MOTION OF THE DELAY LINES OF AN OPTICAL INTERFEROMETER WHEN RECONSTRUCTING AN IMAGE BY REDUNDANT SPACING CALIBRATION

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Abstract. In an optical interferometer, the delay lines compensate the optical path difference between the different arms of the interferometer, so that the interference patterns, which contain the information, can be observed. Thanks to the phase closure technics, the phase information can be extracted, despite the random phase shifts introduced by the atmospheric turbulence. As we used the redundant spacing calibration to reconstruct an image, the telescopes of the interferometer have to be arranged according to a given iterative procedure. The advantage of this technics is to enable the reconstruction of an image without any a priori knowledge on the object. But this implies constraints on the configurations of the telescopes array, and therefore on the offsets and on the kinematics of the delay lines. Their motion have been studied to define the future layout of the 3 telescopes optical interferometer of the Calern's Observatory (CHARON III project) and also to define the operational procedure.

Key words: interferometry - image reconstruction

1. Introduction

CHARON III (Calern High Angular Resolution Optical Network) is a three telescopes optical interferometer project at the "Observatoire de la Côte d'Azur". This interferometer is intended to work at visible wavelengths. An intermediate step of this project already exists and is called CHARON-II. It is composed of 2 telescopes (26 cm of diameter; alt-alt mount) based on a north-south horizontal baseline. The northern delay line is fixed, while the southern one is movable with a translation stroke of 1 m. The project consists in introducing a third base, on the west direction of the array. The third delay line, whose reflection's device is a cat's eye, would have a translation stroke of 3 m.

The aim of the project is to build a prototype to demonstrate the feasibility of image reconstruction with phase closure methods in order to prepare the future large projects like the ESO Very Large Telescope (VLT). For CHARON III the stroke of the delay line are only 1 and 3 m for the southern and the western arms respectively. This drawback is compensated by introducing large delay offsets. The physical constraints on the motion of the delay lines have been studied to see if all degrees of freedom necessary for the image reconstruction are available.

2. Method of image reconstruction

In order to reconstruct a two-dimensional image, we need the information on the modulus and on the phase of the object's Fourier transform. The phase closure technics allows to recover the phase information on the object, despite the random phase shifts introduced by the atmosphere. In order to reconstruct an image without a priori knowledge on the object, we use the method of "Redundant Spacing Calibration" (RSC) (Cruzalèbes, 1992), to recover the spectrum from the bispectrum.

The raw data are photo-events. We compute the bispectrum of each frame and then we integrate the different bispectra. This operation eliminates the atmospheric phase perturbations, since each bispectrum phase corresponds to a phase closure (Roddier, 1986). In this study, we have

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considered 43 different configurations allowing a complete coverage of the (U,V) plane. Expression of the bispectrum:

$$\tilde{I}^3(u,v) = \tilde{I}(u)\tilde{I}(v)\tilde{I}^*(u+v) \tag{1}$$

where u and v are the two-dimensional spatial coordinates in the Fourier plane.

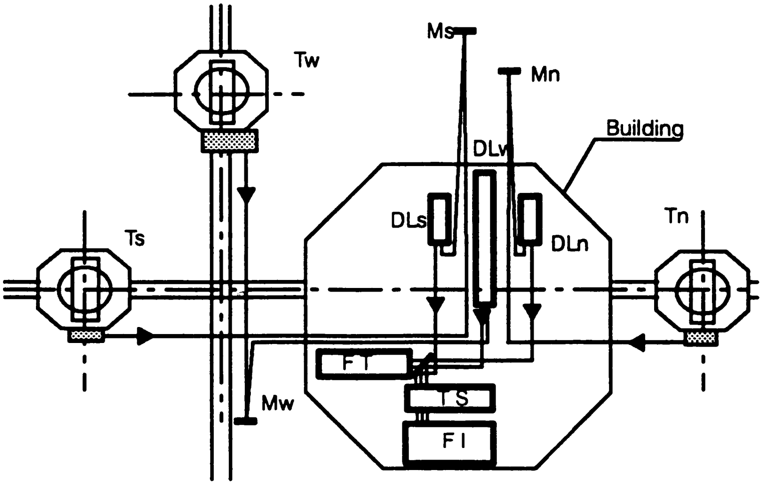

Fig.1: Layout of the CHARON III project (FT = fringe tracker, TS = tilt sensor, FI = focal instrumentation)

We consider the case of three small apertures, where each configuration of the array of the telescopes provides only one closure phase γ_{ijk} given by:

$$\gamma_{ijk} = \phi_{ij} + \phi_{jk} + \phi_{ki} \tag{2}$$

where ϕ_{ij}, the individual measured phase corresponding to the paires of the apertures (ij), are a combination of the object phases θ_{ij} with the random phase shifts of the atmosphere α_i and α_j according to the relation:

$$\phi_{ij} = \theta_{ij} + \alpha_i - \alpha_j \tag{3}$$

Each pair of apertures selects only one specific spatial frequency described by a frequency vector. With n apertures, the number of unknown spatial frequencies is n (n-1)/2 and the number of independent phase closure relationships is only (n-l)(n-2)/2. The equations set has to be solved to recover the spectrum from the bispectrum. In redundant spacing calibration, one introduces redundant frequencies to reduce the number of unknowns. The order of redundancy is defined as the number of different baselines which gives the same spatial frequency. It can be an internal redundancy (within a same configuration) or an external redundancy (between different configurations).

