Vibration control of ELTs

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Abstract. MPIA is the PI-institute of the MCAO-supported Fizeau-imager LINC-NIRVANA at the LBT, and a partner of the E-ELT first light NIR imager MICADO (both SCAO- and MCAO-assisted). LINC-NIRVANA is a true pathfinder for future ELT-AO-imagers both in terms of size and technology. We present our vibration control strategies, involving accelerometer based real-time vibration measurements, feedforward- and feedback optical path control, predictive filtering, resonance insensitive active control of actuators, and the development of a dynamical model of the entire telescope. Our experiences, made with LINC-NIRVANA, will be fed into the MICADO structural AO design to reach highest on-sky sensitivity.

1 Introduction

To push our knowledge of the universe, ever larger and more complex telescope systems are being build to increase both the light collecting and resolution power. Light-weight construction and numerous optical elements are needed to realize primary and synthetic aperture diameters beyond the current 8m class telescopes. This results in fast mirror vibrations of amplitudes comparable to or larger than the observing wavelengths. If such vibrations remain uncorrected, the performance of the astronomical measurement will be severely corrupted.

The LINC-NIRVANA instrument of the LBT [1] suffers, as adaptive-optics assisted Fizeau imager, both from mechanical tip-tilt and piston vibrations beyond the atmospheric phase noise power spectrum [2]. In this article, we present in the following sections two different projects of ours to minimize the residual piston vibration seen by the interferometer. In Sect. 2, the active control of the piston actuator is discussed, which supresses self-induced vibrations while moving the mirror. Our custom solution for the piston mirror control can be conceptually similarly applied to any other large, fast-moving mirror (e.g. a deformable mirror used in adaptive optics systems, [3]) to improve speed and precision, and to minimize disturbance of neighboring optical elements. Sect. 3 discusses details of our strategies to control the optical path vibrations along the LBT optics. A dedicated accelerometer network monitors the 3d motion of involved mirrors. Eventually, in Sect. 4, we briefly discuss how we plan to use similar strategies to optimally supress tip-tilt vibrations of future AO systems to help sensitive wavefront sensing.

2 Resonance insensitive active control: The LINC-NIRVANA piston mirror

The central beam-combining element of LINC-NIRVANA is the so-called piston mirror (PiMi), which folds the individual beams, coming from each side of the LBT, towards the common focal plane in the cryostat (Fig. 1). Moving the piezo-driven actuator back and forth shortens the optical path of one or the other of the two LBT telescopes. However, fast piston correction beyond a few tens of Hertz excites resonance modes of the mirror mount.

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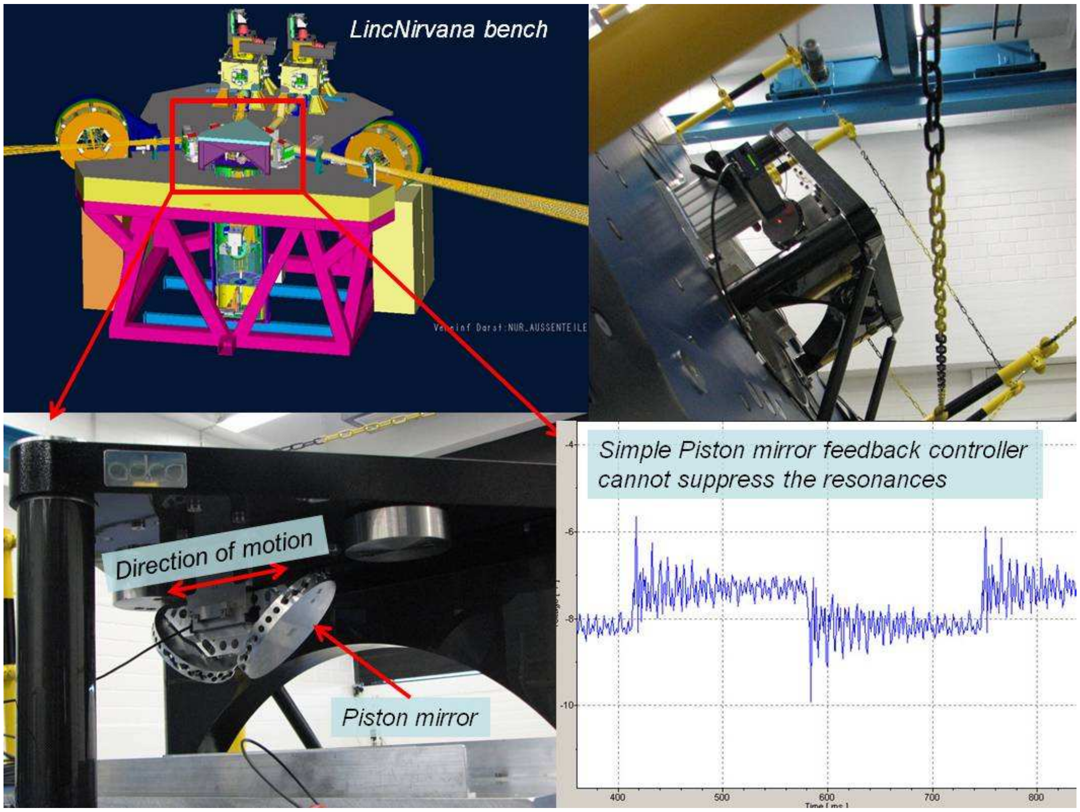

