GEMINI

8-M Telescopes Project

MCAO Beam Transfer Optics Requirements Document

MCAO Conceptual Design Review Material

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1. Introduction

1.1. General

The MCAO Beam Transfer Optics (BTO) is a subsystem of the Cerro Pachon Multi-Conjugate Adaptive Optics (MCAO) system. Very similar but not identical beam transfer optics subsystems are included in the Mauna Kea Laser Guide Star (MK LGS) system and the Cerro Pachon Hokupa'a Laser Guide Star (CPH LGS) system. This document describes the MCAO Beam Transfer Optics performance specifications and requirements.

1.2. Acronyms

AO	Adaptive Optics
AOM	Adaptive Optics Module
BTO	Beam Transfer Optics
CP	Cerro Pachon
LGS	Laser Guide Star
LLT	Laser Launch Telescope
MCAO	Multi-Conjugate Adaptive Optics
MCAO CS	MCAO Control System
MK	Mauna Kea
NGS	Natural Guide Star
SALSA	Safe Aircraft Localization and Satellite Acquisition System
WFS	Wavefront Sensor

1.3. Design requirements

Both Cerro Pachon and Mauna Kea will have the same overall BTO design.

The CP BTO will be designed in order to accommodate both the first-generation LGS AO system to be implemented at Cerro Pachon, (1) the proposed 85-element Hokupa'a South curvature system with a 2-W laser, and (2) the Multi-Conjugated Adaptive Optics system with 5 Laser Guide Stars and a total laser power of about 50 W.

Because the position of the laser system on the telescope is not yet known and could be different according to the laser(s) used, we will suppose in the following that the laser system output is located at the level of the telescope center section.

2. Performance requirements

2.1. Beam quality

The additional wavefront error due to the BTO must be compared to the additional wavefront error due to the atmospheric turbulence on the way up to the sodium layer. For r_0=15 cm @ 589 nm, this is 70 nm rms. Ideally, the BTO should not contribute more than the atmosphere to the degradation of the laser spots on the sky.

2.2. Transmission coefficient

The overall BTO transmission requirement at 589nm is equal or better than **0.8**. This value must be achieved on the telescope under routine conditions. The goal is 0.9.

The BTO should include as few mirrors and lenses as possible in order to optimize the overall transmission coefficient.

2.3. Laser beam alignment

The BTO must ensure that the 5 laser beams are always correctly aligned so that they overlap fully on the primary mirror of the Laser Launch Telescope with the correct overall propagation direction, and differential tilt angles of 42.5 arc seconds. Potential static and dynamic misalignment sources are telescope flexures vs. elevation angle, temperature changes, dome turbulence-induced beam jitter, etc.

2.4. Pointing accuracy & steering range on the sky

The 1-axis blind positioning accuracy on the sky is **1 arcsec**.

The 1-axis, 2-sigma pointing accuracy requirement for each individual laser beam is **0.05 arcsec on the sky, including atmospheric turbulence effects, @ 800 Hz**. If the LLT magnification is equal to G, then the 1-axis pointing accuracy requirement is G*0.05 arcsec for the BTO steering mirrors (e.g. for G = 300/5 = 60 this gives 3 arcsec = **15 mrad**).

There is no BTO steering range requirement on the sky for the MCAO system because there will be no dither mode.

3. Functional requirements

3.1. Beam path

The beams must be transferred from the output of the laser system to the input of the Laser Launch Telescope, along the telescope truss and over the (-X, +Y) vane. All beams must be hidden behind the 10 mm-large vane.

3.2. Beam size

The 99% encircled energy diameter of each laser beam will be kept smaller than 10 mm.

There will be two or more lens assemblies along the laser path to re-image the laser output pupil, re-collimate the beams and compensate for their natural divergence. The baseline is that the beams are delivered to the LLT with a 99% encircled energy diameter equal to about 8 mm at the input of the LLT. A goal for the lens assemblies is to act as a zoom lens in to adjust the diameter of the beams at the LLT input and optimize the LGS spot sizes at the sky.

3.3. Reflection angles

Whenever possible reflection angles on BTO mirrors will be close to 45 degrees in order to use off-the-shelf optical coatings and preserve laser beam polarization.

3.4. Heat dissipation

The BTO elements, such as optical surfaces heated by the powerful laser beams and miscellaneous electronics mounted on the telescope and used to operate the BTO, should dissipate less than 10 W into the air. The beam dump mounted on the Gemini telescope top-end ring should also dissipate less than 10 W.

3.5. Polarization

The mirror coatings will be chosen so that they preserve the laser circular polarization. However, due to differences between the reflection coefficients for s and p polarization and because of reflection angles different from 45 degrees, a beam beginning with circular polarization at the center section level will become elliptically polarized at the top end. The shift in polarization must be calibrated once (assuming that the laser system is mounted on the telescope, the shift is independent of the telescope elevation angle). A quarter-wave-plate located at the output of the laser will correct for the polarization ellipticity by introducing the opposite amount of ellipticity in the beam, so that the polarization remains circular at the top-end.

3.6. Shutters

3.6.1. Safety shutter

A fast shutter (safety shutter linked to the MCAO SALSA subsystem) must be implemented at the output of the laser system. The shutter must be able to shut down the laser radiation faster than **0.1 s**.

