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REMEASUREMENT OF THE STANDARD BASE LINE LOENERMARK

by

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PREFACE

Since 1957, when the standard base line "Loenermark" was established by our Finnish colleagues Prof. Dr. T. J. KUKKAMÄKI and Prof. Dr. T. HONKASALO, its length has served many times for the calibration of invar tapes used in primary geodetic measurements. The most important of these measurements were: remeasurement of the German base line near Meppen (1960) and measurement of the new 24 km - long triangulation base line "Afsluitdijk" in The Netherlands (1965).

Moreover the standard base has proved its value in calibrating electromagnetic distance measurement instruments, since exactly in the years after 1957 many such instruments appeared in this field. In this way the base line was used in accordance with the ideas of Prof. Dr. W. HEISKANEN, former Director of the Finnish Geodetic Institute, expressed in Resolution No. 2 adopted at the 10th General Assembly of the International Association of Geodesy (Rome, 1954).

Since the length of the base line is given to one hundredth of a millimeter (relative accuracy 1 in 10^7) small displacements of the underground markers seriously affect the length of the base and consequently its accuracy. In a country with a rather unstable sub-soil like The Netherlands such displacements are not unlikely in the course of years. At the 14th General Assembly of the International Association of Geodesy (Lucerne, 1967) this question was discussed with the present Director of the Finnish Geodetic Institute, Prof. Dr. T. J. KUKKAMÄKI, who was of the same opinion. He kindly offered to have the base remeasured by Finnish scientists using the same equipment as in 1957. The remeasurement became the more urgent when Dr. K. D. FROOME, National Physical Laboratory, Teddington (U.K.) wished to test his Mekometer at a very accurately determined length and at the same time make a new determination of the velocity of light. The matter was discussed at a meeting of the Netherlands Geodetic Commission in December 1967, resulting in an official request to the Finnish Geodetic Institute for remeasuring the base. A favourable reply was received and the work was carried out in the autumn of 1969 by Prof. Dr. T. HONKASALO and Mr. P. GRÖHN. The results of the remeasurements are presented in this paper.

The Netherlands Geodetic Commission is very grateful to Prof. Dr. T. HONKASALO and Mr. P. GRÖHN, not only for the very accurate results that once again gave The Netherlands a reliable standard base, but also for the pleasant collaboration in carrying out this project. Sincere thanks are also due to the Netherlands Triangulation Service, in particular to Mr. HAARSMA who assisted our Finnish colleagues during the whole time of the remeasurement.

G. J. Bruins

REMEASUREMENT OF THE STANDARD BASE LINE LOENERMARK

1 Introduction

The International Association of Geodesy has recommended countries performing triangulation to establish a standard base line using the Väisälä comparator, or similar apparatus, for assuring a uniform scale in all networks, and for calibrating invar tapes and geodimeters. Such standard base lines have been measured in Finland, Argentina, The Netherlands, Western Germany, Portugal, Eastern Germany and USA.

The principle of the Väisälä comparator was first published in 1923 and the apparatus is described in detail e.g. in [13] and [2]. The measuring principle is the following:

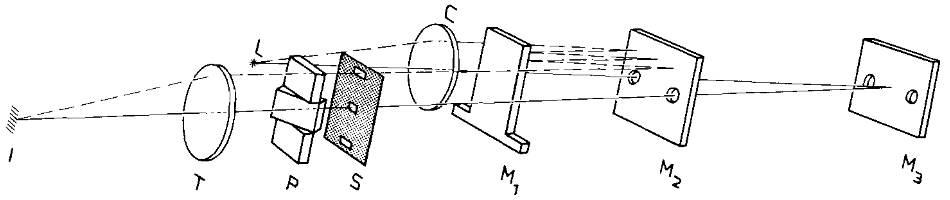

Fig. 1. Principle of the Väisälä comparator.

White light from a point-like source (L) is made parallel by a collimator lens (C) and divided by means of the mirror M_2 into two parts. While one part is reflected from mirrors M_1 and M_2 back and forth several times (in Fig. 1 three times), the other part travels the distance between mirrors M_1 and M_3 back and forth once. Both light beams meet in the focal plane of the telescope (T). If the lengths travelled by the beams are equal, diffraction interference fringes (I) appear on the image of the light spot. The fringes disappear as a result of different diffraction of different wavelengths in white light if the distances travelled by the beams differ by more than 1.3 μm from each other. High accuracy of comparison is attained when the achromatic central diffraction fringe is centred in the image.

In order to obviate the necessity for adjusting the mirrors to exact positions, two plane-parallel compensating glass plates (P) are interposed in the paths of the light beams. By turning one of the compensator plates the optical length of the beam in question can be increased by an amount which can be computed from the angle of rotation. Thus, the distance between the first two mirrors (M_1, M_2) can be multiplied by an integer number. In Fig. 1 the distance (M_1, M_3) is three times the distance (M_1, M_2) apart from the compensator correction. The distance (M_1, M_3) can further be multiplied in the same way. The first mirror distance (M_1, M_2) is measured by an end meter bar of fused quartz. The length of the meter bar is determined with the wavelength of light in the laboratory.

The Väisälä comparator is installed on concrete pillars and the measured mirror distance then projected to underground markers which are more stable than the concrete pillars. The longest standard base line measured with the Väisälä comparator has a length of 864 m.

The field measurements can be based on quartz meters which are stable and have small temperature coefficients, and refraction has a very small effect on the result, thus making the Väisälä comparator very accurate. In fact, only the difference of refraction indices at two mirror distances must be determined. This difference seldom exceeds a value of $5 \cdot 10^{-7}$. For the determination of the refraction correction several mercury thermometers are hung along the light beam.

Only two of the above mentioned standard base lines were measured more than once, viz. the Nummela standard base line in Finland and the Ebersberg standard base line in Western Germany. The Loenermark standard base line was for the first time measured in 1957. The second measurement of this base line in October 1969 is described in the present publication.

2 Measurements programme

The standard base line Loenermark was measured with light interference in 1957. It was a close cooperation between the Netherlands Geodetic Commission and the Finnish Geodetic Institute. The Netherlands Geodetic Commission built the underground markers, the concrete pillars for the comparator and made all necessary preparatory measurements. The instrument used was the Väisälä comparator of the Finnish Geodetic Institute. The observers, Prof. T. J. KUKKAMÄKI and Prof. T. HONKASALO, were assisted by Ir. M. HAARSMA, Ir. J. C. MUNCK and Mr. H. A. VERHOEF.

