

Interferometric Recording of the Deflections of Towers and Telescopes

R. H. Hammerschlag

Wind generates vibrations in towers and in telescopes placed in the open air. Interferometers for measuring these vibrations were developed. Applications to scale models of a telescope led to improvements of the telescope design. An optoelectronic system using three photocells for scanning the interferometer fringes allows the application of an inexpensive laser with several longitudinal modes as a light source for the interferometers.

Introduction

Fluctuations in the air temperature in the direct neighborhood of a telescope deteriorate the image quality. Therefore, it is advisable to place the telescope above the forced convection on a transparent tower in the open air. Even a light breeze can keep the air temperature homogeneous. However, the wind may generate vibrations in the instrument. In some directions deformations as small as $1\text{ }\mu\text{m}$ may already be troublesome. Such deformations can be measured simply and cheaply by optical interferometric methods.

Figure 1 shows a schematic drawing of a telescope of which most parts are mounted on an open frame. Such a construction is the best compromise between a minimum area exposed to the wind and a maximum stability. The most critical part is the pyramidal frame work consisting of four tubes and carrying the head, which contains the secondary optics. Vibrations of the secondary optics with respect to the primary mirror are not allowed. These vibrations can be resolved into six components: three translations and three rotations. The two translation modes perpendicular to the axis of the optical system turned out to be most critical. Optical calculations showed that only translations of less than $1.22\text{ }\mu\text{m}$ are allowed in those directions.

Interferometer for Measuring Translations

An interferometer, which is able to measure these translations, is shown in Fig. 2. The beam of a laser is split into two beams, which are reflected to the

head by two mirrors $M1$ and $M2$ at the periphery of the base plate, which carries the primary mirror. In the head two mirrors $M3$ and $M4$ are mounted, which reflect the light into mirror $M5$. In front of the microobjective the two beams meet and form an interference pattern. This pattern is enlarged by the microobjective. A translation of the head causes a shift of the interference pattern. If α represents the angle of the mirrors $M3$ and $M4$ relative to a line parallel to the line $M1$ – $M2$, β the angle of the light beams relative to the perpendiculars on the mirrors $M3$ and $M4$, P the shift of the head, and λ the wavelength of the light, the interference pattern shifts over $(4P \sin\alpha \cos\beta)/\lambda$ fringes.

A more sensitive arrangement is obtained when one light beam passes from $M1$ to $M4$ and the other beam from $M2$ to $M3$ —i.e., the beams cross each other—because in that way the angle α is larger.

The distance between two fringes in the interference pattern is large when the distance between the mirrors $M3$ and $M4$ is small. In that case the interferometer is insensitive to motions of the microobjective relative to the telescope construction, and it measures only the motions of the head relative to the base plate.

Application to a Telescope Model

Originally the interferometer was applied to a model of the pyramidal construction on a scale of 3 to 1 in order to check whether such a construction would meet the stability requirements. Figure 3 shows the interferometer arrangement on the model that corresponds to the drawing in Fig. 2. The head is loaded by weights over a cord. The interference pattern on the screen can be seen in Fig. 4. The sensitivity in this arrangement with crossed beams was 0.6 fringe displacement/ μm translation of the head.

The author is with the Astronomical Institute, Zonnenuig 2, Utrecht, The Netherlands.

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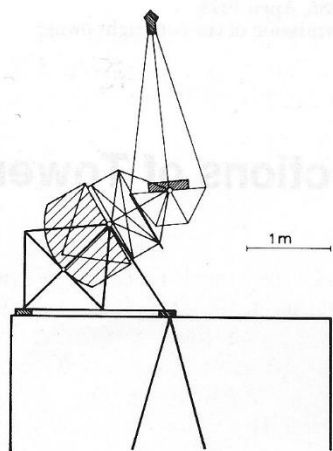


Fig. 1. Telescope construction stable against wind vibrations.

