Camera Plan	Document # LCA-00282-A		Status: LSST Camera APPROVED. Effective Date 20 July 2018
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	Subsystem/Office: Systems Integration, Integration and Test, Commissioning		

Document Title

Camera Operations Concept Document

1. Change History Log

Revision	Effective Date	Description of Changes
A	18-July-2015	Initial draft
	24-May-2018	Draft updated to captured final LSE-71 Camera-OCS ICD states
	27-June-2018	Modified to include refined mode definitions, use cases for lower-tier camera modes; added input from Exchange System
	20-July-2018	Released under LCN-2140

2. Contents

3. Acronyms

CCS	Camera Control System
CPS	Camera Protection System
DAQ	Data Acquisition System
FCS	Filter Control System
FDB	Facilities Database
HCU	Hardware Control Unit
ICD	Interface Control Document
I&T	Integration and Test
LPM	Local Protection Module
MCM	Master Control Module
MPM	Master Protection Module
OCD	Operations Concept Document
OCS	Observatory Control System
PLC	Programmable Logic Controller
PCM	Power Control and Monitoring
QoS	Quality of Service
SMR	Sphere-Mounted Retroreflector
TBD	To Be Determined
TBR	To Be Resolved
UT	Utility Trunk
WSS	Worker Subsystem

4. Applicable Documents

[1] LCA-00145, "Camera Internal Interfaces"

[2] LCA-00343, "Camera Internal Block Diagrams"

[3] LSE-71, "OCS-Camera Software Communication Interface"

[4] LSE-209, "Software Component to OCS Interface"

[5] LSE-10204, "Auto Changer Lift Volume"

[6] LCA-16589, "Camera Maintenance Activities

[7] LCA-69, "LSST Camera Environmental Specification Supporting Analyses"

5. Purpose and Scope

5.1. Purpose

The objective of the Operations Concept Document (OCD) is to capture planned system behavior. This behavior is developed in conjunction with the derivation of system design. Functional decomposition derives and allocates functions to sub-components of the overall system, but this is always done with a concept of behavior in mind. Therefore, the functional allocations captured as requirements in lower level specifications carry with them expectations of behavior. While these must also be captured as requirements in the specifications, they are detailed as system behavior in this document.

This document covers all aspects of Camera operations for hardware and software elements resident on the Camera as well as in the summit facility. It also includes support elements of the Camera that may be physically located on the summit or at subsystem facilities elsewhere but are integral to the operations or maintenance of camera systems.

5.2. Scope

This defines camera behavior for all aspects of camera operations. Requirements that are derived from this document may be capture in subsystem specification or in Interface Control Documents (ICDs). In particular, ICDs between Camera Control System (CCS) and Camera Integration and Test (I&T), and other Camera subsystems address control system implementation of behaviors described here, as well as maintenance provisions, accommodation, and equipment to support maintenance operations described here. See Ref. [1], LCA-00145, "Camera Internal Interfaces" for a list of all Camera ICDs.

5.3. Document Organization

Camera operation reflects the operational architecture of the camera as a collection of coordinated subsystems and the states and modes which delineate functional capabilities. The following sections describe these camera operations and capabilities. First, camera operational elements are described in Section 6. This lays out groupings of controlled elements of the camera as they relate to the how the camera is operated.

Next, camera states are described in Section 7. These are the states of the camera as represented by the CCS to the outside world, either the Observatory Control System (OCS) or to an operator at an OCS console. This section also describes internal states of the CCS as it relates to operations of camera worker subsystems (WSS).

Section 8 then details camera modes. This lays out the set of capabilities or functions for each distinct mode of the camera and criteria for entering and exiting each mode. This sets the stage for the remaining sections of the document that detail camera use cases and behavior when in each mode. Each section addresses use cases for a different mode.

6. <u>Operational Break-Down of Camera Components</u>

The camera has been parsed into subsystems and components as shown in Ref. [2], LCA-00343, "Camera Internal Block Diagrams." However, this defines physical and logical connectivity of camera elements, but not operational dependencies. As camera operational modes have been developed, camera components have been organized into operational groupings that support key camera functionality for these modes. As are result of this process, four operational groupings of camera components have been identified. These are detailed in the following subsections.

6.1. MCM Core

The Master Control Module (MCM) manages all command and control communications with outside actors, including the OCS, human operators, and scripts run from engineering consoles. MCM core elements include the hardware and software components needed to manage all such communications, including publishing of events and telemetry.

MCM Core hardware elements include the racks and crates in the computer room running MCM Core software and network switches. Software includes the MCM global console, OCS bridge, health and safety monitoring, telemetry aggregation, and the command sequencing engine.

Note that all of these elements are not physically part of the camera but located in the computer room.

6.2. Camera Core

Camera Core elements are the elements of the camera providing power, basic communications, and safety monitoring functions on the camera. These elements include the CCS network switch, the Power Control and Monitoring Local Protection Module (LPM) and Hardware Control Unit (HCU), and the Master Protection Module (MPM) programmable logic controller (PLC).

These all power up and become functional with the application of voltage on the main camera power feed, with no external commanding required.

6.3. Environmental Core

Environmental Core elements include those control and hardware systems that provide temperature, humidity, and environmental (vacuum, air flow, coolant flow) control. These elements include the HCUs and LPMs for the cryostat vacuum system, heat exchanger vacuum system, cryo refrigeration system, cold refrigeration system, Utility Trunk (UT) thermal control, and camera body and mechanism purge unit control.

These elements include the controllers and protection elements to monitor and control worker subsystems that maintain environmental control of the camera, including sensors and HCUs. However, they do not include the actual hardware being controlled.

6.4. CCS Worker Subsystems

All other CCS worker subsystems form the remainder of the camera operational systems. These actually perform the functions needed to meet camera performance and functional requirements. These elements include the refrigeration system, science raft tower modules, corner raft tower modules, shutter, and filter exchange system.

Note that the refrigeration system compressor cabinets, controllers, and MPM are located under the telescope azimuth floor and not physically with the camera.

7. Camera States

States define an exact operating condition of a system, uniquely describing how the system responds to events. A state can be thought as corresponding to a switch position for the system, where it can exhibit some specific behavior(s) in each switch position. The CCS uses several state models to represent the overall state of the camera and its subsystems. These include Internal state model, Operational state model, Internal Command state model, and External state model, each described briefly in the following subsections.

7.1. External Command State Model

The external view of the camera includes 5 mutually exclusive states: Offline (with 2 detailed sub-states), Standby, Disabled, Enabled, Fault

The definition of these "summary states" follows the OCS device model described in Ref. [3], LSE-71, "OCS-Camera Software Communication Interface," and further detailed in Ref. [4], LSE-209, "Software Component to OCS Interface." In addition to these summary states, there are a number of lower-level "detailed states" that either expose targeted command sets or camera subsystem hardware conditions. These are further described in the reference documents.

Each camera state is defined in the following subsections.

7.1.1. Offline-PublishOnly

The camera is operating independent of the OCS. The CCS may or may not publish telemetry, state changes, and events, depending on the functionality and connectivity of the MCM. In this state, it will not accept OCS commands. To exit this state, an internal CCS command is required to change state to "Offline-Available" state.

