Variable Curvature Mirrors

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Since the very beginning of the VLTI project, it has been foreseen that observations with this unique interferometer should not be limited to on-axis objects and the possibility to have a “wide” field of view (2 arcsec) was planned. It turned out that the “wide” field of view goal could not be achieved without a precise pupil management.

A variable-curvature mirror system (VCM), tertiary mirror of the delay line cat’s eye, has been developed for this pupil management purpose. While the VLTI is tracking an astronomical object, the delay line provides for the equalisation of the optical path of the individual telescope by varying positions in the interferometric tunnel, and the VCM variable focal length permits positioning of the pupil image at a precise location after the delay line.

The range of radii of curvature required for the VCM is determined by the position of the delay lines. The two major parameters for the determination of this range are (1) the distance between the position of the pupil image following the coudé optics and the entrance of the cat’s eye and (2) the distance between the exit of the cat’s eye and the required position of the pupil image in the recombination laboratory. Considering the field of view planned for the VLTI (2 arcsec) and the OPD (optical path difference) to compensate for, the cat’s eye secondary curvature must be continuously variable within a range from 84 mm^{-1} to 2800 mm^{-1} for the various configurations of 8-m Unit Telescopes and Auxiliary Telescopes.

Table 1: Required and achieved optical surface quality for the VCM.

• <u>For radius 2800 mm:</u>	
Required performance:	λ/4 PTV over ∅ 5 mm
Design Goal:	λ/10 RMS over ∅ 14 mm
Achieved performances:	λ/6.5 PTV over ∅ 5 mm λ/10.6 RMS over ∅ 14 mm
• <u>For radii in the 230–2800 mm range:</u>	
Required performance:	λ/2 PTV over ∅ 5 mm
Design Goal:	λ/2 PTV over ∅ 14 mm
Achieved performances:	λ/2.8 PTV over ∅ 5 mm
• <u>For radii in the 84–230 mm range:</u>	
Required performance:	3λ/4 PTV over ∅ 5 mm
Design Goal:	λ/2 PTV over ∅ 14 mm
Achieved performances:	λ/2.5 PTV over ∅ 5 mm

Realisation of the Mirror

The Optical Laboratory of Marseille Observatory (Laboratoire d’Optique de l’Observatoire de Marseille, LOOM) was selected for the design and realisation of this special device, because of its expertise in the active optics domain.

The location of the VCM in the delay-line system, on the piezo-translator used for small OPD compensation, led to minimise its weight and to realise a very small active mirror with a 16-mm diameter. The range of radii of curvature, with such a small optical aperture, corresponds to *f* ratio from plane to *f*/2.5, and the maximal central flexion achieved is 380 microns.

In the VCM system, presented with its mounting in Figure 1, the curvature is obtained with a uniform loading applied on the rear side of the mirror and produced by a pressure chamber. In order to use easily achievable pressure (<10 bar), the active part of the system is a very thin meniscus with a 300-micron central thickness.

Due to the large bending of the mirror, the full domain of curvature is not achievable with a classical optical material as vitroceramic glass (Zerodur). Metal alloys having 100 times higher flexibility than glasses, a stainless steel substrate (AISI 420) was chosen for the realisation.

Figure 1: Variable Curvature Mirror mounted and unmounted with its support. The active part is a very thin (300mm) meniscus and the deformation is achieved with a uniform air pressure applied to the back side of the mirror. The optical aperture is 16 mm.

Optical performances of the VCM

The VCM optical surface quality requirements were really tight for such an active mirror.

A careful analysis of the meniscus deformation, using theory of large amplitude elastic deformations, allowed to fulfil with success these requirements as presented in Table 1 and Figure 2.

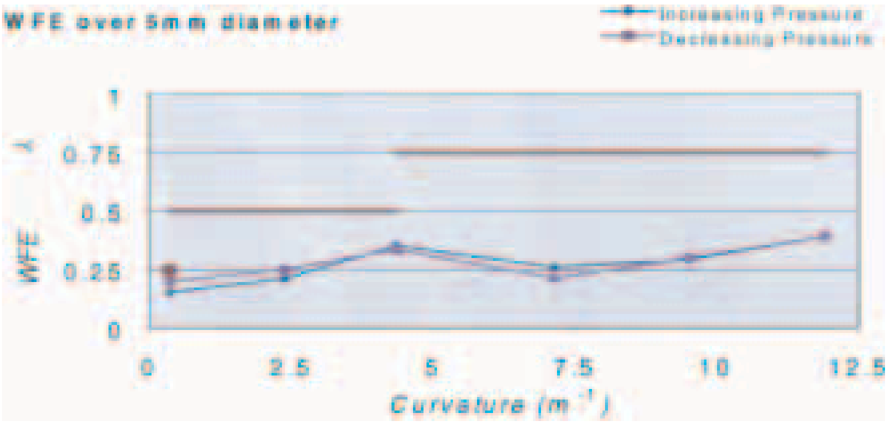

Figure 2: VCM optical surface quality over a 5-mm diameter. The wavefront error (WFE) is given as a peak-to-valley (PTV) in fraction of λ.