3.6.2. Power shutters

Beyond blocking the beam when aircraft are detected, two "power shutters" (if possible one of them will be the same shutter as the safety shutter) will be used routinely whenever the LGS MCAO loop is not closed or ready to be closed. (For example, it would be convenient to block the beam when slewing the telescope from one science field to another.) The MCAO CS will provide control of both power shutters.

The first power shutter will be located at the interface between the Laser System and the BTO to allow running the laser without having the beam go through the BTO path. The second shutter will block the beam before it enters the LLT so that it is possible to run the whole system without propagating to the sky. These shutters will be able to absorb the full power of the beams indefinitely, with no degradation to dome seeing once the beams have been unblocked for 5 minutes.

3.7. Beam shielding

3.7.1. Safety issue

The laser beam must be enclosed at least at the origin of the BTO, where the beam propagates at eye level for someone walking on the access platform.

3.7.2. Turbulence issue

It would be preferable to not enclose the entire beam path to the top end, so that turbulence in the beam is flushed by the dome vents. If the laser path must be enclosed, the tubes must be air-flushed to prevent turbulence from stagnating. Note that in such a case, the vibrations created by the beam path conditioning system must be controlled.

3.7.3. Light scattering issue

The BTO will be designed so that the light scattered in the dome, and especially in direction of the science path, is minimized.

The Baseline approach is to use demi-tubes to shield the beam in direction of the telescope, without having to flush air along the beam path.

3.8. Mirror covers

All mirrors and BTO optics must be protected from dust by appropriate covers when the system is not in use. The covers will be designed so that they are retractable and remotely controlled by the MCAO Control System.

3.9. Control and electronics

3.9.1. Pointing and centering loops along the laser path

The control of the beam propagation will be done automatically, independently of the telescope observer. This task belongs to the MCAO CS. It will receive the signals from beam position sensors and send command to the mirrors.

Whenever possible, position sensors will use light transmitted through the mirrors instead of intercepting the beam with pick-off elements.

The sampling rate for “slow” tip/tilt corrections (due to telescope flexures and vibrations + slow laser beam pointing drifts) will be **10-20 Hz**.

3.9.2. Laser pointing on the sky

The BTO includes an array of 5 fast tip/tilt mirrors to correct for differential turbulence jitter introduced on the way up to the sodium layer.

The fast tip/tilt mirrors receive data from the Adaptive Optics Module via the MCAO Control System. The sampling rate requirement is **800 Hz**, with a goal of 1 kHz.

3.10. Beam diagnostics

The beam diagnostics are located on the Gemini telescope secondary frame before the laser beams reach the LLT.

The following parameters are measured continually for each of the 5 laser beams:

(i) the beam near-field (includes beam positions/centroids, and if possible beam profiles + beam quality diagnostics). The information on the beam positions will be used to control beam centration on the LLT pupil. Sampling rates are 10-20 Hz for the beam positions and a few times a minute for beam profiles.

(ii) the beam far-field (includes tip/tilt measurements, and if possible far-field profiles, beam widths, and beam quality diagnostics). The information on the beam tip/tilt will be used to control beam pointing angles at the LLT primary. Sampling rates are 10-20 Hz for the beam angle measurements and a few times a minute for beam profiles.

Note that sampling rates should be reviewed when more information is available on the telescope vibration modes and amplitudes.

(iii) a power meter to measure beam powers on the top end

(iv) a polarization sensor to measure the laser beams polarization.

3.11. De-rotation optics

The BTO must include de-rotation optics to compensate for the rotation of the X-shaped LGS constellation on the sky when the Gemini telescope is tracking.

4. Operation requirements

The BTO operational requirements are described in the MCAO Operational Concepts and Definitions Document.

5. Integration and tests

All BTO elements will be integrated and the BTO performances tested in the lab. All control loops and other automated elements will be tested along with the parts of the MCAO Control System dealing with the BTO.

Once the BTO has been integrated with the telescope, it will be possible to align and calibrate the system using a Natural Guide Star for comparison.

6. Requirements summary

Requirement	**Specification**
Optical Wavefront Quality - Mirror optical surface quality - Lens optical transmission quality	 λ/40 rms (TBReviewed) λ/50 rms (TBReviewed)
Optical Efficiency	> 0.8 (goal=0.9)
Polarization	Preserve circular polarization
Heat dissipation	<10 W for BTO and LLT elements mounted behind the secondary mirror < 10 W for the beam dump mounted on the top-end ring
One-axis blind positioning accuracy	Peak one-axis error < 1 arcsec on the sky
One-axis pointing accuracy @ 1 kHz	0.05 arcsec RMS (TB Reviewed) on the sky for each beam
Range of steering	Mirror controls should not direct beam outside of designated beam path.
Fast tip/tilt mirrors sampling rate	800 Hz, with a goal of 1 kHz
Slow tip/tilt mirrors sampling rate	10-20 Hz
Beam diagnostics for each of 5 beams	Beam alignment, beam profiles (near and far-field) and beam quality Beam power (calibrated) Beam polarization
Miscellaneous functionalities	Safety shutter and power shutters Beams hidden behind the secondary vane Beam shielding Mirror covers De-rotation optics