BRISE: a multipupose bench for cophasing sensors

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ABSTRACT. *The cophasing sensor (CS) measures the disturbances between the sub-apertures of multiple-aperture telescopes. As telescopes become more ambitious, CS have to cope with low flux, sub-nanometric accuracy, extended objects, larger number of beams. Focal-plane sensing is a solution for all these requirements, with a very simple opto-mechanical setup. To evaluate accurately the performance of CS or other high-resolution devices, ONERA has built a multipurpose bench called BRISE (Banc Reconfigurable d'Interférométrie sur Sources Etendues) and a software MASTIC (Multiple-Aperture Software for Telescope Imaging and Cophasing). BRISE has already been used for several applications, such as the validation of CSs for Earth imaging or nulling interferometry. BRISE and main results are described in this paper.*

RÉSUMÉ. *Le capteur de cophasage (CS) mesure les perturbations entre les sous-pupilles d'un télescope multi-pupilles. Ces télescopes devenant plus ambitieux, les CSs doivent concilier faible flux, précision sub-nanométrique, objets étendus et grand nombre de faisceaux. La mesure en plan focal est une solution, avec un dispositif opto-mécanique très simple. Pour évaluer précisément les performances de CSs ou d'autres dispositifs à haute résolution, l'ONERA a construit le banc BRISE (Banc Reconfigurable d'Interférométrie sur Sources Etendues) et le logiciel MASTIC (Multiple-Aperture Software for Telescope Imaging and Cophasing). BRISE a déjà été utilisé pour plusieurs applications, comme la validation de CSs pour l'imagerie de la Terre ou l'interférométrie en frange noire. BRISE et ses principaux résultats sont décrits dans ce papier.*

KEYWORDS: *interferometry, wave-front sensing, cophasing, phase retrieval, phase diversity.*

MOTS-CLÉS : *interférométrie, analyse de surface d'onde, cophasage, diversité de phase.*

1. Context

Multiple-aperture optical telescopes are considered for high-resolution needs, such as Earth imaging from space (Mugnier *et al.*, 2004) or astronomy [DARWIN or its precursor (Le Duigou *et al.*, 2006)]. The Cophasing Sensor (CS), measuring aberrations for their real-time correction, is a critical component. CSs are most often operated in pupil-plane on unresolved source, in a pair-wise mode, and with non-common paths. Putting many CSs together leads to a strong complexity. Another solution is to use a single CS that can measure simultaneously all the modes of interest over all the sub-apertures, for any kind of objects. This is possible with a focal-plane sensor, intrinsicly providing interference between all the sub-apertures. Focal plane techniques are *Phase retrieval*, using data from the sole focal plane (assuming a known object) and *Phase diversity*, using additional extra-focal data. Phase diversity is one of the very few interferometric techniques that can be operated on an extended object.

To test such CSs, ONERA has designed in 2002 BRISE (Banc Reconfigurable d'Interferométrie sur Sources Etendues) for an Earth imaging study (Mugnier *et al.*, 2004). It was built in 2003 and is operated since 2004.

2. The BRISE bench

BRISE is mainly composed of six sub-systems: the source delivers an extended scene EXT and a reference point source REF; the perturbation module images the source on the CS, defines the aperture configuration and introduces calibrated aberrations with a deformable mirror (DM); the CS module records focal or extra-focal images of the two objects ; the control module drives the experiment; the software module MASTIC (Multiple-Aperture Software for Telescope Imaging and Cophasing (Mocœur *et al.*, to be submitted)) is used for data reduction, with phase retrieval or phase diversity. Afocal input/output ports allow easy interface with "visitor instruments" like our Zygo interferometer (Fig. 1). The spectral band currently used ([0.55 ; 0.83] μm) is limited by the refractive components in the CS module, but the all-reflective bench will be operated soon in the IR. BRISE and the CSs are detailed elsewhere (Cassaing *et al.*, 2006b).

Special care has been taken for the control of phase disturbances. EXT and REF are observed simultaneously through very close paths. BRISE is enclosed inside a wooden hut in a temperature-controlled room. All the electronics and sources are located outside the hut. A metallic baffling minimises volume around the beams. Active pneumatic supports isolate BRISE from vibrations.

