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SCALING OF EDM CALIBRATION BASELINES BY GPS AND CONTROLLING OF EDM PARAMETERS

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ABSTRACT

The calibration values of electromagnetic distance measurements, which have been given by their own firms, can lose their currency in time. So, the EDMs must be controlled in the particular time intervals. The EDM controls have been usually made in the EDM calibration baselines, which are constituted for this aim. Zero addition, scale coefficient and phase difference measurement function constitute the measurement function as a result of control done. The EDM calibration baseline must be scaled to determine the scale coefficient. Not only high accuracy instruments as Kern Mekometer 3000 but also GPS can be used for scaling. In this study, it has been investigated that possibility of scaling of EDM calibration baseline by using GPS and the scaled EDM calibration baseline, and the calibration parameters of Sokkisha SET2, Topcon GTS701, Topcon GTS 229 and Sokkia Power SET 2000 electronic tacheometers have also been estimated.

KEYWORDS. EDM calibration. Baselines by GPS. EDM parameters

INTRODUCTION

The common errors are usually caused by instruments of electromagnetic distance measurement. These errors are consisted of proportional part of the scale changing by the time, zero addition and phase difference measurement function, which are also called instrument parameters. Essentially zero addition error is a constant systematic error, scale error is a systematic error dependent on distance, and phase difference error is a periodical systematic error. The control and calibration of electromagnetic distance measurements have to be done at regular intervals to obtain the best result [**2**]. The instrument controls have been usually made using EDM calibration baselines, which are established with respect to H.R.Schwendener's suggestion [**8**]. The investigations show that the control and calibration of the electromagnetic distance measurements have to be periodically made to obtain correct and reliable results for these instruments.

The EDM calibration baselines have to be scaled to determine the scale error, which formed by changing frequency of proportional part of the scale in time in the electromagnetic distance measurements. On the other hand, true values of certain distances obtained by dividing the whole control baseline and the distances, which are formed as combinations of these distances, have to be known. Calibration of electromagnetic distance measurements and design of EDM calibration baselines were studied by many scientists [**6**], [**1**], [**10**], [**11**], [**9**]. Up to now, in the studies in Turkey, the EDM calibration baselines were established having 6 or 7 points and the EDM calibration baselines were scaled by using Kern Mekometer 3000(0.2mm ± 1ppm), Wild DI2000 (1mm ± 1ppm), which are the distance measurement instruments with high precision, and the scale coefficients of instruments, which is controlled, were determined according to these baselines. In this study, it was investigated whether GPS could be used for scaling of control baselines or not.

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THE DESIGN OF THE EDM CALIBRATION BASELINE

In an EDM calibration baseline, which is formed to determine the zero addition, scale factor and the phase difference measurement function, the fractional parts in the measurements of divided distances and in the distances, which are formed as combinations of these divided distances, have to be adjusted with respect to the unit length of the tested instrument. To eliminate the centering errors at the points of EDM calibration baselines, they have to be established as a pillar [**4**]. Mean error of the zero addition has to be as small as, or equal to half of mean error of, the one measurement. So, an EDM calibration baseline must be established with at least with 6 or 7 points. In addition the EDM calibration baseline has to provide the following conditions.

1. There must be a good sight between pillars
2. The EDM calibration baseline has to be established at a site with no slope or a small one
3. The EDM calibration baseline has to be established on land with suitable surface cover of vegetation
4. The pillars have to be established on a site with strength
5. Pillars must be reached easily by car and the pillars have to be protected against any kind of outside effects.

