REFRACTION FREE METHOD OF LASER ALIGNMENT

by

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Abstract

Physical models of measured object has been created. Appropriate measurement method elaborated on the strength of the physical model allows to execute a very essential step towards elimination or at least minimize the refraction influence over alignment measurements. The proposed method is based on laser light intensity fluctuations.

There are many instances in engineering surveying where three or more points have to be collinear at longer or shorter distances. There are various methods to achieve this, including those employing mechanical devices, telescopes, various laser devices, collimators, autocollimation devices and reflecting spheres, interferometers and other. Alignment may be defined as changing the spatial position of a line given by a direction or by two points until other points, fixed in positions will become part of that line.

Of course, undertaking of any measurement task must be a prelude to treat a physical model of any measurement method. This demands, first of all, to produce a physical model of the object which must be measured. Supposing we are allowed do deal the object as a pure static structure, every model illustrated on the upper part of the Fig.1 is correct and possible to use at definite cases. It follows that any possibility to accept the object as a static structure secures us a big comfort during the measurement. There is such a big and tempting comfort that we oft shut one's eyes to a great deal of phenomenons which univocally indicate that uor acceptance that the object is really static, is far from actuality. It conduct to big mistakes, sometimes simply to mistakes of art. That is why, in every big-accuracy-measurement the assumption that the object is static must be beforehand rejected. The following circumstances decide that man can here only about dynamic structure say:

(i).In well-defined interval of time which can be as real time accepted, examine points established on the object prove any mutual micro-displacements.

(ii).The object itself proves any micro-displacements in relation to the surrounding, where are established the reference points.

(iii).Optical device serving to carry into effect the reference line is unsteady.

Let us now investigate the four models of alignment methods appearing on Fig.1.

As we said before, in the upper part of Fig.1 man introduced four cases of the static and in the under part the dynamic pictures of measurement methods.

1.Reference line is defined by means of initial point and direction which is realized by e.g. a line of sight any instrument. In static circumstances this is a very often applied system, because the line of sight of instrument enables an excellent achievement of reference line. In dynamic circumstances this is, however, a completely defective system, for the movements of the initial point cause a continuous phenomenon of translation and rotation. In this way defined reference line can be introduced as a bar settled in a joint and suspended on a spring.

2.Reference line is defined by means of two utmost, independent placed points, between which exist the object with its examine points. This is a classical example of alignment method, very often applied in engineering surveys. In static circumstances this is a most advisable system, for the reference line is realized by two points being in existance outside of the object. In dynamic circumstances this model proves to be very difficult to achieve owing to appearance of mutual displacement of initial, intermidiate and last points. The correct alignment will be possible only at that time, if any possibility exists to set up the reference line continually. Finally, however, it should take place the absolute determination with regard to external points, also with external accuracy, as is well known, always much smaller in size than the ever indispensable intern one.

3.Reference line is defined by two points existing on the some object which is represented by a lot of examine points. Reference line is defined by two utmost or other freely selected intermediate points. Projection of the reference line takes place from an external point settled outside in the production of the line defined by two reference points. In static circumstances this is a classical task of setting up a line with naked eye, standing behind one of the rod. In dynamic circumstances however, we have to do with a far-reaching quantitative change in relation to the two previous cases. If over there the series of intermediate points has been refered to an external reference system, here the reference line is locating directly on the object, being a subject of measurement. The role of the projector of the reference line is altered as well; situated behind the initial point of the reference line is unceasingly settin up in the production of it.

We have here to do with a classical case of relative determination, where the set of points must satisfy only the internal conditions, without respect to the external reference system. In case of assembling of machines (e.g.turbines) this model is to the full correct for the internal assembling accuracy is in general for two-three orders higher than the external one. In dynamic model is there a far-reaching compensation of the object's own movements in consideration of remaining the reference points in the same sphere of influences. Similar is there with projector; through it must be permanent settled up in the reference line or in the production of it, owing to seating on the same object, it proves considerably smaller movements than in case of its seating outside of the object. Just now can man distinctly spot how justly is usage as reference line a string, which is stretching between reference points. It is, since, to react automatically to every possible displacements of the points which define the reference line. Clearly, mention is made of a physical model of the string, in which the reference line is fulfilled not necessarily by stretched string but by e.o. a motor telescope, which is permanently putting right in the line position.

