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Multilocalization of interference fringes in the Mach-Zender interferometer

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Abstract: The phenomenon of multiple localization in a Mach-Zender interferometer illuminated by a system of incoherent equidistant linear sources is studied. The relation between multilocalization and diffraction at a grating of period equal to the spacing between the sources composing the illumination system is analysed. Using the former relation an adjustment method is developed for interferometers of separated beams. This method enables the interference fringes at the different focalization planes to be seen without readjusting the alignment. This enables to observe perturbations at different planes with the simple focalization of the camera.

Key words: Interferometers – fringe localization

1. Introduction

If an interferometer is illuminated by a point source there are fringes in the whole volume where the exit beams are superposed. We say that this interference pattern is nonlocalized. If the source is extended and incoherent then the fringes are only seen on a surface, that is, they are localized.

In a previous paper [1] we showed that if the source consists in a succession of equidistant lines there are various localization surfaces.

In the present paper we study this phenomenon in a Mach-Zender interferometer. We find relations between the multilocalization and the diffraction at a grating of period equal to that of the array of equidistant sources. We show how this can be used to adjust the Mach-Zender and to determine the position of the different localizations.

A simple way to adjust a Mach-Zender illuminated by a classical extended source is by steps. First by a not expanded laser beam to find the alignment necessary for the beams travelling through both branches to intersect, that is, to assure there are no skew rays. When the source is replaced by an extended one this intersection point belongs to the localization surface.

In the aim of this study, the situation is not so simple since there are various localization surfaces. If, at first, besides the laser mentioned above we use a grating of period equal to the final array of sources, placed at the plane where this array will be, then for each interferometer branch there are multiple beams. The points where possible pairs of rays intersect yield the position of the different localization planes while the accurate superposition of the beams indicates the correct adjustment.

2. Adjustment for interferometers of the Mach-Zender type

For simplicity we describe the method to adjust the interferometer taking into account a Mach-Zender. Nevertheless the method can be immediately generalized to consider other interferometers of separate beams such as the Michelson, Linik and others.

The first step towards the adjustment of an interferometer is usually the use of a non expanded laser beam. The case of multilocalization requires this method to be generalized. To do so we consider the relation between the diffraction of a beam at a grating and the conditions of multilocalization in an interferometer illuminated by an array of sources of the same period as the grating.

In a previous paper [1] we saw that for a point on the localization surface of order m, two successive lines sources yield a variation of the optical pathlength difference between the two beams that interfere of $m\lambda$. This is expressed in eq. (10) of that paper which, in the case of vacuum is

$$\delta x(\cos\beta_1 - \cos\beta_2) = m\lambda . \tag{1}$$

In this equation the angles are measured from the source surface and m is the order of the localization. To analyse what follows it is convenient to measure angles from the normal to this surface, and the latter equation can be written as

$$\delta x(\sin\theta_1 - \sin\theta_2) = m\lambda . \tag{2}$$

From this equation we see that the angles θ_1 and θ_2 are related in the same way as the angles corresponding to orders of a grating of period equal to that of the sources array.

Let P be a point on the localiation surface order m (fig. 1) and let P′ and P″ be its images in the source space (obtained by inverse ray tracing). If the source array is replaced by a grating of equal period and the order j passes through point P′ then the order $j + m$ passes through point P″. This is because, on the one hand, the variation of the difference in optical pathlength between two diffraction orders, j and

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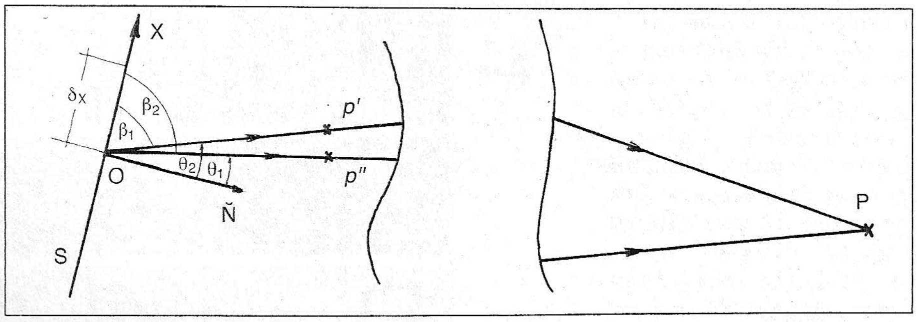

Fig. 1. P is a point at the localization surface, P′ and P″ are its conjugates at the entrance to the interferometer obtained by inverse ray tracing, *N* normal to the source and *δx* period of the source.