7.1.2. Offline-Available

When an operator at a CCS control console transitions the camera into this state, it is ceding camera control to the OCS. From here, the CCS can take back control, or the OCS can continue transitioning the camera to fully-integrated functionality by executing the 'enterControl' command.

7.1.3. Standby

In this state, the OCS controls the camera through either script-driven control or OCS operator console. The camera configuration is undefined in this state.

7.1.4. Disabled

The 'start{}' command transitions the camera into this state, in a known, preset configuration. In this state, the camera is fully functioning and fully configured for operation, but not responsive to operational commands.

7.1.5. Enabled

Invoking the 'enable' command transitions the camera into this state. Here, it is fully operational and capable of executing the full suite of OCS commands, and returning events and sending telemetry. This is the standard camera state during normal observations, while taking calibration images, and while quiescent with not commanded activities to execute.

7.1.6. Fault

The camera enters the Fault state if any type of non-recoverable error occurs, including:

Execution of a command fails after the command has been accepted.

An error or hardware fault is detected during monitoring of hardware devices, including if a monitored quantity is measured outside of the allowed limits.

A non-recoverable software error occurs (e.g. network communication error).

Once in a fault state the camera will no longer be commandable by the OCS. To get the camera out of Fault state it is necessary to use a camera engineering console to understand and correct the problem, then issue a CCS 'clearFault' command to get the camera back into the "Offline-PublishOnly" state.

Once the camera enters the Fault state it will never spontaneously leave that state, even if the reason the camera entered the fault state (e.g. out of tolerance measurement) is corrected.

7.2. Internal State Model

Camera internal states include: Initializing, Operational, Closing

Initializing and Closing: these are transient states that assist in defining the logic and behavior when CCS worker subsystems are starting or being (re)configured and during shutdown.

Operational: this is the primary in-use state.

7.3. Operational State Model

Camera operational states include: Normal, Engineering, and Quiescent

A CCS commanding entity could be the OCS, an engineering console, or a script that has been loaded. When a commanding entity registers it gets a "lock" on the system. The locks will come in different flavors or “levels”. With no commanding entity registered the camera is in the Quiescent state. The lowest level lock corresponds to use by the OCS, corresponding to the “Normal” state. Higher level locks transition the camera into “Engineering” state and provide distinct command capabilities for servicing or diagnostic purposes. An operator with appropriate authority can register at a higher level than another and take control.

7.4. Internal Command State Model

CCS internal command states include: Ready, Active

CCS internal commands are generally of three types: query, action, and signal. Query commands can be satisfied at any time without blocking as they return only existing information. Action commands are only accepted when the command state is “Ready”. Signal commands are “out-of-band” and can interrupt the active state. An example would be an abort command issued in response to some emergency.

8. Camera Modes

Modes define the set of capabilities or functions which are valid for the current operating condition. The camera as a whole has seven modes, each of which incorporates a clear set of functional capabilities. These are enumerated in the subsections below.

8.1. Offline

The camera is not communicating with either the OCS or any operator consoles, CCS core services are not actively managing the camera, CCS worker subsystems are either off or operating independent of the MCM. Hence, while various parts may be powered up and functioning, the "camera" is not functioning as a single entity. The camera would be in this mode when it is fully shut down, when computer room racks lose power or when the MCM re-boots. Note that worker subsystem HCUs may still be powered and functioning, but not in communication with the MCM and telemetry is not being published by the CCS.

In this mode, there is no communication with the OCS, thus, when in this mode, the camera is not in a defined OCS state.

8.2. Power-on/Re-boot

CCS control room racks are powered up and CCS MCM core capabilities are online. Communications have been established with an operator through a camera engineering console, and the MCM is publishing camera telemetry and events to the facilities database (FDB). This provides the basic camera functionality.

MCM core capabilities that are functioning in this mode are an engineering console, OCS bridge, health and safety monitoring, telemetry aggregation, and the command sequencing engine, although other CCS modules may be running. These are all off-telescope items, so the "camera" as defined in this mode consists solely of software modules providing basic infrastructure functionality.

In this mode, there may or may not be power to the on-telescope elements of the camera, and they may or may not be functioning.

In this mode, the camera transitions into the "Offline-Publish Only" OCS state.

8.3. Base

On-telescope camera core facilities are powered up and communications have been established with the MCM. These facilities include the Master Protection Module, network switch, and the Power Control and Monitoring (PCM) LPM and HCU. The PCM HCU comes on in a quiescent state or a nominal safe mode; it will not change hardware state without operator commanding.

Note that worker subsystem HCUs may or may not be functioning. However, the MCM does not issue commands to non-core facilities or worker subsystems while in this mode. This includes the refrigeration compressor cabinets and their attendant HCU. This is on the telescope but physically separate from the rest of the camera, and its functioning does not require core facilities.

In this mode, the camera remains in the "Offline-Publish Only" OCS state.

8.4. Engineering

Camera core environmental systems are powered up and functioning. Temperature, humidity, flow, vacuum and attitude telemetry is being published to the FDB through the CCS, and the MCM is controlling the Camera internal environment, through the corresponding CCS worker subsystems. This defines the base functionality required for entry into this mode. Other parts of the camera may also be functioning.

In this mode, the camera is under stand-alone control through a CCS console. The CCS decides when and how to exit engineering mode, with a standard exit involving operator confirmation to transition to Nominal state. The CCS can power up or down any worker subsystem while in this mode, except the environmental core systems or the Camera core facilities. If any of these are powered down or lose communication with the MCM then the camera drops out of Engineering mode and into Base mode.

Worker subsystems can be separable or run concurrently, with the CCS controlling their interactions. The MCM can issue power-up commands to the PCM to bring up or shut down any non-core subsystem

HCU and hardware. Worker subsystem HCUs can power up, achieve a safe configuration, detect subsystem hardware status, and get ready to receive commands from the CCS.

Subsystem HCUs come on in a quiescent, safe state or some nominal safe mode, and should not change hardware state without operator command.

Image data can be published by the Data Acquisition System (DAQ) if it is on and functioning, but may or may not be depending on operator control. Furthermore, overall camera operating configurations can be changed and the configurations themselves re-defined in this mode.

In this mode, the camera remains in the “Offline-Publish Only” OCS state.

8.5. Nominal

In this mode the Camera and its subsystems are fully functioning. The configured camera is functioning normally and all critical telemetry defined in the configuration are functioning within limits. All MPM enables are on with no faults or disable/inhibits. Non-critical telemetry could be out of limit, with alarms published. Here, the camera configuration can also be changed by operator command from a CCS console.

Camera telemetry and events are published and image data from the DAQ is published, as well.

In this mode, an operator at a CCS console can transition the camera from “Offline-Publish Only” state to “Offline-Available” state. This state transition cedes control of the camera to the OCS, at which point the OCS—through an operator at an OCS console or a script—can continue transitioning the camera through OCS-managed states to enable it for full observation.

8.6. Error

This mode is entered either when a fault condition or out-of-range alarm is detected in critical telemetry in the CCS, signifying there is a condition affecting camera health or safety, or an MPM or LPM enable is tripped (de-asserted). The mode could be entered from Nominal mode (OCS or CCS console control), or Engineering. In either case, the CCS stops taking commands from the OCS and reverts to local camera console control. Camera telemetry is still published to the FDB and image data can be sourced by the DAQ.

