LINEAR AND ANGULAR MEASUREMENTS

TESTS ON A LASER PHASE DISPLACEMENT METER WITH AN
ILK-25 LINEAR COMPARATOR

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A description is given of the ILK-25 interference-type linear comparator. The metrological characteristics are given element by element for a long-range phase-type linear displacement meter, the IPL-FD. The instrumental error of the IPL-FD in an appropriate method of measurement is not more than 0.05 mm. It is concluded that the IPL-FD can be used in a length standard for long-range measurements.

The error characteristics of a means of measurement govern the performance in fundamental and special applications in metrology and other areas of science and engineering. Research on these characteristics is therefore one of the main lines of metrological support to measuring any physical quantity. A particular place is taken by precision means of measurement, which head the corresponding test schemes and are in essence initial means of measurement in the system for providing unified measurements. Such instruments include an optoelectronic device [1], whose analog under the name precision rangefinder has been incorporated into the UVT 5-84 highest-accuracy equipment [2].

However, the means of measurement described in [1] is not a rangefinder but instead a long-range laser phase meter for linear displacements (IPL-FD). The length measure is the displacement length for which the phase of the measurement electromagnetic wave changes from 0 to $2\pi$ (one phase cycle).

The performance of any instrument is governed by the metrological characteristics, so metrological studies were performed on the IPL-FD in the UVT 5-84 equipment by means of an ILK-25 interference-type linear comparator [3].

The basis of the comparator is constituted by two pairs of precision guides. Each guide is assembled from tubular elements of length 800 mm each. Two elements are joined by a connecting sleeve, and a reliable joint is provided by combining threading with a close-fitting part. The surface of each guide element has been treated with chromium compounds and polished to an appropriate finish. The precision guides are mounted on cylindrical boats, whose positions may be adjusted in any direction by means of adjusting screws. The carriage mounted on one pair of precision guides is displaced by a rack system, which is controlled remotely. The two carriages on the other pair of guides are displaced manually. Between the guide pairs are rotating tables for mounting surveyor’s tapes and measuring wires of length up to 25 m.

The effects of external factors on the measurements are reduced by mounting the ILK-25 on seismically decoupled bases in a building having a basement at a depth of 5 m. Also, as it is necessary to correct for the refractive index of the medium in all forms of measurement involving electromagnetic radiation, we examined the temperature patterns in the comparison zone under conditions of forced heating and natural cooling. This defined the optimum modes of operation on the comparator with various types of ranging system and with linear-displacement meters. The metrological parameters in the comparator room were measured as follows:

1) temperature with quartz temperature sensors type PTKI-01A, error 0.07°C;
2) pressure with a mercury inspector barometer type IR having an error of 0.25 mm Hg;
3) humidity with an Assman aspiration psychrometer, error about 10%.

The estimated relative error in correcting for the refractive index of the air was taken as $2 \cdot 10^{-7}$.

The metrological characteristics of the interference-type linear comparator are determined by the adjustment of the guides and of the laser interference system for measuring linear displacements, with which the comparator is equipped. The guide adjustment in the ILK-25 was performed by means of the reference axis of the supporting guide provided by the ring structure in the laser beam \[4\]. The laser method of centering has substantial advantages over ordinary optical method, the main ones being the high accuracy, the long range, the throughput, and the objectivity.

The ILK-25 guides were adjusted with a three-element ring collimator, an LGN-208 laser, and a target consisting of black concentric circles on a white background with a step of 10 mm between them. The adjustment was performed as follows. The laser and the ring collimator were set up in front of one of the ends of the guides. The mobile carriage bore the target, which was oriented towards the laser. Displacement of the laser and ring collimator one relative to the other produced a clear-cut interference pattern in the plane of the target, which was located at the far end of the guides in a position concentric relative to the center of the target. The bright spot for the zero interference order was then exactly at the center of the target.

One displaces the carriage to the near end of the guides and again brings about coincidence between the zero order and the center of the target. This operation is repeated until there is no further need for adjustment in the setting of the carriage in the end positions. Then one checks the rectilinearity of the displacement. For that purpose, one displaces the carriage from the far end to the near one, successively stopping it at the points of the adjustment supports for the guides. If the zero-order interference spot deviates from the center of the target, coincidence is provided by regulating the adjusting supports. The displacement of the carriage is taken as rectilinear if the zero-order spot remains always at the center of the target as it moves along the guides. Then the deviation from rectilinearity does not exceed 0.25 mm.

The ILK-25 comparator is equipped with a Razmer-2K laser interferometer system, which is slightly inferior to foreign analogs as regards working characteristics \[5\] but on the whole corresponds to the requirements for comparison with rangefinders. In certain measurements, we used an LMS-100 laser interferometer system certified by group comparison. On the whole, the ILK-25 has an error of \(0.3 + 3 \times 10^{-7} \text{ L } \mu \text{m}\), where \(L\) is the comparison length in micrometers.

This comparator was used to define the following metrological characteristics of the IPL-FD long-range laser phase displacement meter in the UVT 5-84:

- \(\Delta_1\) — the error component due to coupling between the data channels and interference at frequencies multiples of the frequency obtained on transforming the laser radiation (phase cycle error);
- \(\Delta_2\) — the error component due to inhomogeneity in the phase of the electromagnetic waves across the section of the probe beam;
- \(\Delta_3\) — the error component due to distortion of the working signal in the photocell zone;
- \(\Delta_4\) — the error component due to amplitude and phase dependence in the receiving system; and
- \(\Delta_5\) — the error component due to drift.

Component \(\Delta_1\) was determined as follows. The carriage with rigidly mounted triple-prism reflector was set successively at distances of 1.5, 15, and 20 m from the IPL-FD. In each position we measured the carriage displacement length with a step of 20 mm over a distance of 1000 mm. The measurements were made simultaneously with the IPL-FD and Razmer-2K systems. The error in the phase cycle was found to be less than 0.04 mm, namely the spread in the measurement results.

To estimate \(\Delta_2\), the IPL-FD reflector was set at a distance of 25 m. A mask was fitted to the receiving lens of the IPL-FD having a hole with a diameter of 5 mm (the diameter of the beam arriving at the lens was 15 mm). Then the reflector was displaced upwards the downwards and to left and to right. In each displacement, we recorded the reading on the digital display of the IPL-FD units. The reflected beam thus arrived at various points on the lens when the reflector was displaced. Cross-type displacements of the reflector enabled us to determine the mean phase error over the cross section of the laser beam was less than the spread in the readings, i.e., less than 0.04 mm.

We determined \(\Delta_3\) by a method analogous to that for determining \(\Delta_2\), the difference being that the reflector was set at 15 m, while the mask was removed from the IPL-FD receiving objective. The reflected beam thus arrived at various points on the lens when the reflector was displaced. Cross-type displacements of the reflector enabled us to determine the mean phase error over the objective, which was 0.15 mm.

We estimated \(\Delta_4\) as follows. The reflector was placed at 25 m from the IPL-FD. The digital display in the IPL-FD electronics recorded a series of 11 readings. Then the laser beam (before the receiving lens) was partly covered and a fresh series of readings was taken. The difference between the averaged readings is the estimated value of \(\Delta_4\), which was 0.04 mm.

The estimate for the error component \(\Delta_5\) was obtained from measurements on a fixed length over four hours with a time step of 15 min. The value was 0.03 mm.

We also estimated the error due to frequency instability in the reference oscillator, which was \(5 \times 10^{-8}\).