Selection of one of these models depends on the characteristics of the object and on adopted method of measurement. In this connection, by great accurate alignment use man in principle entirely measurement methods which correspond with models Nr 3 or 4.

It takes place e.g. by execution of manual measurement using the most famous precise instruments: FF 01 (Fig.2) and Micro-Telescope (Fig,3). Instrument FF 01 is standing a dozen or so millimetres behind the initial point of reference line. During the measurement there is in progress its perpetual analytic setting up in the reference line or rather in its production (Fig.4). Owing to it man can with great approximation fulfill the model Nr 4.

Micro-Telescope, next, is precisely centered at the initial point and than orientated to the last one. During the measurement the orientation of the instrument is constantly corrected what allows us, like previously, for a good fulfillment of the model Nr 4.

In, for us interesting, modern methods, which base on application of laser beam, the physical models are not only similar but methodically all to the good. Location a laser-light-source in the production of the reference line is observed both in the interference method and in the diffraction one. As is well known, even a considerable displacement of the laser-light-source does not influence on the change of the run of the reference line which is defined by a slit diaphragm and a screen with centering device by diffraction method(Fig.5) or a straightness adaptor and reflector by interfence method (Fig.6) By the direct method, where the generator of laser light is located at the initial point of the reference line, at the last point there is a device which constantly records the current position of this line. This is also a good fulfillment of Model Nr 4.

Man can now most certainly say that usage of a correct physical model of the mea-

surement method enables to far-reaching or even complete eliminating of any influences of micro-displacements of optical devices, which fulfill the reference line. Owing to it a sole care remains to minimize the influence of environment.
Differences in temperature, humidity and pressure on the way of ray of light cause the phenomenon of refraction. This phenomenon has been enough good quantitatively estimated and described with any formulas. Difficulties, connected with measurement of adequate parameters are however so qreat, that man can rather not hope for significant progress in useful for practice, analytic method of elimination of refraction influences from results of measurements. Considerably more hopes awake appropriate measurement methods, elaborated on the strength of the physical model of the object. Flows of the air, which occur frequently in the interior of spaces, where measurements are executed, destroy completely, at the same time, homogenity of the measurement environment, which parameters must be determined.
Fermats' principle, expressed by formula

$$Si = \int_A^B n \cdot ds = min \qquad (1)$$

says, the optical way between points A and B as the product of refracting index n and section of way disproves, that any local fluctuations of index n caused by variations of temperature, consequently of air density as well, conduct to deformation of the way of light. Supposing, the variations proceed fiercely, vibration makes the measurement impossible.
The atmospheric effects on laser beam propagation because of the variable refractive index n can be divided into two parts: a determined part and a stochastic one.

$$y(t) = s(t) + z(t) \qquad (2)$$

where: $s(t)$ - determined part,

$z(t)$ - stochastic part

The characteristic property of the determined function $s(t)$ is there, that its value can be calculated, in principle, for any point t. The stochastic function $z(t)$, on the contrary, depends on exactly unknown influences, which fluctuation is disorderly and that is why its value can not be foreseen for any point t.
To make use of formula (2) allows to execute a very essential step towards elimination or, at least, minimize the refraction influence over alignment measurements. Just as in any time-process, man can show, also here, a determined part (systematic refraction) and stochastic part (random refraction). (Tab.1)
The phenomenon of refraction, always accompanying a light propagation, has its source in a variability of the light refractive index as function of both space and time. Regular changes of that index, created by thermal gradients, cause a continuous and slow change of laser propagation path. In factory halls the reason

Table 1

SYSTEMATIC AND RANDOM REFRACTION	Atmospheric refraction	
activity:	systematic	random
determination:	regular refraction	random refraction
reason:	physical state of atmosphere (modelling of atmospheric space)	time and space fluctuations of refractive index
example:	determinate model of refraction	scintillation

of these phenomenons can be the following:

- a cyclic reproducible production process which causes a specifier thermal state,
- day and night fluctuations of temperature field connected with the sun light beam running through glass walls and windows,
- a periodic switching on heating installations and ventilators.

