Cases

11.5.3.1 KIDM3 Module ID

The TCSU system shall support a unique module ID for the KIDM3 module. The module ID will enable the TCSU to differentiate between forward Cassegrain, legacy tertiary, or new tertiary.

11.5.3.2 Position Command/Query

The KIDM3 module shall provide a means to command and status the “extended” or “retracted” positions.

11.5.3.3 Location IDs

The “extended” KIDM3 shall support the location ID’s used by the TCSU system. These are enumerated as follows: 0=LNAS, 1=LBC1, 2=LBC2, 3=STOWED, 4=RBC2, 5=RBC1, 6=RNAS.

11.5.3.4 On Location Status

The “extended” KIDM3 shall support a status word that indicates the mirror is on location and locked.

11.5.3.5 TCSU Command Support

The “extended” KIDM3 shall support the standard command interface used by TCUS. The TCSU supervisory system shall issue the following commands as part of its normal subsystem sequencing: INIT, MOVE, ABORT, SHUTDOWN (formerly Standby), STOP (formerly Halt).

11.5.3.6 Instrument Rotator Command/Status Interface

The “retracted” KIDM3 module shall support a command / status interface consistent with what is specified in KSD 46 – DCS Keyword Reference Manual.

11.5.3.7 Cassegrain Position Tracking

The “retracted” KIDM3 module shall track the Cassegrain instrument position by monitoring the ROTPOSN or ROTPDEST keywords.

11.5.4 Regulatory Design Requirements

None.

11.5.5 Standards Related Design Requirements

Software design and coding shall comply with KSD 50 and KSD 210.

11.5.6 Integration Related Design Requirements

None.

12 Interface Requirements

12.1 Purpose and Objectives

This section is reserved for interface requirements that are not addressed by other portions of the document. Where interface requirements are addressed elsewhere they are cross referenced here.

12.2 Performance Requirements

12.2.1 Parametric Performance Requirements

None.

12.2.2 Operational Performance Requirements

12.2.2.1 Handling

See §8.4.4.3.

12.3 Implementation Requirements

12.3.1 Feature Implementation Requirements

12.3.1.1 Optical Requirements

See §7.3.1.

12.3.1.2 Mechanical

See §8.3.1.

12.3.2 Common Practice Implementation Requirements

12.3.2.1 Glycol Cooling

See §8.3.1.6.

12.3.2.2 Stray Light

See §9.3.2.1.

12.3.3 Standards Implementation Requirements

None.

12.3.4 Regulatory Implementation Requirements

None.

12.4 Design Requirements

12.4.1 Technological Design Requirements

None.

12.4.2 Regulatory Design Requirements

None.

12.4.3 Standards Related Design Requirements

None.

12.4.4 Integration Related Design Requirements

12.4.4.1 Optical Interface

See §7.

12.4.4.2 Mechanical Interface

See §8.4.4.

12.4.4.3 Electrical/Electronic Interface

See §9.2.1.1 and §9.3.1.4.

13 RELIABILITY REQUIREMENTS

13.1 Purpose

The purpose of this section is to describe the reliability requirements for the K1DM3.

13.2 Scope

Unless otherwise indicated all of the requirements of this section apply to all components of the K1DM3.

13.3 Performance Requirements

13.3.1 Operational Performance Requirements

13.3.1.1 Operational Reliability

As a goal requirement, when installed in the telescope the K1DM3 shall never cause loss of a Keck I telescope observing night. Modification of the observing program to confine operations to a single instrument shall not be considered loss of the night. This goal shall be achieved without requiring physical access by nighttime staff to the K1DM3 module.

It is an absolute requirement that the K1DM3 shall never fail in a manner that causes damage to any other part of the telescope or to any of the other observatory equipment and facilities.

13.3.1.2 Operating Lifetime

The K1DM3 shall meet the operational reliability requirements over a 10 year operating lifetime.

13.4 Implementation Requirements

None.

13.5 Design Requirements

13.5.1 Failure Modes and Effects Analysis

At present telescope daytime operations procedures include checkout of the instrument selected for use that night, and checkout of the telescope, tertiary mirror, dome, and other supporting systems. These checkouts are scheduled in a way that provides an opportunity to find, diagnose, and often repair or work around any faults that are found. The same process will be followed with the K1DM3. An important difference is that the K1DM3 operating paradigm will require checkout of more than one instrument to support observing nights where TDA or ToO observations are anticipated.