As control on the stability of the standard base was considered necessary, the Netherlands Geodetic Commission approached the Finnish Geodetic Institute as to remeasurement of the base line. The latter made available for this purpose its comparator and two observers, Prof. T. HONKASALO and Mr. P. GRÖHN. The Netherlands Geodetic Commision paid the travelling and accomodation costs of the observers, the transport costs of the instruments and gave all necessary technical help at the site. Ir. M. HAARSMA assisted throughout the installation and measuring period. His kind and effective help made it possible to fulfil the task in spite of unfavourable weather conditions. The auxiliary instruments, theodolites, levelling instruments etc., were put at the observers' disposal by the Delft University of Technology.

It was planned to use the same quartz meters and make a new measurement of the total base line with the same accuracy as 12 years before. Also the comparator was the same as the one used in 1957. It was installed on the pillars from 23rd September to 1st October 1969.

The interference measurements of distance 288 m were performed on October 2, 3, 7, 14, 15, 21, 22 and 25 and those of distance 576 on October 24, 25 and 26. Exceptional clear and sunny days made the work difficult, but the expected degree of accuracy was obtained.

The projections of the measured distances to the underground markers were made on the following dates:

0-m mirror:	Sep. 26, Oct. 6, 26 and 27
288-m mirror:	Sep. 30, Oct. 15 and 27
576-m mirror:	Sep. 27, Oct. 20 and 27

3 The quartz meters

The distance measurement with the Väisälä comparator is based on end meter bars of fused quartz. The end surfaces of the bars are spherical. Comparison of these meters with an accuracy of 0.01 μm is made with the aid of Newton fringes using a special comparator.The meters, about 60 in all, thus form a system of their own with high inner accuracy.

The absolute lengths of some quartz meters have been determined in various laboratories:

Table 1. Determinations of absolute lengths of quartz meters

no.	year	quartz meter	reference	standard of length	length 1 m + μm	standard error	adjusted value μm	difference
1	1932	XV	[6]	Finnish prototype No. 5	−2014.63	±0.3	−2014.20	−0.43
2	1932	I	[6],[8]	German prototype No. 18	+ 324.5		+ 325.43	−0.93
3	1933	VIII	[6]	German prototype No. 18	+ 150.3	±1	+ 150.96	−0.66
4	1952	XI	[9]	^{198}Hg green line	+ 136.20	±0.5	+ 136.96	−0.76
		21			− 94.44	±0.5	− 93.40	−1.04
5	1953	VIII	[10]	^{198}Hg green line	+ 149.89	±0.1	+ 150.94	−1.05
		XI			+ 135.94	±0.1	+ 136.97	−1.03
6	1964	42	[15]	^{86}Kr primary standard line	+ 34.21	±0.05	+ 34.20	+0.01
		53			+ 34.57	±0.05	+ 34.58	−0.01
7	1965	53	[11]	^{86}Kr primary standard line	+ 35.07	±0.02	+ 34.59	+0.48
8	1966	53	[12]	^{86}Kr primary standard line	+ 34.84	±0.03	+ 34.60	+0.24
9	1967	several	[15]	^{198}Hg green line		±0.04		+0.12

To study the constancy of the lengths of the quartz meters, all intercomparisons during the 38 years period between 1929-1967 ([6], [14] and data of recent comparisons) received from Y. VÄISÄLÄ) were adjusted with the least square method taking the lengths and their yearly changes as unknowns and supposing that the arithmetical mean of all meters does not change. According to this adjustment the standard error of one intercomparison of two meter bars was ±24 nm. This value includes the deviation from the linearity of the change. A second order term of the change was computed for meter No. XI, since this meter had shown an exceptionally large change (cf. [4] p. 14). In most cases the changes were only some nanometers per year. This adjustment also proves the good constancy of the quartz meters.

The first field measurements [2] were based on a microscopic comparison with the Finnish prototype meter No. 5, in 1933 (determination No. 1 in Table 1). Since the comparison with the wavelength of light in 1953 by the Bureau International des Poids et Mesures (BIPM) in Sèvres (No. 5 in Table 1) was considered to be much more accurate than the previous determinations, the lengths derived from it were used for all international measurements of standard base lines during the period 1953–1964. This decreased the scale of the earlier measurements by $0.6 \cdot 10^{-6}$. In 1964 two Väisälä quartz meters were compared by the Physikalisch-Technisches Bundesanstalt (PTB) in Braunschweig with the new standard of the metre, the wavelength of ^{86}Kr orange line (No. 6 in Table 1). The results showed a length more than 1 μm longer than the BIPM values. Because of the great difference between these two results Professor Y. VÄISÄLÄ decided to study this question. He made a provisional absolute length determination of several quartz meters (No. 9 in Table 1). His results agreed well with the PTB calibrations. The difference was 0.12 μm. Since VÄISÄLÄ made his determinations using the green wavelength of ^{198}Hg in normal air pressure he considered the PTB calibration to be more accurate and recommended the use of it for international work. In the BIPM too, two additional determinations were carried out in the years 1965 and 1966 (Nos. 7 and 8 in Table 1).

The adjustment of all quartz meter comparisons combined all absolute measurements performed on these meters into one and the same system and made it possible to compare the results. The last column in Table 1 shows these comparisons in the form of deviation from the PTB value. Since the determinations Nos. 5, 7 and 8 in Table 1 by the BIPM do not fit together and none of these agree with the results of PTB and VÄISÄLÄ, it was considered that there must be some unresolved systematic error and therefore these values are not used here. Thus, based on the recommendation of Professor VÄISÄLÄ, the value and its standard error determined by the PTB are adopted for the Väisälä comparator measurements of the standard base lines made by the Finnish Geodetic Institute. All the international base line measurements have been recomputed into the PTB system [5]. The scale of the measurements in 1953–1964 was thus increased by $+1.03 \cdot 10^{-6}$.

In the adjusted system with lengths based on PTB calibration, the lengths of the meters used for the Loenermark standard base line measurements in 1957 and 1969 are:

$$\text{No. VIII:}\quad 1\text{ m} + \{150.92 - 0.00140(\alpha - 1964.5) + 0.430(t - 20°) + 0.00159(t - 20°)^2 - \\ - 0.00347(B - 760)\}\ \mu\text{m}$$

$$\text{No. XI:}\quad 1\text{ m} + \{137.05 + 0.00397(\alpha - 1964.5) - 0.0030(\alpha - 1964.5)^2 + 0.434(t - 20°) + \\ + 0.00159(t - 20°)^2 - 0.00477(B - 760)\}\ \mu\text{m}$$

In standard conditions (20°, 760 mm Hg) the lengths were:

	No. VIII	No. XI
1957:	1 m + 150.93 µm	1 m + 137.01 µm
1969:	1 m + 150.91 µm	1 m + 137.06 µm

of which the former values were used for recomputation of the 1957 measurement and the latter ones for computation of the 1969 measurement.