Fig. 1. *Upper left:* Overview sketch of Linc-Nirvana; *Lower left:* mounted PiMi in the lab; *Upper right:* testing the resonance behaviour with a laser vibrometer on tilted bench; *Lower left:* shown is the recorded motion of the PiMi surface induced by a clean step signal. Standard proportional-integral (PI) feedback control gives poor performance due to the resonances of the mirror mount, starting at 76 Hz.

The large (1arcmin) size of the MCAO corrected field of Linc-Nirvana requires, that the PiMi is relatively large. To enable fast motion, we custom designed and manufactured a light-weight, but stiff aluminum mirror (AlSi40). The final dimensions (200x145 mm surface) and 3.2 kg of the movable part are still a challenge for the precise motion. The custom mount (the black triangular table-like carbon fiber reinforced plastic (CFRP) structure in Fig. 1), has various stiffening elements, the first resonance, excited by the moving mirror is at about 76 Hz. Several resonances are apparent in the mirror response to a step signal in the lower right of the figure. Here the mirror-piezo is controlled by a simple PI controller. Using adequate low-pass filter to avoid the exitation of resonances of the loaded mirror mount would render the performance of the PiMi below the required bandwidth of 100 Hz.

Since the piezo stage was chosen to be fast and powerful enough to enable bandwidths of a few hundred Hz, the problem can be solved by designing an adequate controller for the piezo stage. We chose a combined feedback-feedforward controller design. The feedforward part essentially inverts the previously identified resonance behaviour of the mounted PiMi surface, which then allows a classical PI-feedback loop to control the piezo position (Fig. 2). The controller has been realized on a dedicated, programmable DSP.

The described control strategy allowed us to actuate the PiMi with a settling time of 10ms and a corresponding peak-to-peak error of $\leq$ 17%. We verified that the mirror mount is stable against the changing gravity vector, when tilting the optical bench, simulating telescope behaviour (Fig. 1). The change of resonance behaviour is minimal when tilting the bench to 70deg from zenith, and the controller is robust enough to handle this change. Furthermore, the temperature sensitivity was verified. Runnig the piezo in a climate chamber at telescope operation conditions (-15 .. 25 degC) showed that

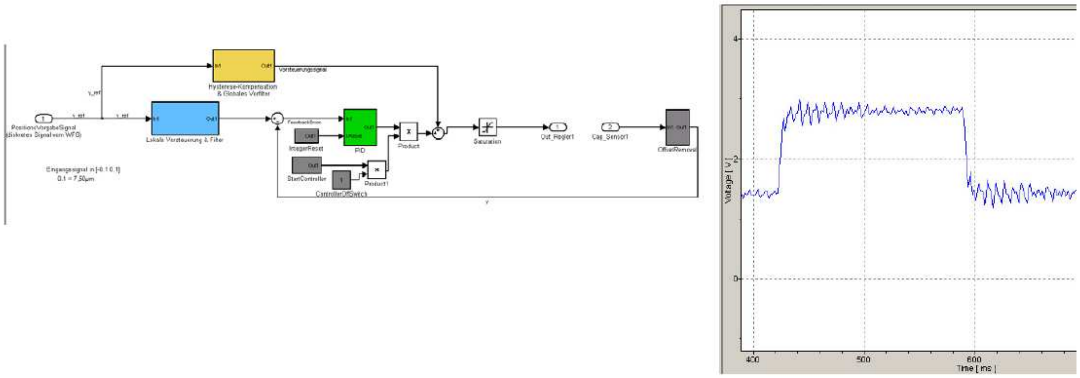

Fig. 2. *Left:* Block diagram showing the combination of feedforward (yellow, blue) and feedback (green) elements in the design of the PiMi controller. *Right:* Measured performance is now within spec with significantly suppressed surface vibrations and a settling time of order 10ms.

the zeropoint of the capacitive position sensor needs to be carefully chosen to accomodate for such a large range of temperatures. The temperature coefficients of the CFRP material of the mirror mount is not expected to show significant changes within that range, but the controller is also robust enough to handle modest modifications of the resonance behaviour.