Figure 2 presents the optical quality (PTV) achieved with one of the VCM mirrors on the whole curvature range, compared to the required performances.

On the central part of the VCM, 5 mm diameter, analysis shows that the deviation from a sphere remains below λ/2 ptv during the whole curvature range (2800–84 mm).

Curvature Control Accuracy

The other important point, related to the pupil positioning in the interferometric laboratory, is the adjustment of a precise curvature during the operation of the VCMs.

In order to achieve a precise curvature, the air pressure on the back side of the mirror is controlled on open loop with a 5.10^{-4} accuracy in the 0–10 bar range. This high accuracy on the pressure control has been combined with an "hysteresis" model for the meniscus deformation. The effect is present only during the phase of decreasing pressure and depends on the maximum pressure reached during the cycle.

The model allows to take into account the history of the mirror and computes the right pressure to achieve the required curvature. An output of the model is presented in Figure 3 where ΔP is the correction to be applied (to correct for the hysteresis effect) as a function of the maximum pressure reached during the cycle.

Using the high-accuracy pressure control and the hysteresis model, the resulting error on the VCM curvature is less than 5.10^{-3} m^{-1} and leads to a 15-cm pupil position accuracy in the interferometric laboratory.

The error on the pupil position will be reduced by the beam compressor system, located at the entrance of the laboratory, to less than 1 cm at the instruments entrance and this value has to be compared with the 70 metres stroke of the delay line carriage.

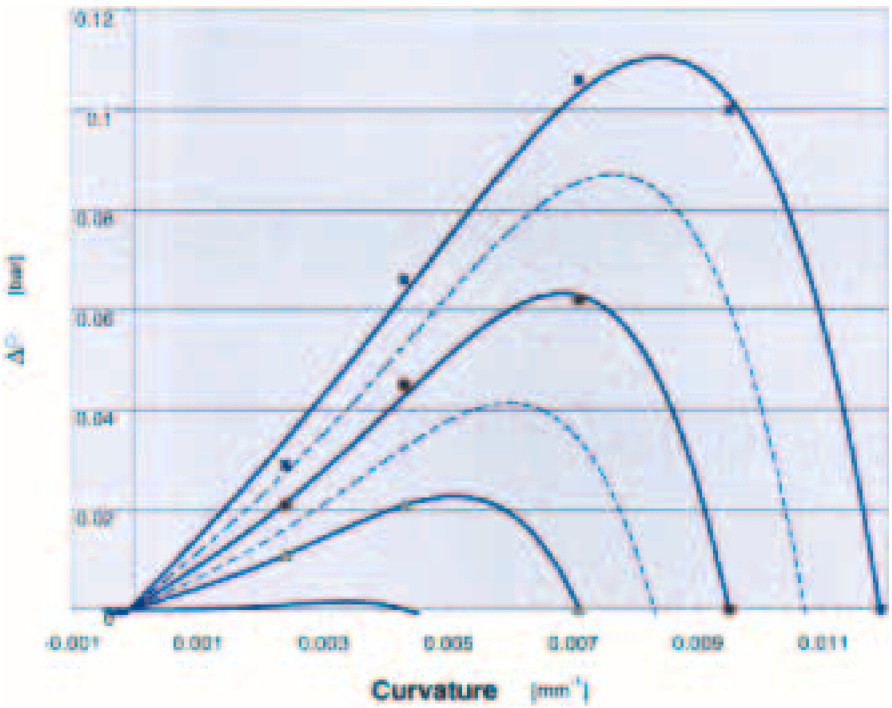

Figure 3: Correction to be applied to correct for the hysteresis effect. The lines represent the hysteresis model and the dots the measured values for various maximal pressures reached during a cycle.

Conclusion

This is not the first time that such an optical device, a varifocal mirror, has been achieved. But this one, thanks to the expertise of the team in Marseille Observatory, has an exceptionally wide range of curvature combined with a very good optical quality and a high curvature accuracy. This will allow the VLTI to deliver a good entrance pupil to the interferometric instruments.

Today this VCM has been delivered to ESO and is being included in the delay lines in order to set up and calibrate the interfaces with the other devices of the interferometric mode. The integration will be done during this year, the first complete systems (delay lines with VCMs) will be installed on Paranal during the year 2000.

The VLTI Test Siderostats Are Ready for First Light

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To allow the technical commissioning of the VLTI in its early phases, without the VLT Unit Telescopes or the Auxiliary Telescopes, two test siderostats have been developed to simulate the main functions and interfaces of these telescopes.

The principal objective of the optical concept (Fig. 1) of the siderostat is to optimise the collecting area over a sky coverage defined by the scientific targets chosen for the commissioning of the VLTI with the test instrument VINCI and the IR instrument MIDI. The diameter of the 400-mm free aperture of the Alt-Azimuth siderostat has been chosen to allow the observation in the N Band of all MIDI targets (Table 1). The angles between the different mirrors are optimised for the latitude of Paranal. To simulate the 80-mm diameter pupil size of a Unit Telescope,