4 Refraction correction

In the Väisälä comparator method the total refraction need not be considered. Only the differences of the refraction indexes at different mirror distances are needed. In open air only the air temperature differences need be measured. As in 1957, this was done with mercury thermometers which now (1969) had a more effective radiation shield. The mercury bulb was placed between two aluminium plates, 14 cm in diameter. In addition, during the shortest interference measurements an electrical resistance thermometer was used to determine any systematic effects caused by radiation of the concrete pillars or the tent which covered the telescope and the first mirror pillars. The locations and the corrections of the calibrated mercury thermometers used are given in Table 2.

The thermometers were read by two observers during the interference observations, one observer starting from the thermometer at 0-m mirror and the other one from the first thermometer behind the last mirror in question. Both observers went once symmetrically

Table 2. Location of thermometers

distance from 0–m mirror in metres	thermometer no.	thermometers read at interference observations					corrections to the thermometer readings at temperatures				
		6	24	96	288	576	+5°	+10°	+15°	+20°	+25°
Q in	3854	×					+0.02	+0.02	+0.08	+0.10	0.00
Q out	3855	×					+0.04	+0.06	+0.14	+0.14	+0.02
0	11131	×	×				−0.04	−0.02	−0.05	−0.09	−0.11
1	11133	×	×				−0.01	+0.01	−0.03	−0.07	−0.08
2	11134	×	×				−0.06	+0.02	−0.02	−0.06	−0.06
4	11135	×	×	×	×	×	−0.06	0.00	−0.04	−0.08	−0.10
9	11136	×	×	×			−0.07	−0.01	−0.02	−0.04	−0.06
15	11137		×	×	×		−0.04	+0.05	0.00	−0.05	−0.04
21	11138		×	×			−0.02	−0.05	−0.08	−0.11	−0.10
36	11139		×	×	×	×	−0.08	−0.04	−0.06	−0.08	−0.10
60	11140			×	×		−0.06	+0.01	−0.03	−0.07	−0.08
84	11141			×	×	×	−0.06	−0.01	−0.03	−0.06	−0.08
120	11142			×	×	×	−0.06	−0.03	−0.04	−0.05	−0.08
168	4477				×	×	+0.06	+0.05	+0.04	+0.01	−0.02
216	4478				×	×	−0.04	−0.04	−0.04	−0.01	+0.02
264	4479				×	×	0.00	−0.03	−0.06	−0.05	−0.04
312	4480				×	×	−0.02	+0.02	+0.06	+0.04	+0.02
360	4481					×	+0.02	+0.03	+0.04	+0.04	+0.04
408	4482					×	+0.06	+0.02	−0.02	−0.04	−0.06
456	4483					×	0.00	−0.01	−0.02	−0.04	−0.06
504	4484					×	+0.02	+0.03	+0.04	+0.06	+0.08
552	4485					×	0.00	−0.01	−0.02	−0.02	−0.02

to and from the measured distance. The mean temperatures in the space between the mirrors were calculated from the means of four readings of each thermometer. The air temperature difference between the last and zero mirror minus mean temperature between the middle mirror and zero mirror was calculated. Assuming that the temperature changes linearly from one thermometer to another we get the following formulas for computing the temperature differences:

$$\left.\begin{aligned}
t_{(0,6)}-t_{(0,1)} &= 1/60\,(-25t_0-20t_1+15t_2+26t_4+4t_9)\\
t_{(0,24)}-t_{(0,6)} &= 1/80\,(-5t_0-10t_1-15t_2-23t_4+13t_9+20t_{15}+19t_{21}+t_{36})\\
t_{(0,96)}-t_{(0,24)} &= 1/960\,(-195t_4-165t_9-180t_{15}-123t_{21}+183t_{36}+240t_{60}+\\
&\quad +220t_{84}+20t_{120})\\
t_{(0,288)}-t_{(0,96)} &= 1/288\,(-19t_4-32t_{15}-45t_{36}-48t_{60}-36t_{84}+36t_{120}+48t_{168}+\\
&\quad +48t_{216}+42t_{264}+6t_{312})\\
t_{(0,576)}-t_{(0,288)} &= 1/288\,(-10t_4-20t_{36}-21t_{84}-21t_{120}-24t_{168}-24t_{216}-18t_{264}+\\
&\quad +18t_{312}+24t_{360}+24t_{408}+24t_{456}+24t_{504}+24t_{552})
\end{aligned}\right\} \quad (1)$$

These formulas were first used for calculating the correction caused by calibration corrections in Table 2. The result is given in Table 3.

Table 3. Corrections for Δt caused by thermometer calibrations

interference	temperatures				
	5°	10°	15°	20°	25°
(0, 1, 6)	−0°.026	+0°.009	+0°.007	+0°.008	+0°.010
(0, 6, 24)	+0 .005	−0 .005	−0 .001	+0. 002	+0 .012
(0, 24, 96)	−0 .011	−0 .009	−0 .005	−0 .001	−0 .008
(0, 96, 288)	+0 .034	−0 .006	+0 .008	+0 .030	+0 .035
(0, 288, 576)	+0 .022	+0 .013	+0 .020	+0 .022	+0 .024

The temperature differences for the refraction correction were first calculated with raw uncorrected temperature readings and then corrected with the interpolated corrections from Table 3.

The refraction correction was then computed on the basis of the corrected temperature differences by the formula:

$$r_{\Delta t} = s\cdot\frac{\mathrm{d}n_L}{\mathrm{d}t}\cdot\Delta t \quad \ldots\ldots\ldots\ldots\ldots\ldots \tag{2}$$

where s indicates the distance and n_L the refractive index of the air in ambient conditions. The latter was computed for $\lambda = 570$ nm with the aid of formulas recommended in resolution No. 9 of the XIIIth General Assembly of the International Union of Geodesy and Geophysics (Berkeley, 1963). The values of $\mathrm{d}n_L/\mathrm{d}t$ at different temperatures and pressures are given in Table No. 4. Since the relative humidity has little influence, the table was computed for an average relative humidity of 90 per cent (cf. [7] p. 48).