THE MEASUREMENTS AND PROCESSING

The measurements, which were obtained to scale the EDM calibration baseline, were collected by using GPS receivers in static mode. The Cartesian coordinate differences ($\Delta X, \Delta Y, \Delta Z$) were obtained as the results of GPS measurements. The slope distances, D'_{ij}, between the points were computed by equation (1);

$$D'_{ij} = \sqrt{\Delta X_{ij}^2 + \Delta Y_{ij}^2 + \Delta Z_{ij}^2} \tag{1}$$

If ΔH_{ij} is the height difference between i and j points, then the horizontal distance, D_{ij}, can be written as

$$D_{ij} = \sqrt{D'^2_{ij} - \Delta H_{ij}^2} \tag{2}$$

The computed distances were reduced to the reference surface by using equation (3)

$$S_{ij} = D_{ij} \frac{(R + H_r)}{(R + H_m)} \tag{3}$$

Where; H_r is the height of reference surface, H_m is the mean height obtained from i and j points, which GPS receivers are established on, S_{ij} is the reduced distance on the reference surface, R is 6373394 m (radius of the earth)

To reduce the effect of orientation error, independent orientation is made in the measurements by EDM and the arithmetic mean of at least five measurements is obtained. The temperature and pressure readings must be performed by a good quality thermometer and barometer at the time of measurements. These readings have also to be done at the level of instrument height and in shadow. The EDM instrument has to be protected from sunshine by umbrella during a sunny weather condition. Before starting measurement, the spirit level of reflector and instrument have to be controlled. They are corrected if it is necessary. The measurements have to be done according to the rules given by the manufacturer[7]. The atmospheric correction was applied to the measurements by correction formula from Instrument Company. Also taking the heights of instrument and targets into consideration, the distance has been reduced to the reference surface. However, the average value of the heights from setup and sight points is computed by equation (4).

$$H_m = (H_i + I_E + H_j + T_p)/2 \quad (4)$$

Where, H_i is the height of the i'th point on which the EDM is set up, H_j is the height of the j'th point, on which reflector is held, I_E is the height of EDM device, T_p is the height of reflector. For each measurement, equation (5) is also written.

$$v_{ij} = K_o + K_{11} \cos \Delta\varphi_{ij} + K_{12} \sin \Delta\varphi_{ij} + S_{ij}\,\alpha + S_{ij} - D_{ij} \quad (5)$$

K_o, K_{11}, K_{12}, α values and their mean square errors are computed by an adjustment process with least-square method.

Where, K_o is the zero addition of instrument - reflector system, K_{11} , K_{12} is the Fourier coefficients to determine the phase difference measurement function, α is the scale coefficient, S_{ij} is the distance determined by GPS and reduced to reference surface, D_{ij} is the distance measured by instrument, whose parameters must be controlled, and reduced to reference surface.

When n is an integer, and u is a unit distance and $n.u < D_{ij}$, $\Delta\varphi_{ij}$ in the equation (5) is computed as following

$$\Delta\varphi_{ij} = (D_{ij} - n.u)\, 2\pi / u \quad (6)$$

The phase difference measurement function F_z; using the equations (7) below.

$$A = (K_{11}^2 + K_{12}^2)^{1/2}$$
$$\rho = \arctan(K_{11} / K_{12}) \quad (7)$$

can be written as following.

$$F_z = A \sin(\Delta\varphi + \rho) \quad (8)$$

Where, A is amplitude of cyclic error, $\Delta\varphi$ is phase angle and ρ is phase shift.

After the adjustment using the least-square method, it is investigated statistically whether the computed instrument parameters are changing. By using K as the zero addition value of the instrument-reflector system, which is given by the manufacturer in the instrument catalogue, and K_o as computed value for the zero addition, the test values, which are denoted by t, are computed for the zero addition as

$$t = |K_0 - K| / m_{Ko} \quad (9)$$

for scale coefficient as

$$t = |\alpha| / m_\alpha \quad (10)$$

for Fourier coefficients as

$$t = |K_{11}| / m_{K_{11}}$$
$$t = |K_{12}| / m_{K_{12}} \quad (11)$$

and these values are then compared with $t_{n-4,\,1-\alpha/2}$ table values. If $t < t_{table}$, it is said that the parameter does not change in the chosen statistical confidence [5].

Where, m_{Ko}, m_{α}, $m_{K_{11}}$ and $m_{K_{12}}$ are mean square error of K_0, α, K_{11}, K_{12}, respectively.