3. Experimental results on BRISE

BRISE has been used to test DWARF (DarWIn AstRonomical Fringe sensor, developped for ESA by Kayser-Threde/ONERA/Alcatel Space). DWARF is a phase

Parameter	Value
Full spectral band	[0.4 ; 1] μm
Field of EXT object	≃250x250 pix
Full-aperture diameter	B=60 mm
Aperture configuration	3x(D=20) mm
Perturbation amplitude	$\simeq \pm 4$ μm
Camera field	1317x1035 pix
Beam height	160 mm

Figure 1. *Left: Photograph of BRISE (right side) with the Zygo interferometer (center) and the visitor DWARF (left side). Right: main current characteristics of BRISE.*

retrieval/diversity CS defined at ONERA, manufactured by Kayser-Threde. Tests for piston/tip/tilt/defocus and astigmatism where carried on BRISE (Mocœur *et al.*, 2006).

BRISE will also be used for Pegase, the DARWIN precursor proposed by IAS and CNES (Le Duigou *et al.*, 2006). R&T programs are currently ongoing at ONERA to define the fine cophasing loops (piston and tip/tilt). Prototypes will be manufactured/tested and included in a future breadboard to demonstrate on-ground stable wideband nulling using only light from the observed source (Cassaing *et al.*, 2006a).

BRISE has also been used to test a phase-diversity CS for Earth observation. Fig. 2 presents, as a function of the piston introduced by the DM, the piston on one sub-aperture measured using EXT (illuminated around $\lambda_e = 650$ nm with a 40 nm width) and using REF source ($\lambda_r = 633$ nm). REF is not used by the phase diversity, but just as a reference to validate results. REF measurements exhibit a good linearity with the expected 2π wrapping. With EXT scene, the slope is not exactly unity and a kind of saturation appears near $+\lambda_e/4$, interpreted as a consequence of the spectral bandwidth. But these two issues are not relevant for closed loop operation. Fig. 2 also shows the repeatability obtained on the piston measurement with EXT. As expected, the standard deviation of the estimated piston is inversely proportional to the square root of the number of photons per pixel (photon-noise regime) and dominated by detector noise for low fluxes. It is below 1 nm when the average flux is above 1000 photo-electrons per pixel, showing that cophasing is possible in usual conditions.

BRISE is currently used for nulling investigations. In the framework of an ESA contract led by Kongsberg, the coupling (amplitude and phase) of distorted wavefronts in single-mode fibres will be measured experimentally for different amplitudes and Zernike modes. And last, although it has never been designed for nulling, BRISE offers the unique feature of combining 3 beams with independent piston/tip/tilt control. We took advantage of this to make what we believe to be the first 3-beam nulling test. With a very quick setup (multi-axial combination of the 3 beams in a single-mode fibre) and a single scan, a null of 100 has been reached around λ=635 nm.

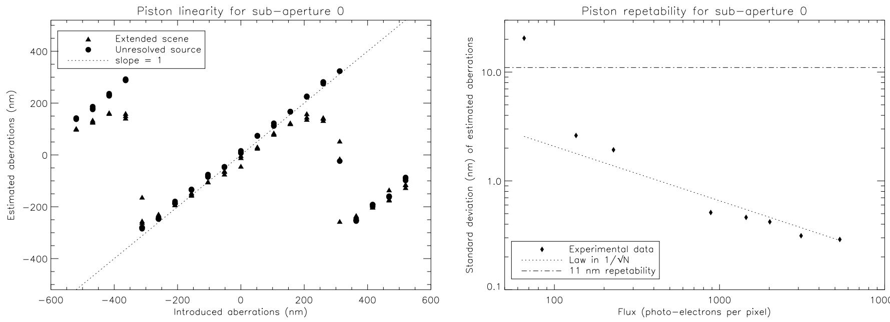

Figure 2. *Measurements with the extended object. Left: Piston measured on one sub-aperture versus the piston introduced by the deformable mirror. Right: Repeatability of the piston measured on one sub-aperture versus the average flux per pixel.*

4. Conclusion and perspectives

The BRISE test bench has validated nanometric phase retrieval and phase diversity for the measurement of Zernike modes from piston to spherical aberration on a three apertures configuration with unresolved or extended sources. Focal-plane fringe-sensing is thus a simple solution which can be easily implemented in future interferometers for astronomy or Earth imaging.

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