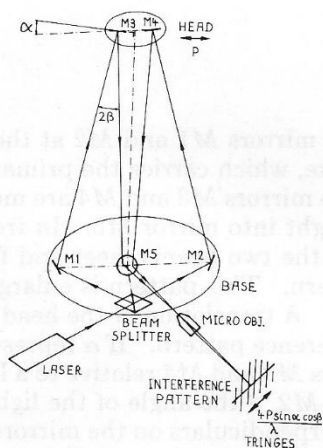


Fig. 2. Interferometer for measuring translations.

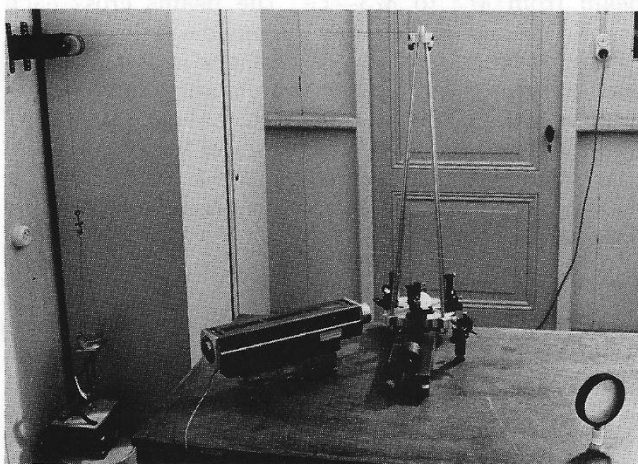


Fig. 3. Interferometer arrangement on the model of the pyramidal construction. The model could be mounted on a simple non-stable wooden table because the interferometer is only sensitive to deformations inside the model.

This model showed in the stability computations that one cannot approximate the trapezia in the construction by triangles. The measured translations were six times as large as calculated from the triangle approximation. A calculation based on the trapezium form agrees fairly well with the measurements. Consequently, the tubes should be connected in a small area very near the axes of the tubes as shown in Fig. 5. Even a cone form at the ends of the pipes may be necessary in order to avoid any bending moment on the long thin tubes. Calculations and measurements showed that the load force on the top of the triangle should apply within $D/2$ (D = diameter of the tubes or bars) from the mathematical triangle point. For the setup shown in Fig. 3, the following equation is obtained:

$$\Delta y = \Delta y_0 \{1 + q[a^2/(D^2 + d^2)]\},$$

in which

- Δy = translation of the head;
- Δy_0 = translation if load would affect the mathematical triangle point as shown in Fig. 5;
- a = distance between the centers of the connection points of the tubes in the head, i.e., the length of the top side of the trapezium;
- D = outside diameter of the tubes;
- d = inside diameter of the tubes;

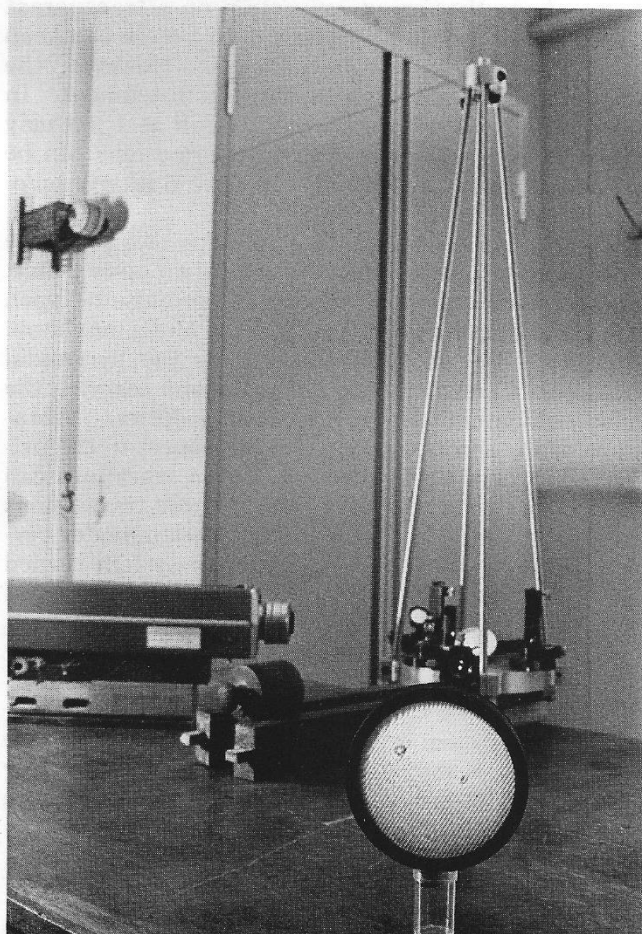


Fig. 4. Interference pattern.