APPLICATION

Description of the established EDM calibration baseline

The EDM calibration baseline is located in the Alaeddin Keykubad Campus of Selcuk University in the city of Konya, Turkey. This baseline consists of seven concrete pillars, which are separated in order to set up baselines from 40 m up to 1450 m (Figure 1). The EDM calibration baseline was established on a site with the same soil, vegetation and illumination conditions and without local deformation (Figure 2). Dimensions of the top part of pillars are 40 cm x 40 cm and, the upper part of the pillar at the surface of the soil is 1.25 m by 1.50 m and the part under the soil is in the dimension of ~1.50 m. The EDM calibration baseline has been designed to determine zero addition, phase difference measurement function and scale coefficient. In Figure 1 the vertical scale has been chosen ten times larger than horizontal scale to perceive the height differences.

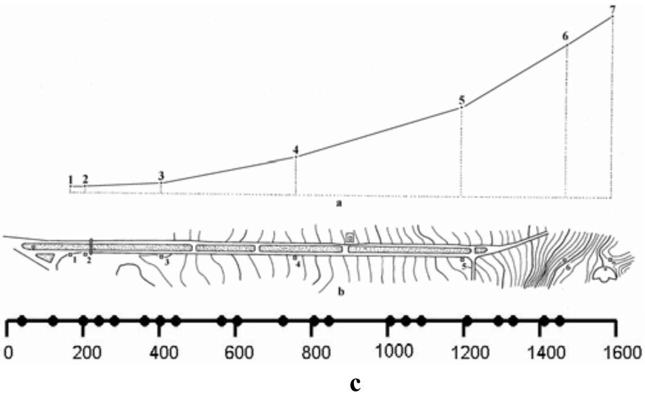

Fig. 1. **a)** Profile of the EDM calibration baseline **b)** topography the site **c)** points along the baseline and distances between these point

Fig. 2. One of the points established along the EDM calibration baseline (point numbered as 4)

Scaling of the EDM calibration baseline and testing of the instrument parameters

For the scaling of the EDM calibration baseline, 7 Topcon Odyssey dual-frequency GPS receivers and antennas integrated into receivers were simultaneously used. The antenna heights were the average of the values, which were measured carefully and accurately twice in the beginning and at the end of observations. The knowledge about occupations is given in Table 1. Approximately 4 hours static GPS observation data are recorded with the sampling rate of 10 seconds and with a 15-degree elevation cutoff.

Table 1. *The list of occupations*

Point or Occup.	Start (GMT)	Span	Num. of Epochs	Sat. ave.	PDOP ave.	Antenna Height (m)
1	27.Apr.06 06:48:00	03:57:00	1423	7.6	1.3	0.1240
2	27.Apr.06 06:45:30	03:56:00	1417	7.6	1.4	0.1195
3	27.Apr.06 06:41:10	03:55:40	1415	7.7	1.3	0.1220
4	27.Apr.06 06:40:00	03:53:20	1401	7.7	1.3	0.1215
5	27.Apr.06 06:30:00	03:58:30	1432	7.7	1.4	0.1200
6	27.Apr.06 07:05:50	03:50:30	1384	7.6	1.3	0.1225
7	27.Apr.06 06:57:10	04:04:00	1465	7.6	1.3	0.1235

Receivers: TPS ODYSSEY , authorized for Pinnacle, Antennas: JPSODYSSEY_I , integrated into Odyssey receiver. manufacturer Javad Positioning,

Like any other types of electromagnetic waves, GPS satellite broadcasting signals are also subject to reflection and diffraction. GPS multipath is antenna reception of signals not directly from satellites but rather bounced off or diffracted from local objects. Since the multipath takes a longer path than the direct signal, it results in an error in pseudorange measurements and thus affects the positioning accuracy. So the effect of the multipath on the P1 and P2 pseudoranges was investigated by using TEQC (**T**ranslation, **E**diting, And **Q**uality **C**heck) tool on the RINEX observation files [**3**]. The multipath RMS values for MP1 and MP2 are listed in Table 2. According to Table 2, mean multipath rms of 5 numbered station is great value relative to others. There is four-story faculty building near the 50 metres north of the this station. It is estimated that this building is increasing multipath effect.