A failure of the K1DM3 during the night may have severe impact, up to and including the loss of the remainder of the observing night, or it may simply limit the flexibility that would normally be available with a fully functioning K1DM3.

A qualitative analysis of the possible K1DM3 failure modes shall be performed as soon as the K1DM3 preliminary design is sufficiently complete to allow a comprehensive and informed identification of the failure modes and their impact on K1DM3 operation. Current best practices in failure modes and effects analysis (FMEA) should be followed when performing the analysis.

13.5.2 Determination of Expected Reliability

A process shall take place to determine the expected reliability of the K1DM3 as designed over a 10 year operating lifetime under the operating conditions given in Table 6.

A recommended procedure to determine the reliability of the K1DM3 is the use of the reliability prediction models for electronic components and systems given in MIL-HDBK-217F-2 “Reliability Prediction of Electronic Equipment” and the reliability prediction models for mechanical components and systems given in the Naval Surface Warfare Center “Handbook of Reliability Prediction Procedures for Mechanical Equipment”, NSWC 98/LE1.

The MTBF as determined by the prediction models shall then be used to establish the operating period before failure based on a 10 year period as follows:

$$R(t) = \exp^{\left(\frac{-t}{MTBF}\right)}$$

where:

R(t) = probability of operation without failure for time t

t = time in hours

$$\mathrm{MTBF} = \frac{1}{\sum(\text{all component failure rates})}$$

The probability of operation without failure for the K1DM3 is expected to be more than 0.90 for this time period (t = 87,600 hours). Software is not included in this requirement or the requested method of reliability assessment. The reliability of the software to be used with the K1DM3 can only be determined by testing.

14 SPARES REQUIREMENTS

Spares shall be provided for all components that are considered “consumable” or are designed with a service life of less than 10 years. For these components the required spares quantity is 20% (or at least 1 unit) of the in service quantity.

15 SERVICE AND MAINTENANCE REQUIREMENTS

The K1DM3 shall incorporate provisions for disassembly for servicing of internal components. Handling fixtures required for and used in the assembly or disassembly of the K1DM3 shall be provided with the K1DM3. Any specialized tools required for assembly, disassembly, or servicing shall be provided with the K1DM3. A written procedure accompanied by illustrations shall be provided for removal and replacement of all major sub-assemblies in the K1DM3.

Large subassemblies (> 25 kg mass) shall be provided with handling fixtures and service access provisions that do not require use of a crane for removal or access.

Components requiring routine service or maintenance shall be accessible by removing a single cover secured by no more than 8 fasteners. Covers that may be removed in a location where fasteners could fall into the interior of the enclosure shall be equipped with captive fasteners. Captive fasteners shall be of the threaded type and shall depend on swaged sleeve fittings. Quarter turn fasteners engaging spring hooks are specifically discouraged for reasons of fit and reliability.

Whenever possible service access provisions shall be provided that do not require disassembly of the entire K1DM3 to access motors or switches for replacement.

16 DOCUMENTATION REQUIREMENTS

Unless otherwise specified all written documentation shall be provided in Microsoft Word 2010 DOCX format and as PDF files.

16.1 Documentation Package

The K1DM3 shall be provided with design, operating and maintenance documentation package including, but not limited to, the following:

1. System overview and design description, including details of optical design, mechanical design (including thermal and vacuum design), electrical design and software design. All design documents shall be supplied in revised form as required to reflect the delivered as-built K1DM3.

2. User's manual, including but not limited to operating instructions.

3. Revised fabrication/procurement drawings, specifications, and schematics that accurately depict the as-built condition of all of the components of the K1DM3. All such drawings shall be detailed enough to allow fabrication of spare parts shall the need arise.

4. Bills of material including supplier information for all components of the K1DM3.

5. A maintenance manual, including all information and procedures needed to maintain and operate the K1DM3 during its lifetime, including but not limited to the following:

    a. Procedures for handling, assembly and disassembly of the K1DM3 and all of its components accurately reflecting the as-built K1DM3. All assembly instructions shall be clear, and include a tools list, parts lists and check list.

    b. Routine maintenance and inspection procedures, as well as a maintenance schedule.

    c. Alignment procedures.

    d. Troubleshooting guide.

    e. Repair procedures.