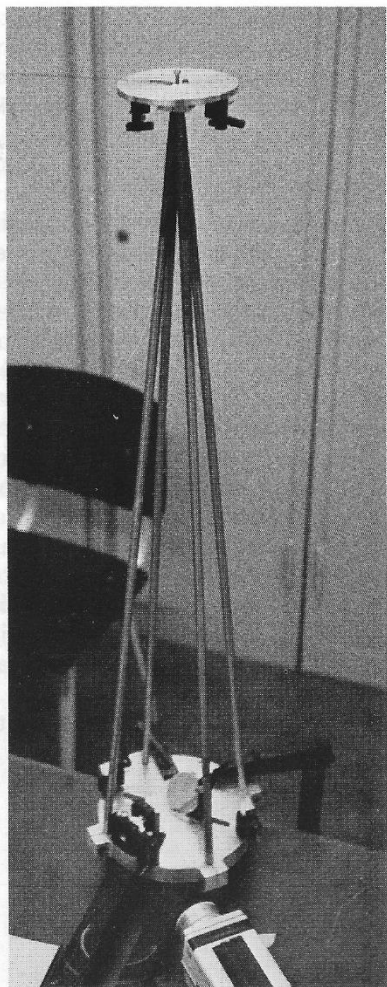


Fig. 5. Improved model with tubes connected near their axes.

q = numerical coefficient, which is approximately 2.

The equation is a good approximation as long as the length a is small compared to the length of the base of the trapezium.

Optoelectronic Scanning System

The measurements described so far were static. A gradually increasing load was made with the help of a balance placed on a table, which was movable in a vertical direction by a screw, (see Fig. 3). In this way the motion of the fringes could be followed by eye. For the study of dynamic effects an optoelectronic scanning system is developed. The principle of the system is shown in Fig. 6. Three photocells are placed in the interference pattern. The mutual distances between the cells are a quarter fringe distance. The currents I_1 , I_2 , and I_3 of the three cells can be represented by the equations

$$I_1 = a + b \sin \theta, I_2 = a + b \cos \theta, I_3 = a - b \sin \theta,$$

in which a represents the mean light intensity, b/a the modulation depth of the fringes, and $\theta/2\pi$ the

shift of the fringes expressed in fringe distances. The quantities a and b can be expressed in the amplitudes of the two interfering beams A_1 and A_2 and the angle θ in the two optical pathlengths l_1 and l_2 :

$$a = \frac{1}{2} (A_1^2 + A_2^2), b = A_1 A_2,$$

$$\theta = 2\pi(l_2 - l_1)/\lambda.$$

Generally the amplitudes A_1 and A_2 are not homogeneous over the cross sections of the beams. The two interfering beams shift slightly with respect to each other because of the deformation to be measured. Consequently, variations in a and b occur during the measurements. For that reason a and b are eliminated electronically. The quantity a is eliminated by an analog circuit that forms

$$I_1 - (I_1 + I_3)/2 = b \sin \theta$$

and

$$I_2 - (I_1 + I_3)/2 = b \cos \theta.$$

A resistor network forms ten signals

$$p(b \sin \theta) + q(b \cos \theta) = br \sin(\theta + \phi)$$

with $r = \sqrt{p^2 + q^2}$, $\tan \phi = q/p$, in which the values p and q are chosen in such a way that ϕ is equal to $K \cdot 18^\circ$ with K an integer ranging from 0 to 9 inclusive. Each signal $br \sin(\theta + \phi)$ goes to a comparator, which gives a digital signal when $br \sin(\theta + \phi) = 0$, i.e., $\theta = -\phi + n\pi$, n = integer. The ten comparators together give a digital signal each time that the interference pattern shifts $1/20$ fringe distance, independently of the values of a and b . Consequently, θ can be determined independently of a variation in the main light intensity and the modulation.