However, on the regular changes (a systematic refraction) are superimposed all refractive index fluctuations (a random refraction) as a result of turbulent motion of the atmosphere. Thus, the value of refractive index of the atmosphere can be given by the formula:

$$N(\bar{r}) = N_0 + N_1(\bar{r}) \tag{3}$$

where: $\bar{r}$ - is the position vector,

$N_0 = \langle N(\bar{r}) \rangle \cong 1$ - is the constant value of the refractive index (a systematic refraction),

$N_1(\bar{r})$ - is its fluctuated part

$\langle \quad \rangle$ - are the angle brackets, which indicate an ensemble average.

The comparison of formulas (2) and (3) proves once more, that to separate the deterministic and stochastic parts is, in the full sense of the word, possible. The division of refraction into two parts leads to the conclusion, that as well activities on the elimination of the refractive influence can be separated. It allows individually to determine magnitudes of systematic and random refractive influence. The importance of this is the following:

- The systematic part is relatively simple for the estimation and elimination. For instance an application of multicolour laser transmitter allows to measure a differential refraction from dispersion of light.
- However, the estimation of random part can be made as a resultant observation of all these factors, which cause refraction index fluctuation. It is well known

that according to Fermat law a light ray elongates its way all the more when atmospheric conditions along path are more differentiated.

One will be to say, that laser light intensity measured at the end point of reference line can be assumed as a standard, when the atmosphere is homogeneous. However, all light intensity fluctuations will cause a laser path alongation in a consequence of appearance of less or greater non-homogeneities of survey medium.

Because the light intensity fluctuation are easy to measure with the help of radiometer, such an instrument can be used for the estimation of random refraction.

As well important is the fact, that intensity measurements do not determine a magnitude of random refraction but indicate the moment, when their influence is the least or simply vanishes.

Now, let us describe practical activities, which should be done for the realization of the new method (Fig.7):

- a laser beam emitted by He-Ne transmitter is divided into a measurement beam, being a reference line and a physical beam serving for the determination of laser light intensity fluctuations,
- a measurement beam is aimed to the target with an receiver placed at the last point of reference line, also it falls sequentially on intermediate points of the line. In every case the laser beam position is recorded in one minute intervals,
- a physical beam parallel and not far off the first one (e.g. 5cm) is directed to the radiometer which is coupled with the target. In this receiver the laser light intensity fluctuations are registered and analyzed,
- a microprocessor (built in the construction of target) calculates an average position on measurement beam in three seconds intervals. Then, it calculates in every interval predicted measurement deviations based on physical beam registrations and choices the average measurement beam position from this interval in which the predicted deviation was the smallest.

The test of the suggested technique lasted for a few months, a period during which the main tasks were to set up and examine the suitable test equipment (especially a high quality radiometer). The tests were performed in the laboratory of the Department of Surveying in Delft (Holland) over 47 m indoor path. He-Ne laser with wavelength of 632,8 nm was mounted rigidly on the optical bench. The output laser beam was divided into two beams by an optical system. Two receiving stations were used to monitor the fluctuation of laser beams. One station consisted of a SC/10 UDT detector (USA) and 30A Linear Displacement Monitor, and the second one consisted of the 450 Radiometer and 550 Multiprobe EG&G (USA). Signals of arriving beams were recorded by multi-pen recorder. The detector SC/10 was used as monitor of laser beam deflections from the straight line in a horizontal plane. The radiometer EG&G was used to record fluctuations of laser light intensity.