The GPS observations were post-processed using double differencing at the Pinnacle (version 1.0) GPS processing software. For short baselines less than a few tens of metres, a network of the same type of GPS receivers and antennas set up to minimize multipath, and processed using only the L1 phase observations will produce results repeatable to a less than 1 mm. So using only L1 phase solution, all observations were used, and ambiguities were resolved. Goad & Goodman troposhere model and the default settings of Pinnacle software were used for data processing and cycle slip search. The results of post- processing are listed in Table 3.

Table 2. *The mean multipath rms on pseudoranges*

Station Number	MP1 (m)	MP2 (m)
1	0.3780	0.3998
2	0.3821	0.4146
3	0.3659	0.4067
4	0.7354	0.7471
5	1.0862	1.0987
6	0.3704	0.3689
7	0.3450	0.3500

The cartesian coordinate differences with root mean square errors were then computed. Round-trip geometric levelling was done between the points belonging to EDM calibration baseline and the slope distances computed were reduced to the reference surface passing through the point numbered as 1 (Table 4).

The measurements were obtained as combinations by electronic tacheometer, which is used to determine the zero addition, scale coefficient and the phase difference measurement function. During the measurement processes, temperature and pressure were measured. The temperatures were measured at instrument height and in the shade with good quality mercury thermometer. The pressures were measured in the shade. Then first velocity correction was made to measured distances and the corrected slope distances were reduced to the reference surface passing though the point numbered as 1(Table 5). The zero addition value of the instrument-reflector system was entered as “zero” to the instruments during the measurement section.

Table 3. *The results of post- processing at Pinnacle GPS Software*

Base Line	Common span	Observations Total / discarded	RMS DD	Ambig. fix/flo	Cartesian Coordinate Difference and its RMS (m ± mm) ΔX	ΔY	ΔZ
1-2	03:53:30	26466/257	0.022	19/0	-0.699 ± 0.7	33.415 ± 0.7	-22.620 ± 0.6
1-3	03:48:50	26647/108	0.024	18/0	-4.031 ± 0.7	200.371 ± 0.6	-135.294 ± 0.7
1-4	03:45:20	25947/109	0.026	19/0	-13.931 ± 0.7	498.180 ± 0.7	-341.658 ± 0.7
1-5	03:40:30	22205/221	0.023	12/0	-28.870 ± 0.8	860.472 ± 0.7	-596.568 ± 0.8
1-6	03:39:10	21738/147	0.027	14/0	44.089 ± 0.9	-1087.065 ± 0.8	763.836 ± 0.9
1-7	03:47:50	22761/110	0.028	15/0	-50.639 ± 1.0	1184.222 ± 0.9	-835.578 ± 0.9
2-3	03:51:20	26679/147	0.023	13/0	-3.332 ± 0.7	166.955 ± 0.8	-112.673 ± 0.6
2-4	03:47:50	26099/213	0.026	13/0	-13.232 ± 0.7	464.765 ± 0.8	-319.036 ± 0.7
2-5	03:43:00	22076/192	0.020	10/0	-28.170 ± 0.8	827.057 ± 0.8	-573.948 ± 0.7
2-6	03:35:40	21186/155	0.024	12/0	43.390 ± 0.9	-1053.649 ± 0.9	741.216 ± 0.8
2-7	03:44:20	22280/181	0.024	13/0	-49.938 ± 0.9	1150.809 ± 1.0	-812.955 ± 0.8
3-4	03:52:10	27125/24	0.023	12/0	-9.901 ± 0.7	297.809 ± 0.6	-206.363 ± 0.6
3-5	03:47:20	22869/115	0.022	9/0	-24.839 ± 0.7	660.102 ± 0.7	-461.274 ± 0.7
3-6	03:31:00	24465/133	0.023	12/0	40.060 ± 0.8	-886.694 ± 0.8	628.544 ± 0.8
3-7	03:39:40	25649/125	0.023	13/0	-46.608 ± 0.8	983.852 ± 0.8	-700.283 ± 0.8
4-5	03:48:30	22921/116	0.023	9/0	-14.938 ± 0.7	362.292 ± 0.6	-254.911 ± 0.7
4-6	03:27:30	23733/88	0.024	12/0	30.159 ± 0.7	-588.885 ± 0.7	422.180 ± 0.7
4-7	03:36:10	24922/116	0.024	12/0	-36.707 ± 0.7	686.043 ± 0.7	-493.920 ± 0.7
5-6	03:22:40	20564/124	0.021	9/0	15.221 ± 0.7	-226.594 ± 0.6	167.269 ± 0.6
5-7	03:31:20	21367/167	0.020	10/0	-21.769 ± 0.7	323.751 ± 0.6	-239.010 ± 0.6
6-7	03:50:30	23381/150	0.020	12/0	-6.550 ± 0.7	97.157 ± 0.6	-71.741 ± 0.6