Figure 7 shows a diagram of the system. The photocells are PIN diodes, which have a high quantum efficiency, low noise, and a short response time. Three beam splitters divide the light into four beams of which three are used for the photodiodes and the fourth for visual control of the interference pattern with the help of an eyepiece. The three photodiodes and the eyepiece are situated in the same interference plane. The sensitive area of the photodiodes has such small dimensions ($0.5 \times 0.5 \text{ mm}^2$) that no separate slits are required. Each photodiode can be moved individually in the interference plane. Con-

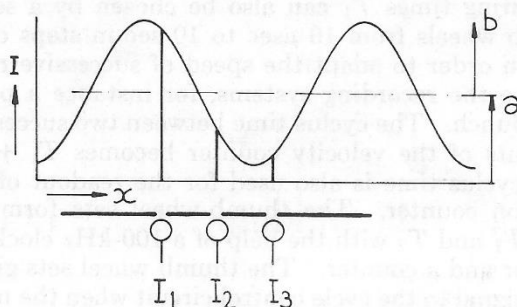


Fig. 6. Principle of the scanning system with three photocells.

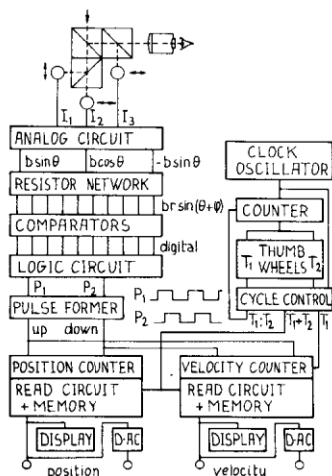


Fig. 7. Block diagram of the optoelectronic scanning system.

sequently, the distances between the photodiodes can be adapted to different fringe spacings, which depend on the type of interferometer in use. The adjustment of the photodiodes is not critical, a deviation of 20% in the distance between the photodiodes is permitted without loss of accuracy, provided the distance between the first and second diode is equal to the distance between the second and third diode.

How the photocurrents are analyzed is shown in the diagram of Fig. 7. These currents I_1 , I_2 , and I_3 enter the analog circuit that forms $b \sin \theta$, $b \cos \theta$ and $-b \sin \theta$. The resistor network produces the ten signals $br \sin(\theta + \phi)$ which are led to the comparators as mentioned before. A logic circuit transforms the ten digital signals from the comparators into two digital rectangular functions P_1 and P_2 with 90° phase shift. On each edge of the functions P_1 and P_2 , a pulse former produces an up or down pulse: an up pulse for a shift to the left, a down pulse for a shift to the right. The up and down pulses are led to a position counter and a velocity counter. The position counter can be read out during the counting process without disturbing it. The velocity counter counts during a measuring time T_1 , which can be chosen with a set of thumb wheels from $10 \mu\text{sec}$ to 10 sec in steps of $10 \mu\text{sec}$. After the time T_1 the velocity counter is read out and reset to zero. Then the measuring time T_1 can start again. The waiting time T_2 between two measuring times T_1 can also be chosen by a set of thumb wheels from $10 \mu\text{sec}$ to 10 sec in steps of $10 \mu\text{sec}$ in order to adapt the speed of successive readouts to the recording systems, for instance a paper tape punch. The cyclis time between two successive readouts of the velocity counter becomes $T_1 + T_2$. This cyclis time is also used for the readout of the position counter. The thumb-wheel sets form the time T_1 and T_2 with the help of a 100-kHz clock oscillator and a counter. The thumb-wheel sets give a logic signal to the cycle control circuit when the number of the counter is equal to the number of the thumb-wheel set, and the cycle control circuit resets

the counter to zero. Digital to analog converters make it possible to connect a recorder or an oscilloscope. The optoelectronic scanning system that is in operation now can follow speeds up to $250,000$ fringes/sec.