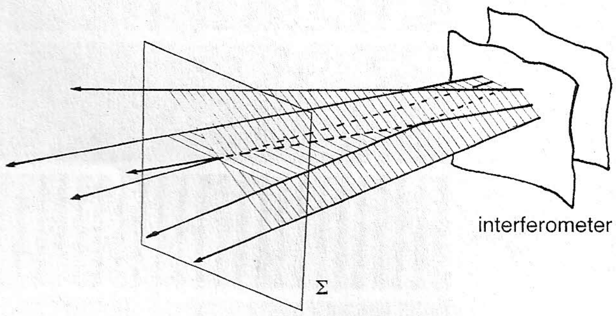

Fig. 2. Fans of rays at the exit of the interferometer. *Σ* is a localization surface. The simultaneous adjust for the different localization surfaces requires the complanarity of both fans.

$j + m$, for the pairs of rays originated at two successive grooves and passing through P′ and P″ is $m\lambda$ and, on the other hand, for the localization of order m the variation for consecutive lines sources of the difference in optical path-length between both branches of the interferometer is m.

This is, the diffracted beam of order j which passes through P′ and travels through one branch of the interferometer at the exit intersects the diffracted beam of order $j + m$ which passes through P″ and travels through the other branch of the interferometer at a point belonging to the localization surface of order m.

If instead of the array of sources, the interferometer is illuminated by an extended source covered by a Ronchi grating of the same period as that of the array, at the exit there are two fans of rays, one for each branch.

For every localization to be well adjusted (so that fringes at every localization surface are visible) the two ray fans must be on the same plane. If this does not occur then only the intersection of a pair of rays can be attained, since the other pairs are skew, and this yields only one localization surface (see fig. 2).

On the other hand, when the intention is to illuminate the interferometer with an extended source (or an array of sources) of a size adequate to assure a small localization depth, the adjustment that can be obtained with a non expanded laser beam is not sufficient to assure the visibility of fringes. This adjustment must be complemented with the use of sources of variable size or by the more practical method of a moving point source [2].

In our experiment, the linear array of sources is obtained using an expanded laser beam which is incident on a rotating diffusor. A Ronchi grating is placed after and on the diffusor.

The complete procedure for adjustment is as follows:

1. With a non-expanded laser we find an angle between the interfering beams which is adequate to obtain the desired density of fringes.
2. Placing a grating in the path of the non expanded laser beam we roughly control that the two fans of rays belong to the same plane. We also roughly estimate the positions of the localization surfaces of order m different from zero.
3. Removing the grating and introducing a microscope objective on a support provided with fine movements to generate the moving point source [2] we strictly control that the two fans belong to the same plane. We adjust the interferometer improving the coplanarity of the rays.
4. Placing the grating again we verify the adjustment of the other orders.
5. To start functioning the microscope objective is displace longitudinally to illuminate the adequate extension of a rotating diffussor which is placed ahead the grating.

3. Experiment

A Mach-Zender interferometer is mounted and it is aligned in the classical way with a non expanded Laser beam, in such a way that the intersection of the beams after the last mirror yield real localized fringes in the case of illuminating the interferometer by an extended source. As an extended source we use a rotating diffusor placed in the path of the laser beam, adequately expanded previously.

We always work with laser illumination, diffuse or not, to obtain great tolerances with respect to the lengths in both interferometer branches. These lengths differ from each other in less than 10 mm. The fringes are registered with a Pulnix CCD with an approximation lens. Seven localization surfaces are found. The one marked with $m = 0$ corresponds to the localization of order zero, the ones $m > 0$ correspond to the two localizations farthest away from the interferometer while $m < 0$ are those closest to the interferometer.

Table 1. Calculated and experimental values [mm] for different localizations. The calculations are performed taking into account the following data: $\lambda = 0.6328$ µm, $\beta = 1.82°$, $\delta x = 0.157$ mm and $h_s = 674$ mm.