3. The CHARON III interferometer project

Fig. 1 shows the layout of the CHARON III project. The baselines cross outside the building, to allow a very short base length between the southern and western telescopes.

The optical layout is such as there is no differential field rotation between the three beams at the coherent focus, during the earth rotation. Each delay line (DL) is composed of a movable part DLn, DLs and DLw, and a part providing a constant offset, made up of the mirrors Mn, Ms and Mw. Those mirrors are located on slots, and can be moved from one configuration to an other one.

In a cophased interferometer the optical path difference between the different light beams must be equal to zero. This is achieved by the delay lines, whose translation strokes limit the observing duration and influence the strategy for the image reconstruction.

4. Motion of the delay lines

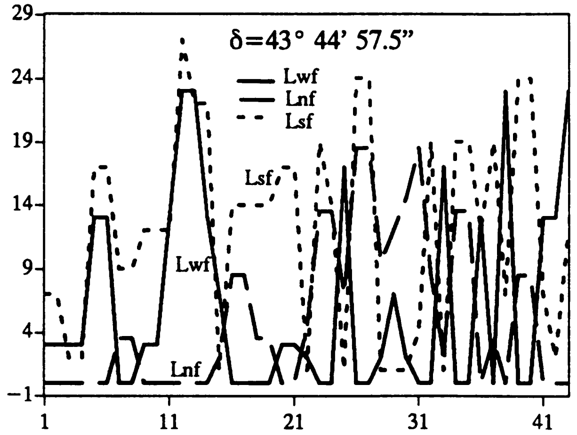

Fig.2 : Variation of the position of the fixed delay lines with the 43 configurations.

In this study, the maximum length of the baseline considered is 50 m in the north, 40 m in the south and 30 m in the western arm. This corresponds for the north-south axis to a resolution of 1.4 marcs, at visible wavelength and a resolution of nearly 2.5 marcs for the other axis.

The position of the fixed DL differs from one configuration to another. When the celestial declination of the star is equal to the terrestrial latitude of the observator, it is noticeable that for each configuration one fixed line is at its zero position. In fact, the southern DL is never at this minimum position. This is due to the layout of the interferometer.

For a star declination equal to zero, the southern DL has to be positioned much further from the recombination table as for higher declination, in order to compensate the big distortion of the baselines seen from the star, in this case.

The fringes of the western baseline move faster as those of the north-south axis. Configurations b are characteristic of the non - symmetry of the interferometer (very long north-south baseline, short western arm). In this last case, the western DL moves to a maximum and then goes back to smaller value. Its motion is constrained by the small stroke of the southern DL. Fig. 3 shows the position of the fixed DL, and Fig. 4 shows the motion of the moving DL.

The constant parameters were defined as: translation stroke of the western DL = 3 m, minimum offset in the western arm = O, translation stroke of the southern DL = 1 m, minimum offset in the southern arm = O, minimum offset in the northern arm = 0.

Declination d of the star given in degree, minutes and second. d = 43 44' 57" corresponds to the declination of a fictitious star being at the zenith at transit time.