If a worker subsystem HCU hangs or loses power, subsystem hardware goes into a pre-defined safe state and the camera enters this error mode.

As the camera transitions into this mode, it also stops taking commands from the OCS and drops into “Fault” state. To transition out of this, operators through a CCS console must clear the fault and transition back into Engineering mode. This will return it into the pre-defined “Offline-PublishOnly” OCS state.

8.7. Maintenance

This mode is entered from the Engineering mode only. This mode is defined by the existence of any of the following four unique conditions:

First, the CCS can re-define the camera "structural" configuration in this mode, regarding what is and what is not functionally part of the camera. This allows for the CCS to essentially disconnect a subsystem component from the camera proper and thenceforth define normal operations as absent that component.

Second, in this mode, hardware or subsystem software is being touched, modified, or uploaded, with personnel directly in the loop.

Third, in this mode, subsystem components can be separated from CCS control and independently controlled locally, with operators driving it directly from the HCU (essentially equivalent to test-stand operation). In this case, subsystem hardware may have overrides activated to clear a fault condition.

Fourth, since personnel may be physically working on the camera, hard interlocks or administrative controls are likely in place (e.g.: locked out power supply).

9. Camera Offline Mode Use Cases

A Use Case defines the interactions between external actors and the system under consideration to accomplish a goal. Each use case represents a portion of the functionality exhibited by the system. Use Cases are based upon, or defined by, their functionality: the "what", not the "how." The Use Case description identifies the goal or goals of the use case, the main pattern of use, and any variant uses, as well as any pre- or post-conditions.

The following use cases are supported while the camera is in the Offline mode

MCM core power up: computer racks and/or crates containing MCM software are powered on, re-booted, or hard reset by manual, hardware reset, or software command. MCM software boots up and initiates communication with FDB.

9.1. MCM Core Power-Up

The following sequence is followed to power up the MCM core:

Turn on power to CCS control room racks (manual operation or by a facility control console)

When voltage is applied to the CCS control room racks, the following occurs:

- CCS Master Control Module (MCM) boots up automatically
- Communication is established with an operator through a CCS console
- MCM core capabilities come online, including the OCS bridge, health and safety monitoring, telemetry aggregation, and the command sequencing engine
- Other CCS modules may also come online, but are not essential for camera power-up
- CCS starts publishing telemetry and events to the Facility Database (FDB)

The Camera enters “Power on / Re-Boot Mode” after successful initiation of publishing to FDB and communication with CCS console

The Camera transitions to “Offline-Publish Only” OCS state after successful initiation of publishing to FDB

10. Camera Power-on/Re-boot Mode Use Cases

The following use cases are supported while the camera is in the Power-on/Re-boot mode

MCM core power-down: computer racks and/or crates containing MCM software are powered off by controlled manual, hardware switching, or software command. MCM software turns off all subsystem HCUs and stops then crates are turned off.

MCM core software update: publishing of events and telemetry to the FDB is suspended as core MCM software is updated or re-loaded.

Camera core power-up: power is turned on to the on-telescope camera and camera core facilities are powered up and communicate with the MCM.

10.1. MCM Core Power-Down

The MCM Core is powered down by removing power to the CCS control room racks

10.2. MCM Core Software Update

TBD - Software updates to the MCM core components

10.3. Camera Core Power-Up

Camera Core power-up can be initiated when the camera is in the "Power on / Re-Boot Mode."

Turn on camera main circuit (TCS or manual operation by operator at TCS console)

When voltage is applied to the camera main, the following occurs:

4 PLCs boot up automatically

Cryo system PLC: monitors select cryo plate RTDs and interlock cryo plate heaters and cryo compressor chassis; receives enable from vacuum PLC

Cold system PLC: monitors select cold plate RTDs and interlocks cold plate heaters and cold compressor chassis; receives enable from vacuum PLC

Vacuum PLC: monitors vacuum gauges and closes valves for cryostat and heat exchanger vacuums

Control/Master Protection Module (MPM) PLC: monitors signals from the UT smoke detector, Dynalene leak detector, UT klixons (interlocks to main power and Dynalene shut-off valve); interlocks REB power from Cold and Cryo PLC heater permit signals

BPU (Bulk Power Unit) HCU boots up automatically—this monitors the PLCs, and monitors/controls the Power Distribution Units (PDUs), Breaker Filter Relay (BFR), UT blower unit, and UT Dynalene circuit

Master switch and lower level network switches power up

UT smoke detector powers and starts working automatically

BPU HCU starts publishing telemetry and events and operator at CCS console confirms that camera has successfully powered up

The Camera enters "Base Mode" after successful publishing of telemetry from the BPU HCU through MCM.

11. Camera Base Mode Use Cases

The following use cases are supported while the camera is in the Camera Base mode

Camera core power-down: core utilities for the on-telescope camera are terminated and core hardware components are powered off by command from the MCM.

Camera environmental core power-up: one or more environmental core systems of the on-telescope camera are powered up and communicate with the MCM through the camera core.

Environmental core system re-configured: set points or thermal control loop parameters are modified.

11.1. Camera Core Power-Down

With the camera in "Power-on / Re-Boot" Mode, core power-down can be initiated

TCS or operator shuts off camera main circuit (TCS or manual operation by operator at TCS console)

When voltage is cut to the camera main, the following occurs:

All PLCs shut down (Control/Master Protection Module (MPM) PLC, Cryo system PLC, Cold system PLC, Vacuum PLC)

Any PLC permits or enables are automatically dropped when the PLC goes offline

This means that refrigeration compressor cabinet enables are dropped, even though the cabinets may still have power and their HCUs and sensors are functioning

Camera protection status is lost, including the position of the Dynalene shut-off valves and state of the UT smoke detectors

Power to all power supplies and circuits is dropped, so all HCUs and subsystem hardware lose power and turn off

Master switch and lower level network switches lose power and all network connectivity to the on-telescope camera is lost

BPU HCU stops publishing telemetry and events and shuts down

Camera enters "Power-on / Re-Boot" Mode after voltage is turned off to the main camera power feed

11.2. Camera Environmental Core Power-Up

When the camera is in the "Base" mode, it can continue start-up by powering up the core elements of the systems controlling camera environments

Operator closes BFR relay J22, powering 24V clean power supply PWR-UTT-PWS-20 and enabling output J13 on PDU-02), providing voltage to monitoring MAQ20 units; this initiates monitoring of all sensors for UT forced air system and temperature sensors, Camera Volume Purge, and Mech Purge systems, as well as CVPurge re-heater PID controller (BPU-UTT-PID-01)

Operator turns on Cryo HCU (PDU-02/J15) and power to gauges (PDU-02/J14)

Operator closes BFR relays for the two 48V dirty power supplies PWS-01 and PWS-02, and turns on PDU output PDU-00/J9 via the BPU HCU; this provides voltage to the Mech Purge and for Vol Purge and UT blowers

Operator initiates UT environmental control (controlled by Cryo HCU)

Turns on Dynalene coolant system: opens and latches shut-off valve (this closes automatically when power is lost to camera and when Control/MPM PLC is turned off) and uses 3-way valve to establish flow control to preset CCS configuration

Turns on UT blower unit and establishes thermal control of the UT by initiating feedback control loop using preset CCS configuration

Operator turns on Camera Volume Purge cabinet (controlled by Cryo HCU)