Table 4. $10^6\cdot(\mathrm{d}n_L/\mathrm{d}t)$

t °C	B_{Torr}		
	750	760	770
+ 5	1.056	1.070	1.084
+10	1.018	1.032	1.045
+15	0.982	0.996	1.009
+20	0.949	0.961	0.974
+25	0.916	0.928	0.941

These values deviate slightly from the earlier ones ([1] p. 25) which were computed on the basis of resolution No. 3 of the XIIth General Assembly of the International Union of Geodesy and Geophysics (Helsinki, 1960). The differences are so small that they have no effect on the final result. The irregular variations of the air pressure along the base line are so small that no correction is needed. Only the permanent air pressure difference due to inclination of the base line must be taken into consideration. Differentiating the refraction index formula:

$$n_L = 1 + \frac{n-1}{1+\alpha t}\cdot\frac{p}{760} - \frac{0.000\,000\,055\cdot e}{1+\alpha t}$$

in respect to p, we get:

$$\frac{\partial n_L}{\partial p} = \frac{n-1}{1+\alpha t} \cdot \frac{1}{760}$$

or numerically:

$$10^6 \cdot \mathrm{d}n_L = (0.3991 - 0.00146t)\,\mathrm{d}p \quad \ldots \quad (3)$$

when dp is indicated in Torr. This correction is small in Loenermark and can be considered constant for all measurements. However, the air temperature difference corrections were computed for every measurement separately.

5 Interference measurements

The plan was to make several measurements up to 288 m and double it as many times as the weather would allow. The weather conditions were poor for this type of work, sunny during the day and a clear sky at night. The refraction corrections were exceptionally large and fog often interrupted the work. The observation programme was similar to the one of 1957. We started from the longest interference and made the shortest multiplications (0-1-6) and (0-6-24) four times, then continued backwards with longer interferences as far as possible. A complete set of one night's observations was:

1. (0---------------96---------------288)
2. (0-------24-----96)
3. (0---6--24)
4. (0-1-6)
5. (0-1-6)
6. (0---6---24)
   change of observer
7. (0---6---24)
8. (0-1-6)
9. (0-1-6)
10. (0---6---24)
11. (0---------------96)
12. (0---------------96--------------288)

During all interference observations the air temperatures were recorded symmetrically by two observers and during the shortest interferences (0-1-6) the differential thermometer was also read. The quartz meters were reversed 180° between steps 4 and 5 as well as between 8 and 9.

Table 5 gives the results of the interference measurements for the 6 m and 24 m distances. The distance(0,1) is not constant since the 1-m mirror must be adjusted separately every time. For computing the refraction correction the mean of mercury thermometers and differential thermometer was used.

Table 5. Compuatation of interference measurements for 6 m and 24 m distances

date	meter no.	observer	temperature	distance (0,1)	compensator correction	refraction correction with diff. thermom.	refraction correction with merc. thermom.	distance (0,6)	compensator correction	refraction correction	distance (0,24)
				1 m +				6 m +			24 m +
Oct.				μm	μm	μm	μm	μm	μm	μm	μm
2	XI	H	+9°.85	+139.70	+13.24	−0.44	−0.12	+851.16	+153.61	−1.42	+3556.83
		H	+10.00	+134.32	+46.28	+0.01	−0.63	+851.89	+152.18	−0.99	3558.75
		G	+10.41	+136.35	+32.43	−0.41	−0.34	+850.15	+152.97	−0.54	3553.03
		G	+10.61	+137.76	+23.60	+0.38	−0.33	+850.18	+155.04	−0.95	3554.81
						−0.12	−0.36	+850.84	±0.42		3555.85±1.24
3	VIII	G	+16.13	+152.22	−57.80	−0.19	−0.29	+855.28	−31.70	−0.27	3389.15
		G	+15.95	+152.79	−60.27	−0.04	−0.32	+856.29	−32.53	+0.20	3392.83
		H	+15.63	+151.17	−51.10	−0.29	−0.25	+855.65	−33.08	+0.42	3389.94
		H	+15.53	+150.72	−49.47	−0.43	−0.75	+854.26	−33.64	−0.15	3383.25
						−0.24	−0.40	+855.37	±0.42		3388.79±2.01
7	XI	H	+20.98	+140.36	+11.43	+1.04	−0.50	853.86	−22.22	+0.09	3393.31
		H	+20.83	+140.18	+13.56	+0.30	−0.98	854.30	−31.78	−0.21	3385.21
		G	+19.56	+141.00	+10.58	−0.36	−0.82	855.99	−34.30	−0.46	3389.20
		G	+19.28	+139.70	+17.86	−0.34	−0.89	855.44	−40.70	−0.79	3380.27
						+0.16	−0.80	854.90	±0.49		3387.00±2.79
14	VIII	G	+16.78	+152.42	−28.02	−0.50	−1.41	885.59	−143.14	+0.09	3399.11
		G	+16.45	+152.67	−29.61	−0.60	−1.03	885.59	−144.35	−0.35	3397.66
		H	+15.53	+152.20	−25.41	−0.47	−1.22	886.95	−142.15	−0.39	3405.26
		H	+15.75	+150.94	−20.27	+0.64	+0.01	885.69	−139.74	+2.40	3405.42
						−0.23	−0.91	885.94	±0.34		3401.86±2.03
15	XI	H	+13.17	+138.44	+70.74	−3.50	−3.09	898.08	−174.49	−0.44	3417.39
		H	+12.36	+136.81	+80.49	−2.47	−2.75	898.74	−186.29	−1.14	3407.53
		G	+10.20	+137.22	+81.31	−4.24	−4.43	900.29	−186.29	−2.14	3412.73
		G	+ 9.58	+135.36	+89.92	−2.67	−3.20	899.14	−181.47	−8.10	3406.99
						−3.22	−3.37	899.06	±0.46		3411.16±2.44
21	VIII	G	+17.54	+152.81	−67.86	−0.04	−0.60	848.66	−18.97	+0.19	3375.86
		G	+17.47	+152.70	−66.26	−0.29	−0.88	849.36	−18.62	−0.13	3378.69
		H	+16.94	+153.50	−70.89	−0.25	−1.19	849.39	−17.93	−0.64	3378.99
		H	+16.87	+150.82	−54.72	+0.05	−1.15	849.65	−19.37	−1.24	3377.99
						−0.13	−0.96	849.26	±0.21		3377.88±0.71
22	XI	H	+16.48	+140.27	+10.47	+0.09	−0.32	851.97	−21.94	−0.08	3385.86
		H	+16.51	+136.95	+30.47	+0.10	−0.25	852.09	−24.24	−0.31	3383.81
		G	+16.07	+138.09	+24.37	−0.26	−0.55	852.51	−24.54	−0.40	3385.10
		G	+15.86	+138.56	+20.66	−0.12	−0.67	851.62	−25.19	−0.48	3380.81
						−0.05	−0.45	852.05	±0.18		3383.90±1.11
25	VIII	G	+11.86	+150.43	−66.41	+0.23	−0.12	836.23	+35.08	+0.59	3380.59
		G	+11.82	+150.21	−64.52	−0.36	−0.08	836.52	+32.26	−0.17	3378.17
		H	+11.73	+149.40	−59.17	−0.40	−0.38	836.84	+31.51	+0.16	3379.03
		H	+11.70	+150.08	−62.94	−0.19	−0.06	837.42	+28.99	+0.54	3379.21
						−0.18	−0.16	836.75	±0.26		3379.25±0.50