The results of the test can be summarized as follows:

- The occurred differences between the observed and predicted deviations checked by Wilcoxons's test pointed out, that there non-essential differences for all experiments with 5% probability of an error commission.
- The normalized coherence function showed the sufficient correlation degree between horizontal laser measurement beam deviations and laser light intensity fluctuations.

That is why the method can be recommended as the method which allows the efficient elimination refractive influences.

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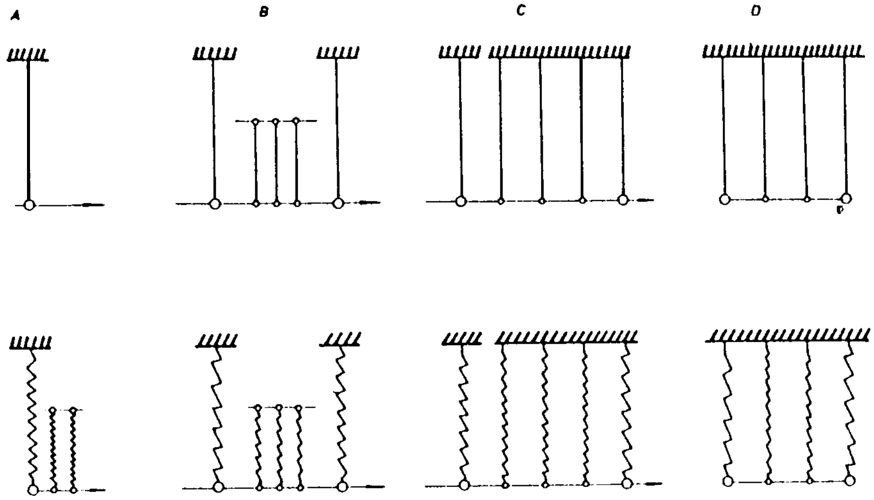