BPU HCU turns on (via BFR) CVPurge 220 V re-heater power relay (PWE-UTT-RYB-00/J12 and /J13)

Cryo HCU checks that CVPurge telemetry from camera body is being monitored

Turns on CVPurge blower unit and establishes thermal control of camera volume by initiating feedback control loop using preset CCS configuration

Operator turns on Mechanism Purge cabinet (controlled by Cryo HCU)

BPU HCU turns on power to MPurge blower (PDU-00/J9)

Cryo HCU checks that MPurge telemetry from camera body is being monitored

Turns on MPurge blower unit and establishes thermal control by initiating feedback control loop using preset CCS configuration

Operator initiates control of cryostat and heat-exchanger can vacuum volumes (controlled by Cryo HCU)

Checks that Cryostat and Heat-X Can vacuum system telemetry is being monitored

Cryostat and Heat-X can vacuums could be vented, under high vacuum, or slowly drifting up in vacuum pressure. Any of these are inherently safe configurations, so establishing control of the vacuum systems more involves checking telemetry and setting up the system for the next move (e.g.: pump-down)

Operator initiates cryo and cold plate thermal control (controlled by Cryo HCU) (MAQ-20 units reading cryo and cold plate temp sensors are already powered)

Checks that cryo and cold plate temperatures and heater current telemetry is being monitored

Cryo and cold plates could be warm, cold, or slowly drifting up in temperature. Any of these are inherently safe configurations, so establishing thermal control more involves checking telemetry and setting up the system for the next move (e.g.: cool-down)

Camera enters "Engineering Mode" after successfully publishing telemetry and autonomous operation of UT blower system and CVPurge and MPurge systems

11.3. Environmental Core System Re-Configured

TBD

12. Camera Nominal Mode Use Cases

The following use cases define camera interactions while in the "Nominal" mode. This includes when the camera is under OCS control while observing, as well as under control of a human operator or script from a camera engineering console.

12.1. Nominal Camera Operation

12.1.1. Description

The camera is operating as defined in "Nominal" mode with the camera in the "Enabled" OCS state. The external actor is the OCS or an operator acting as a stand-in for the OCS by way of an OCS console. It is also possible there is no actor during quiescent periods.

For essentially normal operations, the camera receives and satisfies a command, returning to the "Idle" state on success.

12.1.2. Pre-Condition/Constraint

The Camera will be publishing telemetry, including an event stream of type "heartbeat" containing validation that CCS is functioning. At successful receipt of a command, the camera's most recent state event had a value of "Idle."

If the camera is not in "Idle" state but receives a command, then it sends a 'Reject' response and continues executing the command.

12.1.3. Basic Course

The camera exchanges messages with the OCS. Message types are: Command, Response, Event, Telemetry, DB query, Heartbeat. These are the sole means of communication and form the means by which commands are fully executed.

While in the "Idle" state, the camera receives a command from OCS and sends an 'Accept' response, which optionally contains a timeout parameter informing OCS of a suggested deadline for completion. The camera then transitions to the "Busy" state during subsequent actions, publishing an event corresponding with the state change. The camera carries out the activities associated with the command, publishing additional events and telemetry as the activity is executed. When the activities are fully executed, the camera sends a response of 'Done,' transitions to the "Idle" state, and publishes an event corresponding with the state change

The following subsections provide additional details of the types of messages exchanged between the camera and OCS.

12.1.3.1. Command

Commands from a preset approved list of commands are received from the OCS to operate the camera during the survey. This includes commands for taking an image or changing a filter, as well as to report status, re-initialize and other built-in life-cycle operations. See Ref. [3], LSE-71 "OCS-Camera Command Dictionary" for a complete list of commands.

12.1.3.2. Response

Camera responds to OCS commands. Camera responses are: accept, reject, done.

12.1.3.3. Events

Events published by the camera correspond to changes in the camera or a camera subsystem device state. Events are distinguished from telemetry by their usage within OCS to initiate actions or make decisions.

12.1.3.4. Telemetry

A relatively steady telemetry stream of Camera status values is published for storage in the FDB and operator status displays. The Quality of Service (QoS) of telemetry is lower than for events.

12.1.3.5. DB Query

Events and telemetry received by the camera by way of subscription: These may be telescope tracking status, temperatures, and utility status.

12.1.3.6. Heartbeat

The camera publishes an event containing a timestamp at some frequency. The timestamp is generated by the CCS primary thread (rather than the CCS-OCS interface) and indicates the last known time the CCS was "alive."

12.1.4. Outcome

Camera completes the commanded activity successfully, publishes a 'Done' command reply, and publishes an event signifying changing state to "Idle" state.

12.1.5. Alternate Course

Outcomes other than successful completion of the activity can lead to alternate courses. For all OCS commands to the camera, the only course other than successful completion of a command is due to a fault condition. The reasons for this and camera actions are described in the following section.

12.2. Generic Fault Response

12.2.1. Description

During execution of a command, any non-standard behavior or out of range telemetry triggers the camera to drop into "Error" mode and publish an event signifying that it is in the OCS "Fault" state. Operator attention is needed to address the fault condition and return the camera to nominal mode.

Lower level components (e.g.: worker or management subsystems) take whatever action necessary to protect their dependent hardware in conjunction with the Camera Protection System (CPS).

12.2.2. Pre-Condition/Constraint

An error condition can be entered into while the camera is executing an OCS-originated command, while it is in CCS-controlled engineering or other mode, or while it is idle. The following list identifies triggering events that would lead to the camera dropping into Error mode:

- Loss of CCS heartbeat: if the OCS loses the camera heartbeat, it drops the camera into "Fault" state and stops
- Camera telemetry goes out of range: any of a number of camera sensors detects operating conditions that are outside of pre-defined safe working conditions
- A protection system enable is dropped: this stops or prevents local action, to protect hardware, and publishes a fault condition to the CCS, putting the camera in "Error" mode and publishing a fault event.
- Event signifying Camera has moved out of "Nominal" mode.
- Camera fails to publish an expected "event" causing an error response in the OCS and the OCS dropping the camera into "Fault" state.

12.2.3. Basic Course

CCS transitions to Error mode while continuing to monitor and publish telemetry. With the exception of the ongoing problem, the camera is quiescent/neutral. Subsystems not involved in the error condition continue their normal monitoring functions.

The operator takes control (locking the system) and uses appropriate engineering, diagnostic or maintenance commands to drive the Camera back into the desired mode.

On success the operator unlocks the system and informs the OCS.

The Camera-OCS bridge is likely in the "Error" state which requires a 'reset' command from OCS to transition to "Offline-PublishOnly" state. From this OCS state, state transitions as described in previous sections would be used to return the camera to nominal operations.

12.2.4. Outcome

The Camera returns to "Nominal" mode and the operator at the CCS terminal executes the CCS command to put the camera into the "Offline-Available" state.

12.2.5. Alternate Course

The operator is not able to drive the system back into the desired mode. A full or partial shutdown is initiated to prepare for transition to "Maintenance" mode to make necessary repairs.

13. Camera Engineering Mode Use Cases

When the camera is in Engineering Mode, and the CCS console retains control of all worker subsystems, the CCS can execute a broader set of commands for controlling subsystems. When subsystems are locked out by the CCS for stand-alone control from a console, a fuller set of subsystem command functionality is exposed. However, this describes the intermediate condition when the CCS controls the subsystem, while in Engineering Mode.