Table 6. Computation of the interferences (0-24-96)

date	observer	distance (0.24)	compensator correction	refraction correction	distance (0,96)	standard error of mean
		24 m + μm	μm	μm	μm	
Oct. 2	H	3555.8	+141.2	−2.5	14361.9	
	G		+127.9	−1.3	14349.8	
					14355.8	±6.0
3	G	3388.8	− 57.8	−2.6	13494.8	
	H		− 33.8	+1.0	13522.4	
					13508.6	±13.8
7	H	3387.0	− 26.6	+2.9	13524.3	
	G		− 16.5	−0.3	13531.2	
					13527.8	±3.5
14	G	3401.9	− 91.4	+2.4	13518.6	
			− 95.5	+0.8	13512.9	
					13515.8	±2.9
15	H	3411.2	−138.3	+2.8	13509.3	
21	G	3377.9	− 63.4	+3.9	13452.1	
	H		− 67.2	+1.0	13445.4	
					13448.7	±3.4
22	H	3383.9	− 54.7	+1.3	13482.2	
			− 49.3	−1.2	13485.1	
					13483.6	±1.5
25	G	3379.2	− 12.0	−1.5	13503.3	
			− 21.0	−4.2	13491.6	
					13497.4	±5.9

The standard error of the mean of 4 measurements for (0,6) m was ±0.36 μm on the average and for the distance (0,24) m it was ±1.78 μm. When the temperature drops fast during the measurement, the standard error is large. This is due partly to the contraction of the (0–1) m pillar and partly to the rapid varying refraction correction. The influence of pillar movement is for the most part eliminated from the end result if symmetrical sets of observations are made. A set of four measurements from the quartz meter up to 24 m lasted 50 minutes on the average. The average temperature change during this time was −1°.8 C. Only on one night did the temperature rise. The greatest drop recorded was more than 6°.

The distances (0,96) are computed in Table 6 on the basis of the mean values of (0,24) given in Table 5. Fog interrupted the measurement on October 15, and only one measurement was then possible to the 96 m distance.

The standard error of multiplying the measured distance (0,24) by 4 is ±6.5 μm if the measurements are taken with equal weights. The standard error of one set of measurements up to 96 m was:

$$\sqrt{(4\times 1.78)^2+6.5^2} = \pm 9.6\ \mu\text{m}$$

The distances of (0,288) m are computed in Table 7. Poor weather conditions made even

Table 7. Computation of the interferences (0-96-288)

date	ob-server	distance (0,96)	change of (0,96)	comp. correction	refraction correction	change of (0,288)	distance (0,288)	standard error of mean
		96 m + µm	µm	µm	µm	µm	288 m + µm	
Oct. 2	H	14355.8		− 4.2	− 4.3		43058.9	
3	G	13508.6		−71.8	+ 4.8		40458.8	
			+3.5	−49.2	+ 0.1	−2.0	40489.2	
							40474.0	±15.2
7	H	13527.8		−24.3	− 8.6		40550.5	
14	G	13515.8		−34.4	+ 0.8		40513.8	
	H			−54.5	+ 9.1		40502.0	
							40507.9	±5.9
15	H	13509.3		−45.1	−11.0		40471.8	
21	G	13448.7		+88.2	− 4.5		40429.8	
22	H	13483.6		+ 6.7	− 9.2		40448.3	
	G		+2.5	−11.4	+11.2	0.0	40458.1	
							40453.2	±4.9
25	G	13497.4		−42.9	− 9.2		40440.1	
	H			−49.5	−27.2		40415.5	
							40427.8	±12.3

this distance difficult to measure. When the sky was only lightly clouded or totally clear the temperature drop was often so rapid that fog interrupted the work. For that reason there was only one interference measurement for (0,288) on October 2nd, 7th, 15th and 21st. On October 3rd and 22nd the second measurement was possible after a readjustment of mirrors 0,96 and 288, which was necessary due to the changed refraction conditions. The small movements of the mirrors on the pillars were measured with the transferring device as described in [1] p. 35. The accuracy of the transferrring apparatus is so high that these changes do not decrease the accuracy essentially.

The standard error of multiplying the distance (0,96) by 3 was ± 10.5 µm in cases when two measurements were performed. The standard error of one set of measurements up to 288 m was then:

$$\sqrt{(3\times 9.6)^2+10.5^2} = \pm 31\ \mu\text{m}$$

and in cases of one measurement (0-96-288) only:

$$\sqrt{(3\times 9.6)^2+(14.9)^2} = \pm 32\ \mu\text{m}$$

On October 15th, with only one measurement to (0-24-96), the standard error is:

$$\sqrt{(3\times 11.6)^2+14.9^2} = \pm 38\ \mu\text{m}$$

Table 8. Computation of the distances between the transferring bars

date	quartz meter no.	l_6	ΔL_6	B_6	l_{24}	ΔL_{24}	B_{24}	l_{96}	ΔL_{96}	B_{96}	l_{288}	ΔL_{288}	B_{288}
		6 m +		6 m +	24 m +		24 m +	96 m +		96 m +	288 m +		288 m +
Oct.		mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
2	XI	0.851	+1.669	−0.818	3.556	+9.327	−5.771	14.356	−1.404	+15.760	43.059	+4.505	+38.554
3	VIII	0.855	1.662	0.807	3.389	9.137	5.748	13.509	2.276	15.785	40.474	1.865	38.609
7	XI	0.855	1.658	0.803	3.387	9.132	5.745	13.528	2.275	15.803	40.550	1.875	38.675
14	VIII	0.886	1.675	0.789	3.402	9.148	5.746	13.516	2.279	15.795	40.508	1.872	38.635
15	XI	0.899	1.689	0.790	3.411	9.152	5.741	13.509	2.283	15.792	40.472	1.867	38.605
21	VIII	0.849	1.670	0.821	3.378	9.161	5.783	13.449	2.283	15.732	40.430	1.857	38.573
22	XI	0.852	1.659	0.807	3.384	9.141	5.757	13.484	2.281	15.765	40.453	1.848	38.605
25	VIII	0.837	1.634	0.797	3.379	9.133	5.754	13.497	2.278	15.775	40.428	1.841	38.587
			mean:	−0.804			−5.756			+15.776			+38.605
		standard error:		±0.004			±0.005			± 0.008			± 0.013

This evaluation may be considered as optimistic, but it is only used for the estimation of weights of observations.