Order	–6	–5	–4	–3	–2	–1	0	1	2
Calculus	–291	–261	–226	–186	–136	–76	0	98	229
Experim	–	–	–217	–176	–129	–72	0	91	221

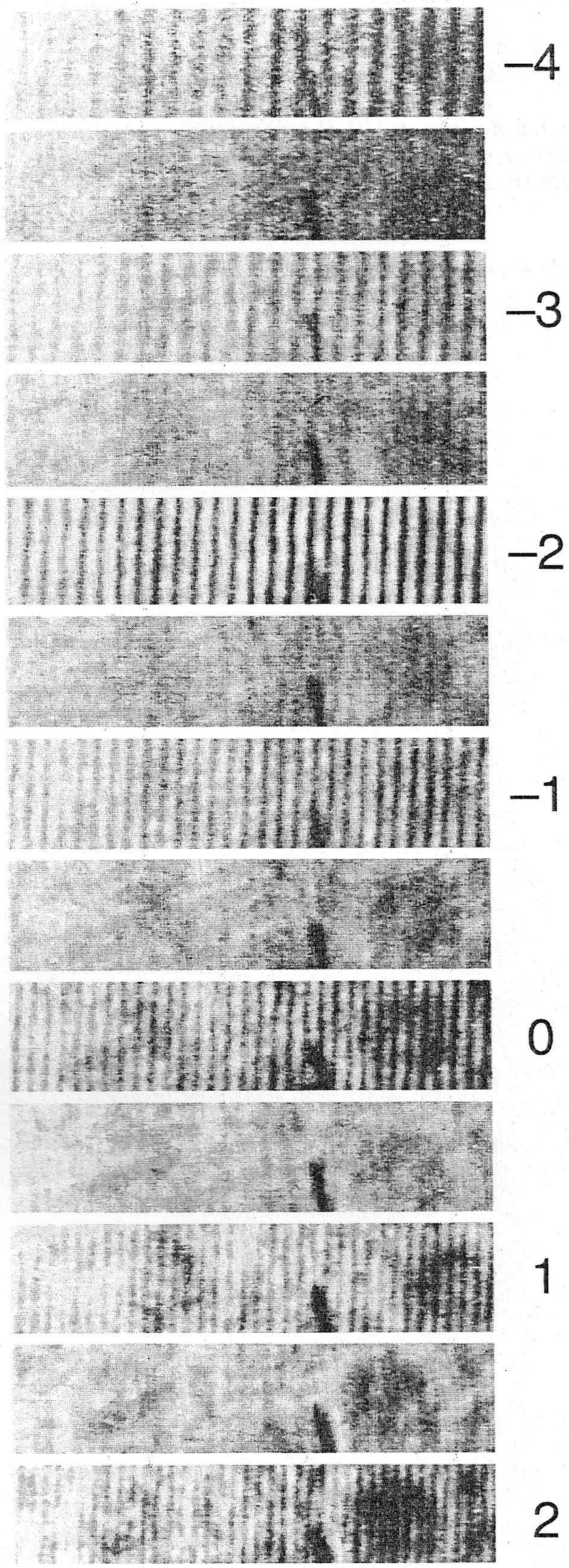

Fig. 3. We show images of the seven localization planes with intermediate planes images.

The number of positive localizations is limited by the length of the table, while the negative ones become virtual for $m < -5$. This is they are inside the interferometer and cannot be seen with the approximation lens used by us.

In fig. 3 we show the fringes corresponding to the seven localization planes mentioned above and between them we show intermediate images. All the images are obtained with the same magnification and processed to compensate for the loss of intensity when the distance to the interferometer increases, but taking care that the contrast adjustment is the same for all and approximately the original one.

The distance h_m from the localization surface of order m to the localization surface of order zero, can be obtained from eq. (22) or ref. [1] which in the case considered here results to be

$$h_m = \frac{m h_s \Delta_0}{\delta x - m\Delta_0} . \tag{3}$$

m is the order of localization, h_s the distance between the source and the localization of order zero, Δ_0 the spacing between fringes in this localization and δx the period of the Ronchi grating.

Since what is easy to measure is the angle β between the beams at the interferometer exit when we have the non expanded laser beam and the Ronchi grating is not placed, it is conventient to write delta as a function of β. Then eq. (3) can be written as

$$h_m = \frac{h_s}{\frac{\delta\, x\beta}{m\lambda} - 1} \tag{4}$$

With this last equation the position of the different localizations are calculated and the results are in good agreement with those obtained experimentally. These results can be seen in table 1.

4. Conclusions

We show the possibility of obtaining multilocalizations in interferometers of separate beams, in particular the Mach-Zender. A method to adjust the interferometer is developed to enable the visualization of all the localizations without needing to readjust when passing from one localization surface to the other. The results suggest the possibility of several localizations within one branch of the interferometer, where the sample under study can be analyzed by simple focalization of the camera.

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Numerical calculations to show the plots for the dependances of the mean temporal value on the quiralty parameter and dielectric constant are done.

It is found that α is practically invariant when the dielectric constant changes and varies slowly with the quiral parameter. Nevertheless for the same parameters the lateral shifts are appreciable.

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