Summarizing, we can report that an adequate combination of feedback and feedforward control elements allows fast and precise actuation of control mirrors at precision levels adequate for NIR-AO. Since the actuator size is expected to rise with the telescope size, similar strategies might be necessary for large, fast tip-tilt correctors.

3 Optical pathlength vibrations at the LBT

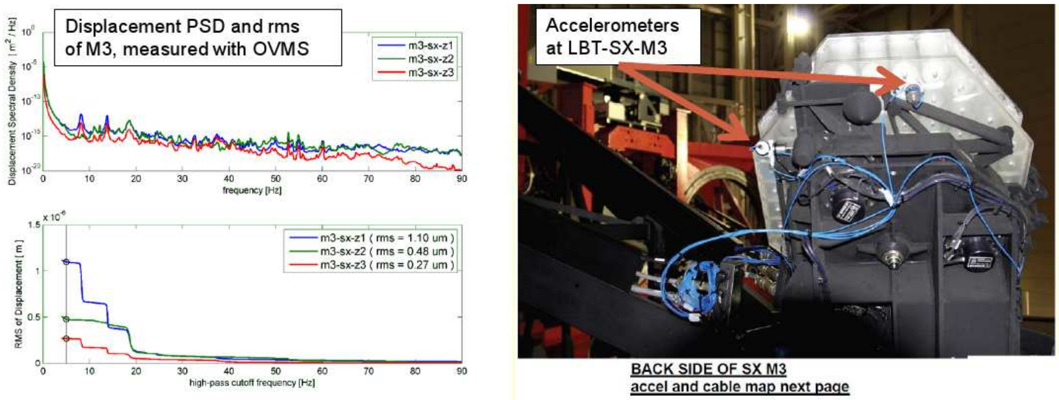

Fig. 3. *Left:* M3 displacement power spectral density and displacement rms, integrated from the given frequency to infinity; clear resonances below 20 Hz are visible, and require correction. *Right:* Accelerometer mounted on the backside of M3, which show the signals plotted in the left panel.

Within the LINC-NIRVANA project, we realize an accelerometer-fed feedforward control to reject telescope tip-tilt vibration. The optical path difference and vibration monitoring system (OVMS) includes 45 sensitive broad -band (0.7-450 Hz) accelerometers [4]. Our primary goal is to sense the OPD-relevant vibrations and correct for this in feedforward, so that the fringe sensor mostly sees the slower atmospheric piston changes. First telescope data of the system is shown in Fig. 3. The goal is a residual OPD noise of less than 100nm, which equals $\lambda/10$ at the shortest scientific observing wavelength. The data shows, that this level is reached beyond 50 Hz, but that significant mirror vibrations happen at lower frequencies (Fig. 3, left). Such vibrations could be measured and tracked by the Linc-Nirvana fringe tracker when reading the detector with a few hundred Hz on natural guide stars. However, to push the limiting NIR magnitude of the fringe tracker to 14, longer detector integration times are required, compliant with the slow atmospheric piston noise at Mt. Graham, which has most power below 10 Hz. OVMS will be implemented to allow for such longer integration times.

Having five accelerometers per mirror will allow us to sense all five relevant solid body motion degrees of freedom. In 2012, we will have identification campaigns at the LBT, and (induced) mirror vibrations will be monitored in parallel by the OVMS, and an optical vibrometer. Goal of these campaigns is to derive a reliable mapping of the accelerometer data to the final OPD, which will be the basis of the OVMS feedforward controller.

4 Accelerometer measured Tip-tilt feedforward for AO control: testing concepts for Micado

A natural adaption of the OVMS-like vibration control can be applied in the similar case of vibration induced tip-tilt noise seen by adaptive optics systems' wavefront sensors. The high-frequency tip-tilt noise derives from mirror vibration. In today's generation of adaptive optics controllers, it is corrected for by starlight-fed wavefront sensors (WFS). We currently study in the laboratory the efficiency of accelerometer-fed feedforward control, including concepts of predictive filtering. The scientific goal is, like in the previous section, to allow for longer WFS integration times, and thus fainter guide stars, by correcting mirror tip-tilt vibrations without starlight.

The results of these studies will be used in the structural design process of the AO-facilities of Micado. Diffraction-limited NIR-images with Micado, planned for the E-ELT [5], will be supported by early single-conjugate AO-correction [6] and later by MCAO, correcting the entire field-of-view of 53" diameter [7].

References

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