Since refraction conditions vary from night to night and also in the course of one measuring set, it is necessary to adjust the directions of the mirrors. This causes small changes in the distances between the mirrors. For longer interferences the middle mirror must be removed from its position and later replaced. To make it possible to combine all measurements performed over a longer period, the positions of the mirrors on the pillars with respect to the steel bar were measured with the transferring device after every interference measurement. This device consists of a sensitive transversal striding level and a micrometer screw. The change in difference of the transferring device micrometer readings expresses the change of the distance between the two mirrors. The results of the interference measurements on different days are collected in Table 8, where:

l_ν = measured distance between mirrors 0 and ν m
ΔL_ν = difference of the transferring device micrometer readings on ν- and 0-pillars
$B_\nu = l_\nu - \Delta L_\nu$

The distance between the index bars is:

B_ν + the thickness of the 0-mirror

The rapid changes in refraction conditions during the night sometimes made it impossible to carry out the whole set of observations without readjustment of the mirrors. The changes in position of the mirrors were measured with the transferring device and taken into consideration in Table 7 as "change of distance" from the starting position.

Experience has shown that the two following effects are the main sources of errors in the long interference measurements: (a) systematic refraction effects and (b) movements of the concrete pillars. Both errors can be detected by the interference mesasurement. Computation of the distances between the various transferring bars gives the following results:

$$
\begin{aligned}
(6{,}24) &= 18\text{ m} + 4.952 \pm 0.0026\text{ mm}\\
(6{,}96) &= 90\text{ m} + 16.580 \pm 0.0055\text{ mm}\\
(6{,}288) &= 282\text{ m} + 39.409 \pm 0.0126\text{ mm}\\
(24{,}96) &= 72\text{ m} + 21.532 \pm 0.0036\text{ mm}\\
(24{,}288) &= 264\text{ m} + 44.361 \pm 0.0103\text{ mm}\\
(96{,}288) &= 192\text{ m} + 22.830 \pm 0.0085\text{ mm}
\end{aligned}
$$

Comparison of the relative errors:

(0,6): 7.0×10^{-7}
(0,24): 2.1×10^{-7} (6,24): 1.4×10^{-7}
(0,96): 0.85×10^{-7} (6,96): 0.61×10^{-7} (24,96): 0.50×10^{-7}
(0,288): 0.46×10^{-7} (6,288): 0.45×10^{-7} (24,288): 0.39×10^{-7} (96,288): 0.44×10^{-7}

shows that the errors of distances from the 0-mirror are the greatest. Obviously the movement of (0,1)-pillar is the greatest, as in most base lines, but it is so small that its influence on longer distances can be neglected.

Table 9. Weight of observations

date	maximum temperature differences at interferences					weights of measured distances				
	(0-1-6)	(0-6-24)	(0-24-96)	(0-96-288)	(0-288-576)	(0,6)	(0,24)	(0,96)	(0,288)	(0,576)
Oct.										
2	0°.21	0°.20	0°.08	0°.26		4.8	2.4	2.0	1.20	
3	0 .12	0 .12	0 .11	0 .09		8.3	4.2	2.9	2.27	
7	0 .30	0 .23	0 .16	0 .33		3.3	1.9	1.4	0.88	
14	0 .28	0 .27	0 .12	0 .22		3.6	1.8	1.5	1.12	
15	0 .94	0 .77	0 .45	0 .48		1.1	0.6	0.3	0.25	
21	0 .34	0 .15	0 .10	0 .19		2.9	2.0	1.7	1.15	
22	0 .16	0 .11	0 .06	0 .25		6.2	3.7	3.0	1.73	
24					0°.17					5.9
25	0 .06	0 .06	0 .11	0 .23	0 .12	16.7	8.3	4.3	2.17	8.3
26					0 .30					3.3

For computing the weights of the refraction corrections the maximum temperature differences along the measured distance were considered. In Table 9 the quadratic means of these are given. If the refraction effects were the only sources of errors, the weights should be inversely proportional to the squares of the temperature differences. Because of other sources of errors this would give too large weight differences. In Table 9 the weights of observations are calculated with the formula:

$$p = \frac{1}{\Sigma \Delta t}$$

The influence of the lacking second half of the observation set was taken into consideration with the aid of standard errors on page 14.

Weighted means for the distances of the transferring bars from 0-m bar are:

$$
\begin{aligned}
B_6 &= 6\text{ m} + 0.803 \pm 0.003\text{ mm}\\
B_{24} &= 24\text{ m} - 5.756 \pm 0.004\text{ mm}\\
B_{96} &= 96\text{ m} + 15.733 \pm 0.007\text{ mm}\\
B_{288} &= 288\text{ m} + 38.602 \pm 0.012\text{ mm}
\end{aligned}
$$

The decrease of the standard errors for every distance indicates that the estimation of weights has been successful.

The question of systematic refraction correction errors due to radiation of the concrete pillars or due to the tent above the two first pillars was studied. In Table 5 we find a small systematic difference of refraction correction between the differential thermometer and the mercury thermometers. If we use the differential thermometer only for the measurement of the shortest distances (0-1-6), the average standard error of the distance (0,6) will be ±0.36 μm, with the mercury thermometers ±0.39 μ and with the mean of both ±0.36 μm. So there is no significant difference in the inner accuracy. The distance (0,288), when computed with the differential thermometer only, will be:

$$B_{288} = 288\text{ m} + 38.611 \pm 0.013\text{ mm}$$

and with the mercury thermometers only:

$$B_{288} = 288\text{ m} + 38.593 \pm 0.011\text{ mm}$$

There is no correlation between the end result and the refraction correction of interference (0-1-6) with the differential thermometer or with mercury thermometers or the total refraction correction of distance (0,288). Consequently we have used the mean of both thermometers. As compared with earlier measurements the radiation shields now used are better than before. The total refraction correction for B_{288} is −28 μm only.

The different quartz meters give the same result, viz.

No. XI: $B_{288} = 288\text{ m} + 38.605 \pm 0.025\text{ mm}$
No. VII: $B_{288} = 288\text{ m} + 38.600 \pm 0.012\text{ mm}$

There is no significant difference between the observers. Based on the values for distance (0,24) in Table 5, the difference of the results of the two observers for distance (0,288) was: 0.010 ±0.017 mm.

On the basis of the investigation above the value:

$$\boxed{B_{288} = 288\text{ m} + 38.602 \pm 0.012\text{ mm}}$$

is taken as the final result. The computation of the total length of the base line is based on this value. The interference (0-288-576) was observed three times. The computation of the result is given in Table 10.