6. Acceptance Test Plan documents, test procedures and all performance data and results of acceptance testing.

7. Descriptions of all recommend spare parts and procedures for removal and replacement including written procedures and assembly drawings and exploded view drawings.

8. All manufacturers' manuals and documentation for COTS components.

9. All software design documents and related documents including, but not limited to software build and install procedures, source code, release description document, software design document(s), software acceptance testing plans and software user's manual. All software design documents and related documents shall be supplied in revised form as required to reflect the delivered as-built instrument software.

10. Safety plan and procedures.

16.2 Drawings

16.2.1 Drawing Standards

The primary units for all drawings are the international system of units (SI). All instrument drawings shall be dimensioned in millimeters. Secondary dimensions may be provided in inches.

All instrument drawings shall conform to the following:

1. Drawings for optical components shall conform to ANSI/ASME standard Y14.18M-1986 "Optical Parts (Engineering Drawings and Related Documentation Practices)".

2. Mechanical drawings shall conform to ANSI Y14.5M-2009 "Dimensioning and Tolerances - Mathematical Definitions of Principles" and ASME standard Y14.100-2013 "Engineering Drawing Practices".

3. Each sheet shall conform to ANSI Y14.1-1995 (R2002), "Decimal Inch Drawing Sheet Size and Format". Drawing size shall be determined on an individual basis.

4. Each drawing shall have a title block with at least the following information:
   - Development group
   - Drawing number
   - Title
   - Designer
   - Prepared by
   - Scale
   - Method for determining next higher assembly.

5. All drawings shall include parts and materials lists in accordance with ANSI Y14.34-2003, “Parts Lists, Data Lists, And Index Lists: Associated Lists”. All items shall be identified with an item number or other label (with reference to the drawing number if one exists) for each part or component with all information required for procurement.

6. Assembly drawings shall include all relevant views required to clearly define the assembly including isometric and exploded views.

7. All detail drawings shall include all views, geometry, dimensions and feature controls required to duplicate the part in accordance with ANSI Y14.5M-2009.

8. Multi and sectional view drawings shall be developed in accordance with ANSI Y14.3M-1994 “Multi and Sectional View Drawings”.

9. Fluid power system schematics shall be drawn in accordance with ASME Y32.10-1967 (R1994) “Graphic Symbols for Fluid Power Diagrams”.

10. Dimensions and tolerances shall be indicated in accordance with ASME Y14.5M-2009.

11. Surface finishes shall be described in accordance with ANSI/ASME Y14.36M-1996 (R2002).

12. All CAD designs shall be developed using 3D models in the version of SolidWorks currently adopted by WMKO and its collaborators. All 3D models shall follow the structure and naming conventions established by WMKO[3]. All 3D models and electronic format drawings shall be stored in a SolidWorks “Vault” hosted by WMKO. All 2D drawings and assembly drawings shall be provided in PDF format.

13. The electronic drawing format for electrical/electronic schematics and printed circuit board layouts and assembly drawings shall be OrCAD V9.0 or a more current release. A less desirable alternative is to provide drawings for electrical/electronic schematics and printed circuit board layouts and assembly drawings as 2D drawings in a standard CAD package such as SolidWorks using the version currently adopted by WMKO and its collaborators. All printed circuit board layouts shall be accompanied by assembly drawings. All electrical/electronic schematics and printed circuit board layouts shall also be provided in PDF format.

[3] WMKO standards document “ADDEMDUM concerning SOLIDWORKS MODELING DATA REQUIREMENTS FOR CONTRACT PURPOSES” revision dated 051013.

16.2.2 Required Drawings

All drawings shall be provided as specified in the formats listed above and in the native format if translated to one of the specified formats.

The following drawings shall be provided:

1. As-built detailed mechanical drawings for all components not commercially available. Drawings shall provide sufficient detail to fabricate the components to original design intent.

2. As-built detailed drawings for all optical components not commercially available. Drawings shall provide sufficient detail to fabricate the components to original design intent.

3. As-built assembly drawings for all assemblies not commercially available along with appropriate detail drawings and assembly tolerances and procedures.