Interferometers for Measuring Rotations

As mentioned before, the telescope should be placed on a transparent tower. A framework that meets the requirements is shown in Fig. 8. It consists of a platform in the shape of a rhombus, the points 13-14-15-16, supported by four triangles with a broad base 1-14-4, 3-13-2, 6-15-7, and 8-16-5. Each pair of parallel triangles gives stability in one direction and parallel guidance to the platform in the perpendicular direction. The platform is implemented as a pyramidal framework with top t in order to obtain sufficient stability. (For a more detailed description of the tower, see Ref. 1.) Translations of the platform cause no harm because the objects to be observed are at infinity. The three rotations $\text{rot} \cdot z$, $\text{rot} \cdot y$, and $\text{rot} \cdot x$ are the critical vibration modes. These vibrations can be measured by means of five interferometers of the type used for the pyramidal construction in Fig. 2. These interferometers are in-

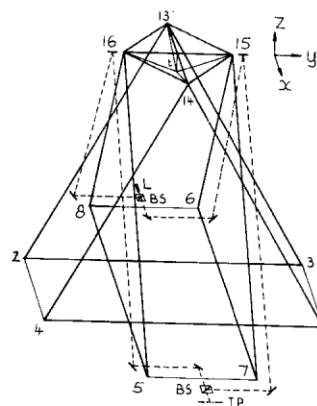


Fig. 8. Interferometer only sensitive to rotations about the x axis.

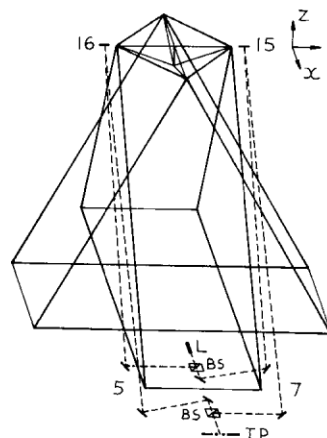


Fig. 9. Interferometer sensitive to rotations about the x and z axes.

stalled in triangles, for instance, 5-16-8, 7-15-6, 1-14-4, 1-*t*-4, and 5-*t*-8. The mirrors M_1 and M_2 are placed in the base points of the triangle and the mirrors M_3 and M_4 in the top. Each interferometer measures a combination of a rotation about the x , y , or z axis and a translation in the x or y direction. For that reason five interferometers are required in order to eliminate the two translations. However, appropriate interferometers can measure the rotations directly. Figure 8 shows an interferometer that is only sensitive to rotations about the x axis. The beam from the laser L is split in a beam splitter BS . The first beam goes via mirrors in the corners 8, 16, and 5, the second beam via mirrors in the corners 6, 15, and 7, to a second beam splitter BS that combines the two beams. The measuring head with the three photodiodes is placed in the interference pattern IP . A similar interferometer measures the rotation about the y axis. Figure 9 shows an interferometer that is sensitive to rotations about the z and x axis. In this way it is possible to measure the three rotations with only three interferometers.

For the sake of completeness we mention that if

the telescope is mounted on three of the four points 13, 14, 15, and 16 in Fig. 8, the rotation of the telescope is determined by the motion of these three points, and the interferometers for measuring the rotations should be adapted to this situation. For instance, if the telescope is mounted on the points 14, 15, and 16, the interferometer for measuring the rotation about the y axis should be replaced by an interferometer with two parallel mirrors in the points 14 and 15 or in the points 14 and 16, similar to the interferometer shown in Fig. 8.

Concluding Remarks

The applied interferometers have nearly equal paths in the two arms. Consequently, a cheap laser with several longitudinal modes can be used. Moreover, the interferometric measurements with the three photocells method are simpler and more flexible than the commercially available laser distance devices.

Reference

1. R. H. Hammerschlag, Joint Organization for Solar Observations, Annual Report (1973), Chap. 14.