Note that an additional set of commands is available when in Maintenance Mode. This capture use cases when personnel are accessing and servicing the camera.

All Engineering Mode use cases are available when the particular subsystem is under CCS control, and personnel are not accessing the camera.

The following use cases are supported while the camera is in Engineering mode.

Camera environmental core power-down: one or more environmental core systems of the on-telescope camera are powered off by command from the MCM.

Subsystem power up: camera subsystem component is powered up and made ready for operation. CCS turns on HCU that controls the subsystem. HCU comes up in a quiescent state and deliveries telemetry and event information, including a heartbeat to signify that it is ready for receiving commands.

Compressor Cabinet power-up

Subsystem power-down:

Subsystem standard testing:

Subsystem troubleshooting:

Set new subsystem configuration parameters

Cool Down Cryo and Cold Plates

Warm Up Cryo and Cold Plates

13.1. Generic Engineering Mode Use Case

13.1.1. Description

While in Engineering mode, the camera can behave as a single entity under coordinated CCS control, or individual camera subsystems can be separated and locked by an operator console for targeted testing and troubleshooting.

13.1.2. Pre-Condition/Constraint

Camera is in "Engineering" mode and in the OCS "Offline-PublishOnly" state or not communicating with the OCS or publishing telemetry to the FDB. The camera operator is driving the system through a CCS engineering console. The console user interface allows the operator to have command sets and privileges corresponding to the activity taking place, including special commands or overrides.

13.1.3. Basic Course

13.1.3.1. Enter Engineering Level

Operator provides credentials by way of console "login" function. In response, the CCS establishes locks and constraints for the appropriate level of engineering mode. This may include a re-initialization of the subsystem or other configuration sequence. Operator chooses a manual mode level corresponding to the activity. Console/System establish locks and constraints for that level.

13.1.3.2. Exit Engineering Level

Operator "logs out" returning the Camera to nominal mode. This only succeeds at the lowest level; higher levels must be lowered while logged in.

13.1.3.3. Operator Driven Commanding

Operator chooses a lower level explicitly. Operator drives the system or subsystem(s) involved into a new configuration, verifies performance and functionality are nominal, then uses configuration management functions to register the new configuration.

Camera protection hardware catches and prevents damage but the CCS will sequence dependencies properly in the absence of a hardware or software fault.

13.1.4. Alternate Course

As in Normal mode, out of range telemetry will trigger an error event and drop the camera into Error mode. Furthermore, protection system interlocks remain fully functional in this mode and protect camera subsystem elements, even if a subsystem is separated and locked to a CCS engineering console.

13.2. Camera Environmental Core Power-Down

Camera starts shut-down in "Engineering Mode" with all environmental systems operational and all other worker subsystem shut down

Camera enters "Base Mode" after initiation of this shut-down sequence

- Operator terminates cryo and cold plate thermal control (controlled by Cryo HCU)) (MAQ-20 units reading cryo and cold plate temp sensors remain powered)
    - Cryo and cold plates are warm, cold, or slowly drifting up in temperature. Any of these are inherently safe configurations, so terminating thermal control more involves turning off the feedback loop
    - Cryo and cold refrigeration compressors must be turned off
    - Operator terminates feedback control loop and manually turns off all heaters on cryo and cold plates
- Operator terminates control of cryostat and heat-exchanger can vacuum volumes (controlled by Cryo HCU)
    - Cryostat and Heat-X can vacuums could be vented, under high vacuum, or slowly drifting up in vacuum pressure. Any of these are inherently safe configurations, so terminating control of the vacuum systems more involves turning off ion pumps and on-board gauges
    - Operator turns off ion pumps and gauges for cryostat and Heat-X vacuums
- Operator shuts down Mechanism Purge cabinet (controlled by Cryo HCU)
    - Terminates feedback control loop and turns off MPurge blower unit
    - BPU HCU turns off power to MPurge blower (PDU-00/J9)
- Operator shuts down Camera Volume Purge cabinet (controlled by Cryo HCU)

Terminates feedback control loop and turns off CVPurge blower unit and re-heater power

BPU HCU turns off (via BFR) CVPurge 220 V re-heater power relay (PWE-UTT-RYB-00/J12 and /J13)

Operator terminates UT environmental control (controlled by Cryo HCU)

Terminates feedback control loop and turns off UT blower unit

Closes Dynalene shut-off valve

Operator turns off PDU output PDU-00/J9 via the BPU HCU and opens BFR relays for the two 48V dirty power supplies PWS-01 and PWS-02

Operator turns off Cryo HCU (PDU-02/J15) and power to gauges (PDU-02/J14)

Operator opens BFR relay J22, powering 24V clean power supply PWR-UTT-PWS-20 and enabling output J13 on PDU-02); this terminates monitoring of all sensors for environmental and other systems, as well as CVPurge re-heater PID controller (BPU-UTT-PID-01)

At this point, the Camera is still in "Base Mode," with all environmental control systems off and telemetry still being published from BPU HCU through MCM

13.3. Subsystem Power-Up

TBD

13.4. Compressor Cabinet Power-Up

This describes the sequence for powering up the compressor cabinets under the TMA floor.

Turn on compressor cabinet main circuit (TCS or manual operation by operator at TCS console)

When voltage is applied to the compressor cabinet main, the following occurs:

PLCs boot up automatically: 1 PLC per compressor (8, total): all come up disabled, requiring a CCS software reset plus an enable from the MPM PLC when it gets an enable from the Cryostat PLC that is monitoring Cryostat and Heat-X Can vacuum gauges

Network switch powers up

Refrigeration system HCU boots up automatically

Refrig HCU starts publishing telemetry and events

Operator checks telemetry from compressor cabinets to confirm readiness for cooldown

Operator initiates cooldown by turning on compressor units via the Refrigeration HCU, in a prescribed order

13.5. Subsystem Power-Down

TBD

13.6. Subsystem Standard Testing

TBD

13.7. Subsystem Troubleshooting

TBD

13.8. Set New Subsystem Configuration Parameters

TBD

13.9. Cool Down Cryo and Cold Plates

TBD

13.10. Warm Up Cryo and Cold Plates

TBD

14. Camera Maintenance

14.1. Maintenance Policies

The Camera maintenance concept puts a premium on up-time of the observatory by focusing on reducing the duration of down-times for servicing, troubleshooting, repair, and replacement. This concept is borne out in three design and operations policies that drive camera element design decisions and maintenance planning.

First, the camera is designed to be modular to allow for relatively straightforward replacement of components with minimal impact on neighboring systems. Modularity requirements are derived in the use cases in Section 15, below. This policy has four consequences:

Down-time minimized: modular design of components allows for more rapid replacement of defective or failed components with the camera on the telescope, reducing the overall down-time of the observatory.

Reduced maintenance times: for both short turn-around and longer maintenance activities, modular component design allows for reduced maintenance times, particularly important for long-duration maintenance and re-builds. Modularity has the effect of pushing maintenance work to lower levels of assembly, which parallelizes the work and allows for the rest of the Camera assembly to be re-started. Furthermore, the risk of delay or further loss of up-time is reduced since the component under maintenance is physically separated from the rest of the Camera.