16.3 Electrical/Electronic Documentation

The following documentation for all electrical and electronic assemblies and modules in the instrument shall be provided:

1. A top level system block diagram.

2. An interconnection diagram showing all interconnecting cables and connected assemblies and modules in the instrument.

3. An interconnection diagram showing the external connections to the instrument.

4. Pinouts and wire color codes for all internal and external connectors and cables.

5. Schematics, assembly drawings, bills of material, printed circuit board designs and printed circuit board artwork for all custom printed circuit boards in the instrument.

6. Programmable logic device source code for all programmable logic devices used on custom printed circuit boards in the instrument.

7. Programmable logic device source code for all programmable logic devices used in COTS components where the programmable logic device source code has been modified or customized for the instrument.

8. Configuration, set up and/or switch/jumper setting information for all COTS components.

16.4 Software

The K1DM3 software is defined as all host, target, embedded controller software (including detector controller code) and data reduction software for the instrument including the code for servo controls such as DSP code, Galil code or other motion control code and the like. The following software data files and documentation shall be provided:

1. Source code for all K1DM3 software in the WMKO CVS repository.
2. Executables for all K1DM3 software in the WMKO CVS repository.
3. One copy of any and all software libraries required to build the K1DM3 software executables in the WMKO CVS repository.
4. A list of any and all code compilers required to build the K1DM3 software.
5. All makefiles required for building the K1DM3 software in the WMKO CVS repository.
6. All configuration files and all data files read by the instrument software executables at start-up time in the WMKO CVS repository.
7. Any scripts required to run the instrument or the data reduction package on CD/DVD.
8. Any aliases, environment variable definitions, etc. required to correctly set up the environment to build or run the instrument software in the WMKO CVS repository.
9. For any models developed for simulation of the instrument including optical designs and control loops the model code and data shall be supplied. The preferred software for optical design is Zemax. The preferred software for control loop simulations and models is Matlab or IDL.
10. For all software control loops full design documentation shall be provided including block-diagrams, transfer-function models of the system, performance criteria and analyses to show how the control loop design satisfies the requirements. Models and simulations of the control loops shall also be provided.
11. Documentation for the instrument software, consisting of:
    a. Users Manual: a detailed tutorial describing how to use this version of the software.

b. List of Source Code: A hierarchical list of all directories, source files, include files, libraries, etc. that can be used as a checklist for new releases.

c. Functional Descriptions: a description of each routine or module describing its function.

d. Startup/Shutdown procedures: descriptions of the steps necessary to cold start the system and the steps necessary to safely shut down a running system. This document shall include descriptions of any configuration files required at start-up time.

e. Installation Manual: a detailed description of the steps necessary to rebuild and install the system from sources.

f. Troubleshooting Guide: A description of the techniques for tracking down failures, checking system health, killing and re-starting portions of the system without a full reboot.

g. Software Test Procedures: a detailed description of how to run the software acceptance tests.

h. Programmer's Manual: This document shall include a description of the theory of operations; data and control flow and how standard functionality can be extended (e.g. add a new command to the API).

17 GLOSSARY

Table 12 defines the acronyms and specialized terms used in this document.

Table 12: Glossary of Terms

Term	**Definition**
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers International
ASTM	ASTM International
ATA	Air Transport Association
CARA	California Association for Research in Astronomy
CCR	Closed Cycle Refrigerator
CENELEC	European Committee for Electrotechnical Standardization
CFR	Code of Federal Regulations
CIT	California Institute of Technology
COTS	Commercial Off The Shelf
dBA	Sound level in decibels, measured using the A contour frequency weighting network
DCS	Drive and Control System
EIA	Electronic Industries Alliance
EMI	Electro Magnetic Interference
FOV	Field Of View
IBC	International Building Code
ICC	International Code Council
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
KSD	Keck Software Document
LRIS	Low Resolution Imaging Spectrograph
MOSFIRE	Multi-Object Spectrometer for InfraRed Exploration
MTBF	Mean Time Between Failures
NEBS	Network Equipment Building System
NEMA	National Electric Manufacturers Association
OSHA	Occupational Safety and Health Administration
TBC	To Be Completed
TBD	To Be Determined
TCSU	Telescope Control System Upgrade
TIA	Telecommunications Industry Association
USGS	United States Geological Survey
WMKO	W. M. Keck Observatory
WRT	With Respect To
UCLA	University of California, Los Angeles
UCO	University of California Observatories
UCSC	University of California, Santa Cruz
UPS	Uninterruptible Power Supply
UL	Underwriters Laboratories Inc.