The standard error of B_{576} is:

$$\sqrt{(2 \times 0.012)^2 + 0.002^2} = \pm 0.024\text{ mm}$$

Table 10. Computation of distance (0,576)

date Oct.	time	ΔL_{288}	l_{288}	comp. corr.	refr. corr.	l_{576}	ΔL_{576}	B_{576}	weight
			288 m +			576 m +		576 m +	
		mm	mm	mm	mm	mm	mm	mm	
24	25h33m	−2.339	40.941	−0.152	−0.017	81.713	+6.117	75.596	5.9
25	20 24	−1.841	40.443	−0.177	+0.013	80.722	+5.132	75.590	8.3
26	15 46	−1.842	40.444	−0.167	+0.010	80.731	+5.134	75.597	3.3
						weighted mean:		75.593	
						standard error of mean:		± 0.002	

The value obtained for the total distance measured with interference is thus:

$$\boxed{B_{576} = 576\ \text{m} + 75.593 \pm 0.024\ \text{mm}}$$

6 Projection measurements

During the interference measurements the places of the mirrors on the top of the pillars were fixed to the transferring bars with the aid of the transferring device. Thus, the distances between the transferring bars were measured. Usually the pillars can be considered as immovable during the measuring period. This is not true for a longer time. The measured distances were therefore projected to the underground markers, placed on top a of concrete block under the A-shaped mirror pillars, but not forming part of these pillars.

The projection measurements were performed according to Fig. 2. The theodolite T (Zeiss Theo 010) was set up perpendicular to the baseline, opposite the underground bolt (U_0). The distance d from the theodolite to the mirror was measured with a steel tape. The distance i between the mirrors M_0 and M_{288} was measured with the interference comparator. The small distance b, the oblique distance of the mirror from the line of the underground bolts, was measured with another theodolite (Kern DKM 2), set up in line. Thus, when the angle U_0TM_{288} was measured, it was possible to compute the actual place of the

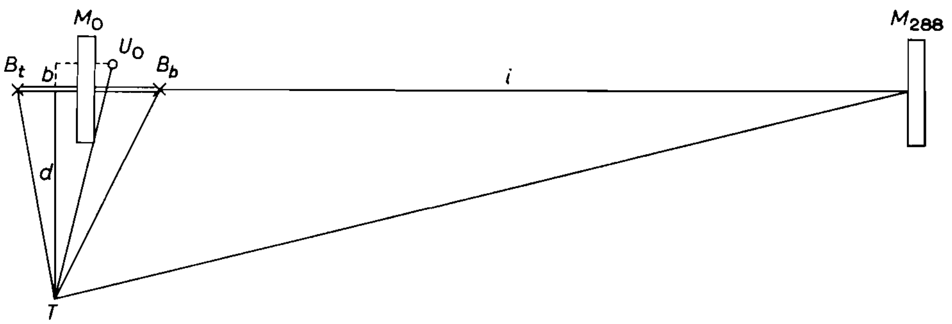

Fig. 2. Projection measurement

theodolite. A target B, a brass bar with a round hole as sighting index, was set up perpendicular to the centre of the mirror. From the angle measurements B_tTU_0 (target on the telescope side) and U_0TB_b (target on the back side) the distance from U_0 to the mirror centre was computed. To avoid large vertical angles a plumbing bar with conical lower end was set up into the hole of the underground bolt. The upper end of the bar, with a sighting hole similar to the target on the mirror, was just below the mirror support. So the elevation difference between the two targets was only 18 cm and observation with a small theodolite was possible.

The plumbing bar was set vertically using two levels. The level in the direction of the base line had a sensitivity of $6''.56$ per scale division. In order to eliminate asymmetry of the plumbing bar it was observed in two reversed positions. Before every projection measurement the mirror was moved to the vertical of the underground bolt and this location was determined with the transferring device. From every projection measurement the transferring device reading, which corresponds to the location of the mirror exactly above the underground marker, was computed. These readings L_0 are given in Table 11.

Table 11. Results of projection measurements

date	L_0	L_{288}	L_{576}
Sept. 26	12.449		
27			8.773
30		15.758	
Oct. 6	12.461		
15		15.799	
20			8.774
26	12.414		
27	12.431	15.792	8.766
mean	12.439	15.783	8.771
standard error	± 0.010	± 0.013	±0.003
ΔL_{288}	-3.344 ± 0.016		
ΔL_{576}	$+3.668 \pm 0.010$		

7 Length of the base line

The computation of the interference measurements has been described in section 5 and the projection measurements to the underground markers in section 6. For computing the horizontal distances between the underground markers several corrections are still needed.

7.1 *Thicknesses of the mirrors*

The thicknesses of the mirrors at the mean measuring temperature were, according to the information of Professor Y. VÄISÄLÄ:

pillar	mirror	thickness at +15 °C
0	VJ	20.116 mm
288	37	19.982 mm
576	41	19.958 mm

7.2 *Optical thickness of the coatings of the 0 and 1-m mirrors*

The determination of the distance (0,1) with the aid of a quartz meter bar gives the distance between the glass surfaces of the mirrors. The comparator light beam, however, reflects between the aluminium coatings. The aluminium coating is still covered with a SiO_2 layer. In order to consider the effect of these two layers their optical thickness is to be determined. This was done by the method of interferences between the light beams diffracted by two slits (cf. [2] p. 70). The measurements were made in Helsinki immediately before the comparator was sent to The Netherlands. The results were:

0-m mirror: -28 ± 3 nm
1-m mirror: -47 ± 4 nm

The optical thicknesses are negative due to the smaller velocity of light in the SiO_2 layer on the aluminium surface than in the air. Since the mirror distance (0,1) was measured with a quartz meter between glass surfaces but multiplied between aluminium surfaces, the correction for the coatings are:

(0,1) m: -0.075 µm
(0,288) m: -22 µm
(0,576) m: -43 µm

7.3 *Inclination correction*

The reduction to horizontality is based on levellings from the bench marks on the concrete pillars ([1] p. 44) and direct levelling of the mirrors during the installation of the instrument. The elevation differences were:

	0 m	288 m	576 m
Elevation of underground markers	0.0000 m	−1.2821 m	−2.5889 m
Height of the mirror above the underground marker	+2.8348 m	+2.8265 m	+2.8564 m
Elevation of mirror from 0-m underground marker	+2.8348 m	+1.5444 m	+0.2675 m
Elevation of mirror from 0-m mirror	0.0000 m	−1.2904 m	−2.5673 m

The height differences 1.2904 m and 2.5673 m give inclination corrections of −2.890 mm and −5.721 mm respectively for the measured distances 288.04 m and 576.08 m.