Off-telescope verification: modular design also allows for re-verification of components off the telescope, which further reduces the risk of problems and delays when the component is re-integrated into the camera. Such re-verification serves to catch residual problems, test that all maintenance work was successfully completed, and ensure that the system is ready for full operations. Doing this off the telescope in a test stand or other simulator improves the probability of success with little or no up-time penalty.

Minimized risk of collateral damage: modular designs provide separability between subsystems and components, which reduces the risk that work on one component negatively affects another. Keeping components modular ensures that verification of neighboring components is not lost during a maintenance time. This reduces the chance that work on one component will actually introduce problems in neighboring systems due to introduced mis-alignments, disconnect/re-connect problems, physical damage, and other collateral damage.

Second, Camera maintenance scenarios involve use cases with well-defined, discrete on-telescope work. Maintenance scenarios are defined based on the expected time/complexity of the use case and location of the work. Clearly, use cases involving maintaining the camera while on the telescope have the most severe time limitations, but all maintenance work is characterized this way to provide insight into requirements on maintenance support elements and on re-work/replace decisions and decisions to ship components back to a home institution for maintenance. A secondary reason to characterize maintenance work is to characterize the increased exposure to hazards associated with an earthquake on site. Of necessity, not all maintenance use cases are performed with Camera and telescope components in seismically safe configurations, so characterizing the duration and configuration of the use case helps in bounding the increase risks associated with the work. The assessment of increased exposure to seismic hazards during maintenance is further summarize in Section 14.3, below.

Third, putting a premium on observatory up-time drives the need to minimize time to repair and maximize availability of maintenance support elements on the summit. This includes developing interface agreements to ensure we have rapid access to the camera while on the telescope through deployable access platforms as well as to define requirements on summit maintenance facilities for the camera. This also drives the need to deliver much of the camera integration and test hardware to the summit, to be able to respond quickly to camera problems and maintenance requirements.

These maintenance policies are further detailed in the following sections, along with requirements derived from their implementation.

14.2. Maintenance Scenarios

The maintenance policies described above describe a tiered approach for camera maintenance. In general, the camera is planning for three tiers of maintenance capabilities during operations. These are described below

14.2.1. On-Telescope Maintenance

Maintenance on the telescope is intended to address relatively short turn-around issues to return the camera to normal operations as soon as possible. Work is done with the telescope in the horizon-pointed attitude, with the maintenance access platforms deployed. While the exact duration of a maintenance activity varies, we have defined three rough duration windows to help characterize the nature of the activity and timing of access. Part of the rationale for this was to better understand the risk associated with the incremental increased exposure to seismic hazards. The three timing scenarios are as follows:

Short-duration on-telescope maintenance: maintenance work taking up to 2 hours to complete, from the time the camera is accessed to when personnel access is no longer possible. This scenario is intended to cover activities and use cases involving inspection, troubleshooting, and limited preventative maintenance. Also, this time frame accommodate the timing for swapping out a filter using the Filter Loader. Activities being performed in this time frame need to be fairly well choreographed to reduce the risk of time slips that may affect other planned maintenance. In general, this work would be done during standard day-time maintenance, but some activities could be performed during a planned or unplanned down during night-time observing.

Medium-duration on-telescope maintenance: work taking up to 6 hours to complete, from the time the camera is accessed to when personnel access is no longer possible. This duration essentially defines a full day's worth of maintenance work, which may or may not put exclusive claim on personnel, access, and equipment resources in the dome. Thus, activities taking up to a full day need to be well understood regarding the resources they require and constraints they put on other parts of the observatory. Also, since this essentially defines a full day's worth of work, the scope and duration of such activities need to be well understood, since exceeding the 6 hour duration could well impact preparations for night-time observing. Activities accomplished in this time scenario include cleaning, re-work/preventative maintenance, lubrication, and replacement modular components

Long-duration on-telescope maintenance: maintenance work taking longer than 6 hours. Work requiring longer durations implies that there will be some loss of observing time involved, or that it is planned to coincide with an extended down-time or weather-related down. The alternative to performing this work is to remove the camera from the telescope and perform the work in on the ground, so the intent of this long-duration work is to reduce the overall down-time. Activities requiring these longer durations include repair or replacement of components that are not modular or not easily accessible, or diagnosing particularly complex problems, such as leak-checking.

14.2.2. Summit Facility Maintenance

Long-duration, involved maintenance work is performed with the camera off the telescope. This includes any maintenance requiring access to the cryostat, and some parts of the Utility Trunk. Such work includes replacing a raft tower, support electronics, or significant maintenance on the Camera purge system or Utility Trunk blower system. This would be done during a longer, planned down-time, and would likely include warming up and venting the cryostat.

The summit maintenance facility must have the room and utilities capable of supporting this work.

14.2.3. Home Institution Maintenance

The final maintenance scenario involves off-line work at Camera collaborator home institutions. For hardware, work at home institutions focuses on repair of high-value hardware, or equipment that is too complex to repair in the summit facilities. This includes raft towers and optics, but may also include repair or upgrade of test equipment.

Maintenance of control system and diagnostic software will also be performed at home institutions, where the software can also be tested on simulators or test hardware, as needed. This allows for more thorough verification of software changes prior to revising and bringing on-line upgrades to the live camera software.

14.3. Seismic Exposure Risk and Maintenance Timing Assessment

Camera maintenance plans have been developed with an eye towards understanding and characterizing the incremental risk increase associated with exposure to seismic hazards during maintenance activities. During all normal and non-maintenance operations of the camera, it is designed to meet or exceed requirements to survive seismic loads as defined in Ref. [7], LCA-69, “LSST Camera Environmental Specification Supporting Analyses”. The only exception to this is that configurations and orientations of the camera that are transient or temporary need not be designed to these seismic load cases. This includes when hardware is being handled during crane lifts, fixture re-orientation, hardware moving or rolling, and other maintenance and servicing activities. It also includes the repetitive transient operations of exchanging a filter and swapping out a filter. Note that all other repetitive transient operations must be inherently seismically safe, including opening and closing the shutter, servicing the cryostat, and running the refrigeration system.

Specifically, the analysis in Ref. [7] specifies four exceptions to the seismic design criteria listed above:

Filter exchange system hardware does not need to be safe against seismic loads during operation

Camera components may be in a configuration not safe to seismic loading for at most 2 hours during routine maintenance of the Camera

Camera components may be in a configuration not safe to seismic loading for at most 6 hours during integration or during longer term maintenance of the Camera

Planned maintenance activities of the Camera that put it in a seismically unsafe configuration for more than 6 hours must be reviewed and approved

15. On-Telescope Maintenance Mode Use Cases

The following use cases have been defined for camera maintenance. They, and the activities that can be performed for each use case, are outlined in the subsections, below, and the full set of activities listed in Ref. [6], LCA-16589, "Camera Maintenance Activities"

Access/Secure camera body

Maintain mechanisms

Remove/replace mechanisms

Inspect components in camera body

Service front of camera

Swap out filter

Service components in back flange

Access utility trunk

Replace components in utility trunk

Service vacuum systems

Leak check cryostat

Maintain refrigeration system

15.1. Access/Secure Camera Body

Access the camera and prepare for use cases involving access to the camera body volume. This involves removing part or all of the shroud surrounding the camera mid-section and adding auxiliary protection to preserve the controlled environment within the camera volume.