Fig.1

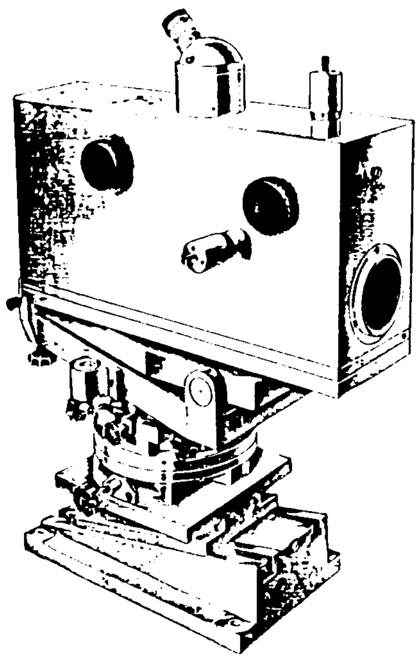

Fig.2

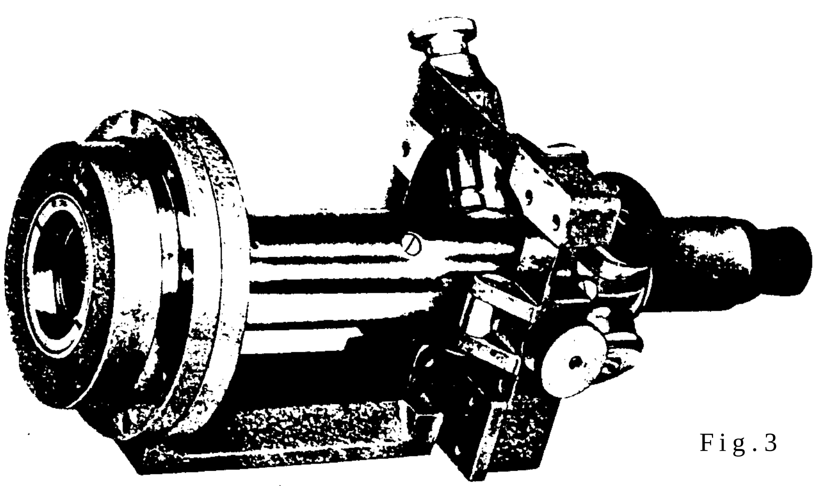

Fig.3

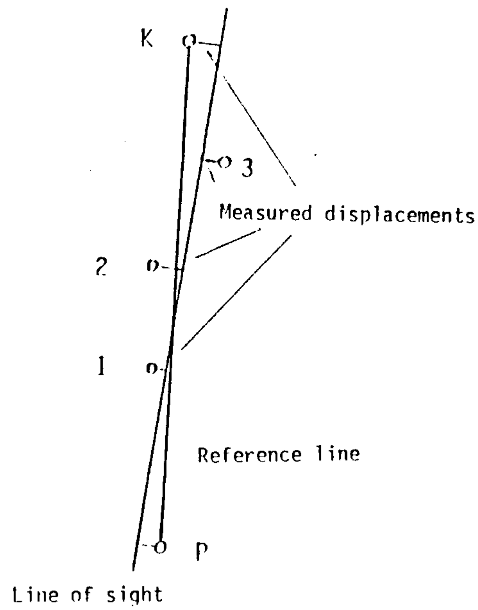

Fig.4

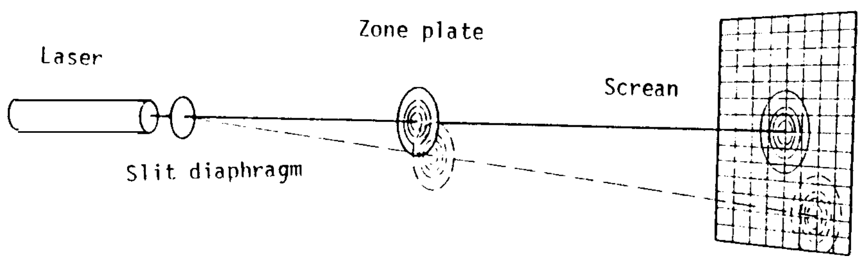

Fig.5

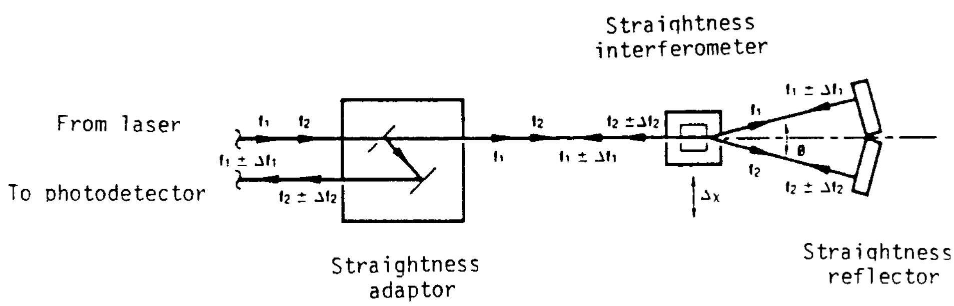

Fig.6

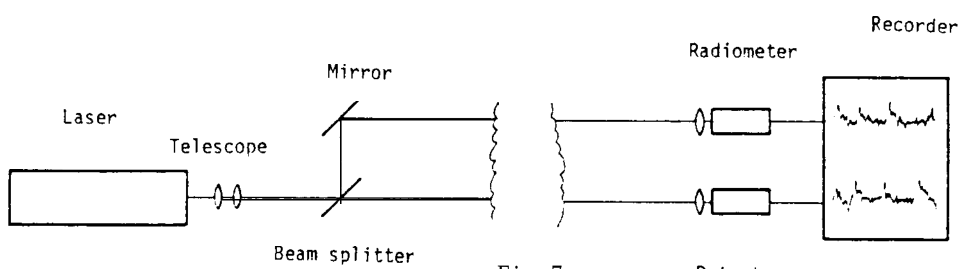

Fig.7