RMS DD is root mean square of phase Double Difference residuals, in units of cycles

The zero additions, scale coefficients and the Fourier coefficient of the electronic tacheometers and their root mean square errors were computed by using equation (5), as long as the distances determined by GPS were used as essential distances. The test values computed by equations (9), (10) and (11) were then compared with the value of $t_{n-4,1-\alpha/2} = t_{17,0.975} = 2.110$ obtained from t student distribution table (Table 6 and Table 7). Two different weight models had been used in the adjustment. First, weights of all measurements were taken as equal and 1. Second, the measurement weights were computed as following.

$$P_d = c / m^2_d \tag{12}$$

Where, P_d is measurement weight, m_d is the measurement accuracies of used instrument and c is constant, which is changeable according to user.

Table 4. *The determined distances by GPS*

Measurement Number	Base Line	Slope Distances (m)	Standart deviation of slope distance (mm)	The reduced slope distances to the reference surface(m)
1	1-2	40.3580	± 0.34	40.3572
2	1-3	241.8038	± 0.60	241.8011
3	1-4	604.2408	± 0.60	604.1781
4	1-5	1047.4439	± 0.50	1047.2073
5	1-6	1329.3236	± 0.54	1328.7361
6	1-7	1450.2196	± 0.30	1449.4596
7	2-3	201.4458	± 0.60	201.4439
8	2-4	563.8843	± 0.60	563.8209
9	2-5	1007.0907	± 0.50	1006.8501
10	2-6	1288.9771	± 0.54	1288.3789
11	2-7	1409.8758	± 0.30	1409.1025
12	3-4	362.4558	± 0.60	362.3769
13	3-5	805.6826	± 0.50	805.4062
14	3-6	1087.6112	± 0.54	1086.9349
15	3-7	1208.5255	± 0.30	1207.6584
16	4-5	443.2360	± 0.50	443.0292
17	4-6	725.2110	± 0.54	724.5580
18	4-7	846.1437	± 0.30	845.2815
19	5-6	282.0550	± 0.44	281.5286
20	5-7	403.0060	± 0.20	402.2522
21	6-7	120.9511	± 0.24	120.7236