To accomplish the activities associated with this use case, the camera, its subsystem, and support equipment need to include certain design features and functional capabilities:

- Auxiliary purge unit: plug-in unit(s) with blower and filtration that mounts to the top of the camera and blows filtered air in through an opening in the upper skirt region or additional openings in the camera housing
- Oxygen deficiency monitor alarm: add-on alarm that is mounted at the opening into the camera volume, to alarm if the purge unit power is lost and nitrogen gas builds up in the camera volume again
- Clean tent: mounts to top of camera and protects openings to the camera with the skirt removed from allowing contaminants into the camera volume; this includes an add-on piece to cover up the underside of the camera skirt region, if this piece is removed
- Camera body includes portals for blower inlet lines, one on each side of the camera
- Skirt side pieces are separately removable, with clean-able mount/seal surfaces at the camera body and L1-L2 ring joints
- Skirt lower piece is self-supporting and separately removable from the side pieces, with clean-able mount/seal surfaces at the camera body and L1-L2 ring joints

15.2. Maintain Mechanisms

Inspect, service, and perform limited repair on mechanisms inside the camera body proper, including work on the shutter, auto changer, and carousel. This requires some level of locking out of power supplies, setting up guards, PPE, and alarms for personnel protection and system safety, and local control of subsystem HCU's through engineering consoles accessed through laptops or tablets on the platforms. However, all subsystems remain in control of the MCM or are checked out for local console control.

To accomplish the activities associated with this use case, the camera and its subsystem need to include certain design features and functional capabilities.

- Auto Changer clamps can be individually clamped/un-clamped
- Auto Changer to provide a clamp block to simulate filter clamped on-line and in the truck, for troubleshooting
- Auto Changer drive system has a slow/jog mode for prescribed slow-speed motion, possibly with manual direction
- Shroud around Auto Changer to prevent dust or extra lubricant from dropping
- Auto Changer drive system has a prescribed run-in/verification mode
- Auto Changer truck, on-line clamp, and position sensor are field-replaceable to allow for replacing a faulty unit
- Auto Changer module operations can be verified while on the bench for all but a clearly delineated set of operations
- Access through camera body portals to service Carousel clamps
- Carousel clamp, magnetic coupling, and position sensors are field-replaceable to allow for replacing a faulty unit
- Carousel drive system has a slow/jog mode for prescribed slow-speed motion, possibly with manual direction
- Carousel drive system has a prescribed run-in/verification mode

- Carousel to provide a clamp bar to simulate a filter clamped into a Carousel socket, for troubleshooting
- Carousel can rotate freely with only 2 or 3 filters loaded, to allow for replacing clamps in situ
- Exchange system has a scripted changer/carousel hand-off verification mode to check filter hand-off over multiple cycles
- Shutter shroud is removable with the L1-L2 assembly, shutter and auto changer installed
- Shutter drive system has a slow/jog mode for prescribed slow-speed motion, possibly with manual direction for use during inspection
- Shutter control system can map errors between motor encoder and positon monitors to look for position errors
- Shutter pulleys, idlers, and cam followers can be re-lubricated in situ
- Shutter belts are replaceable in-situ
- Shutter belts can be tensioned, and the tension measured, with the shutter installed in the camera
- Shutter drive system has a prescribed run-in/verification mode, for one or both blade stacks
- Shutter module operations can be fully verified while on the bench

15.3. Remove/Replace Mechanisms

Disconnect, remove, replace, reconnect, and re-verify a shutter or auto changer module. This requires locking out and physical disconnection of power supplies, as well as local control of subsystem HCUs through engineering consoles accessed through laptops or tablets on the platforms, with eventual physical disconnection/re-connection. Guards, PPE, and alarms for personnel protection and system safety are also required, as well as custom fixtures. Activities in this use case are largely procedure driven. All subsystems remain in control of the MCM or are checked out for local console control.

To accomplish the activities associated with this use case, the camera and its subsystem need to include certain design features and functional capabilities.

- Auto Changer is modular, allowing it to be removed as a single unit in less than 2 hours and re-integrated in less than 3 hours, including re-verification
- Auto Changer module can be removed with or without a filter in the on-line position
- Auto Changer module is fully disconnectable from power and controls at the module, with little or no pig-tail requiring un-threading
- Auto Changer provides lift fixture that mounts to auto changer to lift it in/out of the camera with the crane (used in conjunction with the extraction rail as described below)

Auto Changer provides extraction rail

- Mounts to +Y side of camera only
- Guides an auto changer module in/out of the camera to prevent collisions with neighboring hardware by limiting motion to < 1 mm from nominal X, Z position as it is extracted along the Y-axis as defined in Ref. [10].
- Envelope and hook height constraints are limited to those defined in Ref. [5] “Auto Changer Lift Volume”
- Maximum mass = 30 kg
- Insertion/removal path must clear all other subsystem hardware

Auto Changer provides transport clean box

- Houses and supports the module after it comes out of the camera
- Need one for each auto changer module
- Includes a housing to protect the clean auto changer from the dirty dome environment
- Housing must be re-cleanable so it can be moved into the White Room
- The module support frame should either allow for maintaining the module on the bench top in the White Room, or a separate stand is needed
- Maximum mass of the Clean Box and Auto Changer: 400 kg
- Maximum dimensions of the Clean Box on a cart: 1.85 m high

- Dummy mass to simulate the Auto Changer moment around the Z-axis; this mounts in place of the module
- Shutter is modular, allowing it to be removed as a single unit in less than 2 hours and re-integrated in less than 1 hour, including re-verification
- Shutter module is fully disconnectable from power and controls at the module, with little or no pig-tail requiring un-threading
- Shutter extraction rail; must be light enough to install and align by hand
- Shutter transport clean box to house the shutter after it comes out of the camera; need one for each shutter module

15.4. Inspect Components in Camera Body

Inspect, clean, or align components in the camera body volume. This may require locking out of the mechanisms, depending on the work going on and proximity to them. Activities in this use case are largely procedure driven, with all subsystems remaining in control of the MCM. Much of the work involves work around the lenses, so extreme care, well thought out procedures, and protection is needed to reduce the risk of unintended contact with a lens surface.

The following requirements on subsystem hardware and functional capabilities are needed to accomplish the activities in this use case

- L1-L2 and L2 cell struts need to have gauge points or some other way to easily determine their length and depth of engagement in the field
- L1-L2 and L2 cell struts must be fully adjustable in the field under full gravity loading with the telescope in the horizon-pointed or zenith-pointed orientations
- I&T provides a borescope with high-resolution and magnification for visual inspection of lenses
- Camera Body purge instrumentation is accessible and replaceable from the skirt opening

15.5. Access Front of Camera

Access the front of the camera to service or inspect the region around the L1 lens. This includes mounting and removing L1 lens cap, cleaning and inspecting the L1 lens first surface and mounting or removing SMR reflector balls.

Requirements on camera components to allow for this maintenance work

- Optics: L1 lens cap is lightweight enough for one person to lift and carry up the stairs on the platform
- Optics: L1 lens cap mount posts guide and support the lens cap to prevent accidental contact with the lens during integration or removal, and fully support the lens cap for any orientation of the camera

15.6. Swap Out a Filter

Move a filter out of the camera into the filter loader and remove it, then introduce a new filter and store it in the camera.