5. Equations giving the position of the delay lines

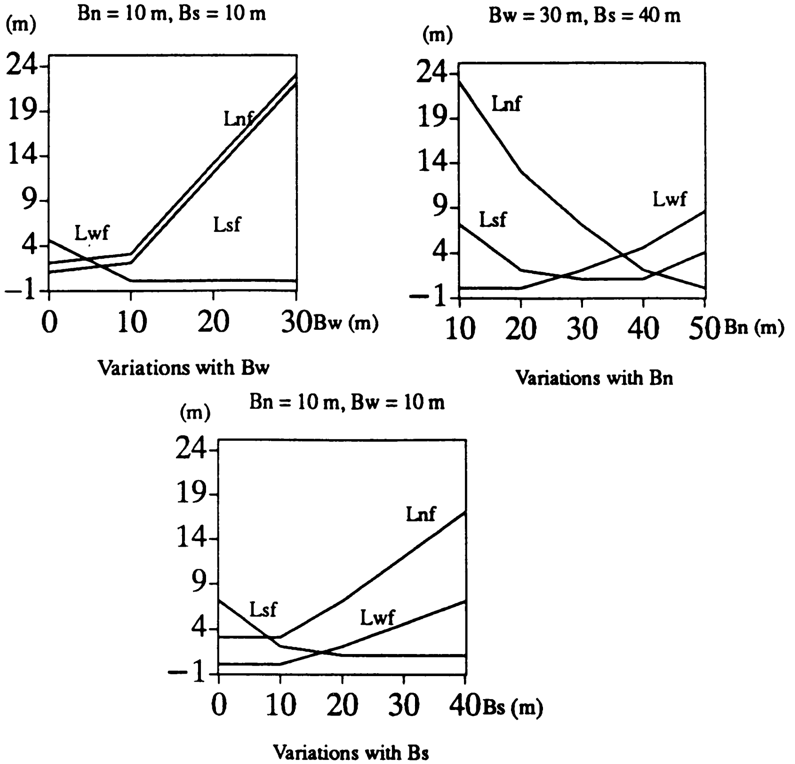

Fig. 3: Variation of the position of the fixed delay lines with the base length.

The position of the southern fixed DL is:

$$L_{SF} = B_n * [1 + \sin(lat - \delta)] - B_s * [1 - \sin(lat - \delta)] - L_{sVmax} + L_{nF} \tag{4}$$

The position of the southern moving DL as function of the time is:

$$L_{SV} = (1/2)[L_{SVmax} + (B_n + B_s)\sin lat \cos\delta(\cos H - 1)] \tag{5}$$

The position of the western fixed DL is:

$$L_{wF} = (1/2)[B_n * \sin lat \cos\delta * (\cos(H_{max} - 1) - B_w * (1 + \cos\delta \sin H_{max}) \tag{6}$$

$$+B_S * (1 - \sin(lat - \delta)) - L_{wmin} - L_{sF} - L_{sVmaX}] \tag{7}$$

The position of the western moving DL as function of the time is:

$$L_{wV} = (1/2)[B_n \sin lat \cos\delta(\cos H - 1) + B_w \cos\delta \sin H + L_{wVmax}] \tag{8}$$

'lat' is the terrestrial latitude of the observatory (43 44' 57.5"); δ, the celestial declination of the star; L_{sVmax} (L_{wVmax}), maximum position of the movable southern (western) delay line and H the hour angle.

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6. Conclusion

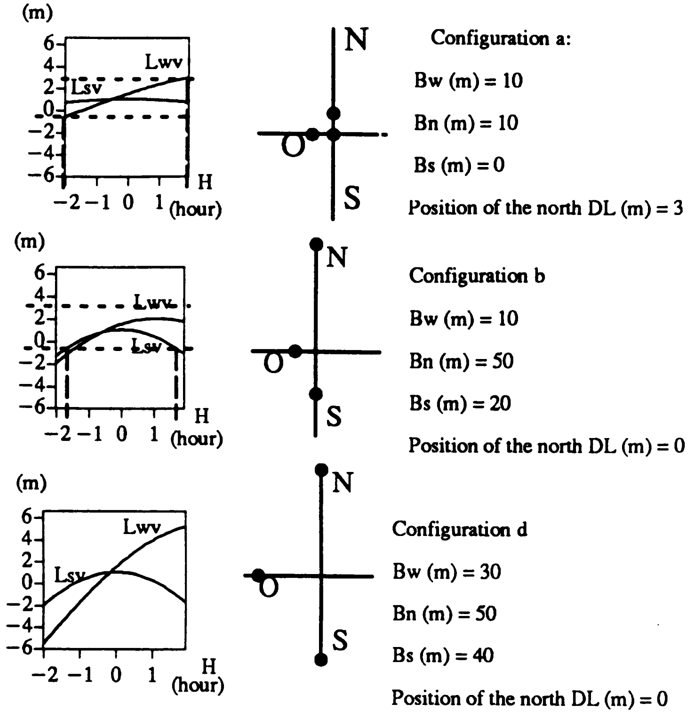

Fig. 4: Motion of the delay lines with time

The great advantage of the "redundant spacing calibration" image reconstruction method is to need no a priori knowledge on the object. However it imposes some constraints on the successive configurations of the telescopes array. This method has been applied on an interferometer simulating the characteristics of CHARON III. It has been seen that for a 3 telescopes interferometer, 43 configurations of the array are needed to get 91 points in the Fourier plane. This method can also be applied to the VLT interferometer. With the short strokes of the CHARON III moving delay lines, this study shows that fixed delay lines are necessary. Their maximum length must be 60 m for the northern and for the southern arm, and about 25 m for the western arm. The maximal observing duration, for each configuration, can also be deduced from this analysis. Its value is included between 3.8 and 0.6 hour; which is satisfying. This calculation shows the best way to move the telescopes for a given image reconstruction method and is an optimization of the observation procedure.

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