7.4 *The systematic difference in air pressure*

Owing to the inclination of the base line the average elevations of the measured distances (0,288) and (0,576) are 0.643 m and 1.281 m smaller respectively than the elevation of the initial distance (0,1) at the mean air pressure of the measuring period, 761 mm Hg and mean temperature, +15 °C. The systematic pressure differences were 0.058 mm Hg and 0.115 mm Hg. According to the formula (3) on p. 11 the corresponding corrections are − 0.006 mm and −0.025 mm respectively.

7.5 *Correction for deviation from parallellism of the mirrors*

The influence of refraction on the velocity of light was corrected for in the computation of interferences. Due to refraction the light beams are not straight lines, but the light was reflected back from the 576 m mirror 16 mm below the mirror centre on the average, though the comparator was installed in such a way that all the mirror centres were in a straight line. This means that the 576-m mirror has been tilted backward. The latter deviated 17″ from the perpendicularity to the centre line. Since during the projection measurements the sighting mark on the mirror was at the height of the mirror centre, the distance between the mirror centres was 0.001 mm greater than the distance measured with interferences. This causes a correction +0.001 mm to the distance (0,576).

7.6 *Correction to the level of the 0-m underground marker*

Since the standard base line is seldom used at the same elevation as the interference measurement is performed, the result of the remeasurement was reduced to the elevation of the 0-m underground marker. A height difference of 1 m causes a correction of 90 μm at the distance of 576 m. For the distance (0,288) the light beam runs 2.190 m and for the distance (0,576) 1.551 m above the 0-m marker. The corrections to the level of 0-m marker are:

Distance (0,288): −0.099 mm
Distance (0,576): −0.141 mm

7.7 *The measured length of the base line*

	(0,288)	(0,576)
	288 m	576 m
1. Result of interference measurements	+38.602 mm	+75.593 mm
2. Result of projection measurements ΔL_{288} and ΔL_{576}	− 3.344 mm	+ 3.668 mm
3. Half the thickness of 0-m mirror	+10.058 mm	+10.058 mm
Half the thickness of terminal mirror	+ 9.991 mm	+ 9.979 mm
4. Correction due to mirror coatings	+ 0.022 mm	+ 0.043 mm
5. Inclination correction	− 2.890 mm	− 5.721 mm
6. Refraction correction due to atmospheric pressure difference	− 0.006 mm	− 0.025 mm
7. Correction for deviation from parallellism of the mirrors		+ 0.001 mm
8. Correction to the level of 0-m underground marker	− 0.099 mm	− 0.141 mm
Horizontal distance of underground markers at the level of 0-m marker	288 m +52.334 mm	576 m +93.445 mm

8 Accuracy of the measurement

Since the standard errors of the interference measurements in section 5 were computed on the basis of the discrepancy of observations made during a period of 24 days, they include, besides the errors of the interference measurements itself, the errors of the refraction correction, the movements of the concrete pillars and the errors of the transferring device.

The projection measurements were made with a theodolite from an average distance of 2.3 m. The standard error of the measured angle between the underground marker and the mirror was ± 2.5 centesimal seconds. Thus, the standard error of one measured projection was ±9 µm. The results in Table 11 show greater discrepancies, obviously caused again by movements of the pillars. As the projection measurements, however, cover the whole period of interference observations, the standard errors of table 11 should be reliable.

The reduction to horizontality was made on the basis of two levellings, direct levelling and levellings from the bench marks in the concrete pillars. The two levellings agree within the limits of 0.3 mm. If we estimate this as the accuracy of the height differences, the error of reduction to horizontality is ±0.001 mm.

The standard error of the intercomparison of the quartz meters during a long period was shown on page 7 to be ±0.024 µm. We used two quartz meters in this base line measurement. The standard error of the Väisälä quartz meter system is thus ±10 µm for the length of the total base line.

The standard error of the absolute length of the quartz meter was estimated in PTB to be ±0.05 µm. This causes an error of ±0.03 mm for the absolute length of the Loenermark base line.

For the lengths of the horizontal distances (0,288) a (0,576) at the level of the 0-m underground marker we get the following standard errors:

	(0,288)	(0,576)
1. Standard error of interference measurements	± 12 µm	± 24 µm
2. Standard error of projection measurements	± 16 µm	± 10 µm
3. Standard error of inclination correction	± 1 µm	± 1 µm
4. Standard error of lengths of the quartz meters	± 5 µm	± 10 µm
Standard error of base line measurement	± 21 µm	± 28 µm
5. Standard error of the absolute length of quartz meters	± 14 µm	± 29 µm
Standard error of the absolute length of the base line	± 25 µm	± 40 µm

9 Final result of the remeasurement

The length of the Loenermark standard base line at the level of the 0-m underground marker was in October 1969, measured in the Väisälä quartz meter system:

first half	**288 052.33**	**±0.02 mm**
second half	**288 041.13**	**±0.02 mm**
total length base line	**576 093.46**	**±0.03 mm**

As compared to the international metre the standard errors are ±0.03, ±0.03 and ±0.04 mm respectively.

10 Constancy of the Loenermark standard base line

Before comparing the new result with the result of the 1957 measurements the mistake in the absolute determination of the lengths of the quartz meters by BIPM must be corrected (cf. p. 8). The new values for the lengths of quartz meters used in 1957 are:

meter No. VIII: ±1.03 µm longer than given in ([1] p. 26)
meter No. XI: ±1.04 µm longer than given in ([1] p. 26)

After recomputation the length of 1957 we get:

1957	
first half	288 051.93 ±0.02 mm
second half	288 040.93 ±0.02 mm
total length base line	576 092.86 ±0.03 mm

When the lengths obtained in 1969 are compared with the old ones, the changes are:

first half	+0.40 ±0.03 mm
second half	+0.20 ±0.03 mm
total length base line	+0.60 ±0.04 mm

The standard errors above are the observation errors. In addition, the accuracy of the stability of the quartz meter system must be estimated. The adjustment of intercomparison of quartz meters (cf. p. 7) was based on the supposition that the weighted mean of yearly changes of all these 17 meters is zero. The observation time, 17 years on the average, and for six meters more than 30 years, was taken as weight. The standard deviation of weight unit was *a posteriori* ±2.6 nm/year and the standard deviation of the supposed mean ±0.40 nm/year. For the time interval of 12 years we get a standard deviation of the quartz meter system of ±0.005 µm, which for the length of the base line has an effect of ±3 µm. This value has no significance in relation to the observation errors above, and we may consider the changes of the lengths and their standard errors as reliable.

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