Requirements to allow for execution of these activities:

- Filter Loader: self-check routine that the Loader can execute at power up, with or without a filter in place, to check that everything is functioning normally
- Filter Loader: umbilical line for plugging in power, controls, and protection into the exchange system
- Exchange system: capability to include/drop the Filter Loader from controls, power, and protection logic without turning off the other parts of the system; self-check routines for checking that a Filter Loader connection/disconnection was successful and that the re-configured system is working correctly

15.7. Access Back Flange

Access the bays in the camera back flange to service components or connections.

Requirements to accommodate these activities:

- Carousel: components mounted in back flange bays are remove-able from the perimeter without disturbing mounting hardware or neighboring components
- Carousel: self-check routine to execute at power up, with or without filters in place, to check that everything is functioning normally
- Carousel: run-in sequences to verify functionality of new components, possibly including cycling actuators
- Carousel: low-speed or jog mode for rotating the carousel slowly to allow inspection of the ring gear

15.8. Access Utility Trunk

Prepare the Utility Trunk to provide access to its contents for repair, servicing, or replacement, or secure it for operations after access is complete. This includes re-orienting the camera to the correct rotation angle to expose the right hardware through the narrow access regions.

Requirements needed to allow for these maintenance activities:

- All components in the Utility Trunk are inherently safe; this says that blind groping in the Utility Trunk is not a personnel hazard and that hazards are only exposed when further covers or panels are removed
- Utility Trunk: access port covers slide or are fully removable, with all hardware captured; don't use hinged doors, since this will block access through the hexapod

15.9. Replace Components in the Utility Trunk

Access a region of the Utility Trunk to replace an electronic component or service UT or camera volume purge systems.

Requirements to allow for these activities:

- Protection system: re-certification method to re-certify the Camera protection system while on the telescope

15.10. Service Vacuum Systems

Service vacuum components in the Utility Trunk and mounted to the back end of the Cryostat. This includes pumping down and venting the Cryostat and cooling it down and warming it up.

Requirements needed to accomplish these activiites:

- Cryostat: vacuum line pump ports are accessible through holes in the Utility Trunk and hexapod
- Cryostat: cool-down script to provide feedback on cool-down rate

15.11. Leak Check Cryostat

Leak check all vacuum seals at each joint in the assembled cryostat. Depending on the extent of the leak checking, this may involve removing a filter into the Filter Loader, then moving a second filter on-line to provide better access around the perimeter of the cryostat housing, or moving the on-line filter off-line for better access to the L3 flange.

The following design and operational requirements are needed to allow for the maintenance operations described above.

- Cryostat: provide a pump cart with valve box to allow individual pumping and leak checking of interstitial pump-out grooves
- Cryostat: support cylinder needs to include removable access panels that can be removed from within the camera body
- I&T: provide borescope and support to allow remote viewing of any feedthrough from outside the camera body

15.12. Maintain Refrigeration System

Access the TMA sub-floor region to access and maintain the refrigeration system compressor cabinets. This includes performing periodic inspection and maintenance on the systems, as well as more major repairs and replacement of components in the compressor cabinets.

16. Summit Facility Maintenance Mode Use Cases

The following use cases have been defined for camera maintenance in the summit facility. They, and the activities that can be performed for each use case, are outlined in the subsections, below. Note that this list of use cases is in addition to all use cases defined for on-telescope maintenance. All on-telescope maintenance can also be performed with the fully integrated camera on the ground in the Staging and Test Area. The use cases described here are delineated by the degree of de-integration and required cleanliness associated with the activities.

This section focusses solely on the additional maintenance activities that can be performed on the integrated camera, major sub-assemblies, or individual components.

The full set of activities are listed in Ref. [6]

Move and test camera in staging and test area

Access, service full camera in staging and test area

Maintain Camera and Units in White Room

Access, service cryostat contents in clean room

16.1. Move and Test Camera in Staging and Test Area

Hoist and lift, and move the fully integrated camera around the staging and test area, to prepare for and recover from more invasive camera maintenance. This includes full camera functional and performance testing.

16.2. Access and Service Integrated Camera in Staging and Test Area

Open up and service camera components while in the staging and test area. This includes de-integrating large camera components to partially disassemble the camera. For all activities, this involves exposing the camera inner volumes to ambient conditions.

16.3. Maintain Camera Units in White Room

Re-commission and perform routine maintenance, cleaning, and refurbishment of the white room and its contents. Prepare for and recover from a filter swap-out and trading out a shutter or auto changer unit with the camera on the telescope. Perform routine maintenance, cleaning, and refurbishment of the camera mechanisms and filters. Prepare for and recover from cryostat access by de- and re-integrating utility trunk from/to the cryostat.

Requirements on hardware and facilities.

Filter Loader:

- Carts to support Filter Loaders that fit in elevator and through halls and doors (1 cart per Loader)

- Stand-alone purge gas system mounted to cart, include flow-control, filtering, gas tank
- Cart and Loaders include provisions for moving them around the facility by hand with two people
- Cart and Loaders include provisions for anchoring and tethering against Recoverable seismic loads
- Filter Loader includes FCS test-stand for stand-alone operation in the White Room
- Compatible with ISO Class 6 clean room, inside and out
- Filter Loader and Cart are easily re-cleanable on the outside to allow for easy re-entry into the White Room
- Filter Loader, Cart, and Storage box must be fully operational with a hook height of 3.66 m.

Storage Box:

- Must contain 1-6 filters
- Capable of being lifted when full, either by a crane or fork lift
- Interfaces to the Filter Loader to allow for hands-free loading of filters
- Includes purge gas system, including flow-control, filtering, and gas tank, for storage and handling outside the clean room
- Compatible with ISO Class 6 clean room, inside and out
- Re-cleanable inside and out
- Includes provision for external anchoring and support of all filters inside against Recoverable seismic loads
- Supports the filter using one of the interfaces defined in LCA-71, Filter Interface Definition Drawing

Bench-Top Stand:

- Supports any filter in the upright or flat orientation
- Provides a mechanism to rotate the filter from upright to flat, using either a crane or an internal rotation mechanism
- Includes provision for anchoring to the bench and support of the filter against Recoverable seismic loads
- Supports the filter using one of the interfaces defined in LCA-71, Filter Interface Definition Drawing
- Compatible with ISO Class 6 clean room
- Re-cleanable

Auto Changer Servicing Frame

- Stand for supporting the Auto Changer and keeping it clean when not in the Camera
- Fully sealable for cleanliness, with sides removable for access
- Re-cleanable for use in a class 1000 clean room
- Mounts/de-mounts to/from the Auto Changer during install/removal

Auto Changer Clamp Block

- Simulates the filter side of on-line and truck clamps, to allow for troubleshooting

Auto Changer Stand-alone control device

- Provide power feed
- Provide HCU with the FCS
- Provide the missing sensor signals coming from the other sub-sytems of the Filter Exchange system
- Provide the electrical connexion with the Auto Changer harness
- Operator consol

16.4. Access and Service Cryostat Contents in Clean Room

Re-commission and perform routine maintenance, cleaning, and refurbishment of the clean room and its contents. Open up part or all of the cryostat to service vacuum feedthroughs and seals, or to replace a raft tower or service the L3 lens.