Table 5. *The reduced slope distances to the reference surface(m)*

Base Line	Sokkisha SET 2 $m_d = \pm(3mm+2ppm.D)$	Topcon GTS 229 $m_d = \pm(3mm+3ppm.D)$	Sokkia Power SET 2000 $m_d = \pm(2mm+2ppm.D)$	Topcon GTS 701 $m_d = \pm(2mm+2ppm.D)$
1-2	40.3931	40.3906	40.3890	40.3796
1-3	241.8318	241.8320	241.8312	241.8234
1-4	604.2171	604.2163	604.2154	604.2069
1-5	1047.2510	1047.2437	1047.2390	1047.2355
1-6	1328.7739	1328.7658	1328.7753	1328.7636
1-7	1449.5082	1449.4922	1449.4944	1449.4850
2-3	201.4685	201.4701	201.4684	201.4595
2-4	563.8528	563.8519	563.8543	563.8454
2-5	1006.8825	1006.8809	1006.8764	1006.8734
2-6	1288.4121	1288.4052	1288.4118	1288.4018
2-7	1409.1466	1409.1305	1409.1336	1409.1221
3-4	362.4118	362.4099	362.4118	362.4028
3-5	805.4419	805.4405	805.4352	805.4299
3-6	1086.9719	1086.9655	1086.9666	1086.9640
3-7	1207.7035	1207.6912	1207.6909	1207.6811
4-5	443.0565	443.0533	443.0539	443.0472
4-6	724.5863	724.5830	724.5844	724.5763
4-7	845.3126	845.3072	845.3077	845.2992
5-6	281.5577	281.5572	281.5543	281.5478
5-7	402.2837	402.2814	402.2792	402.2713
6-7	120.7550	120.7530	120.7516	120.7407

Table 6. *The parameters of instruments and their test results (P_d=1)*

Parameter	Tested Instruments			
	SET 2	GTS 229	SET 2000	GTS 701
Zero Additon (mm)	-29.01 ± 3.36	-32.46 ± 2.76	-29.35 ± 1.77	-19.92 ± 1.88
Test Value	0.29	0.89	0.37	5.36
Decision	Valid	Valid	Valid	Invalid
Scale Coefficient (mm/km)	-7.95 ± 4.22	2.76 ± 3.47	-1.50 ± 2.14	-3.33 ± 2.28
Test Value	1.88	0.80	0.70	1.46
Decision	Valid	Valid	Valid	Valid
Fourier Coefficient (K_{11})	-2.08 ± 1.54	0.43 ± 1.26	0.16 ± 1.14	1.13 ± 1.22
Test Value	1.35	0.34	0.14	0.93
Decision	Valid	Valid	Valid	Valid
Fourier Coofcient (K_{12})	1.13 ± 2.55	2.31 ± 2.09	2.88 ± 1.39	0.67 ± 1.48
Test Value	0.44	1.11	2.07	0.45
Decision	Valid	Valid	Valid	Valid
A (mm)	2.37	2.34	2.88	1.32
ρ	$331^g.6358$	$11^g.6264$	$3^g.4258$	$65^g.9182$

Table 7. *The parameters of instruments and their test results ($P_d = c/ m^2_d$)*

Parameter	Tested Instruments			
	SET 2	GTS 229	SET 2000	GTS 701
Zero Addition (mm)	-30.66 ± 3.12	-33.17 ± 2.60	-30.02 ± 1.63	-20.35 ± 1.68
Test Value	0.21	1.22	0.01	5.74
Decision	Valid	Valid	Valid	Invalid
Scale Coefficient (mm/km)	-5.78 ± 4.14	3.69 ± 3.52	-0.57 ± 2.41	-2.82 ± 2.49
Test Value	1.40	1.05	0.24	1.13
Decision	Valid	Valid	Valid	Valid
Fourier Coefficient (K_{11})	-1.84 ± 1.58	0.71 ± 1.39	-0.43 ± 1.14	0.60 ± 1.18
Test Value	1.16	0.51	0.38	0.51
Decision	Valid	Valid	Valid	Valid
Fourier Coefficient (K_{12})	2.46 ± 2.43	2.86 ± 2.03	2.81 ± 1.47	1.45 ± 1.51
Test Value	1.01	1.41	1.91	0.96
Decision	Valid	Valid	Valid	Valid
A (mm)	3.07	2.94	2.84	1.57
ρ	$359^g.1342$	$15^g.4899$	$390^g.4145$	$24^g.7362$

In the tested instruments, the zero addition value and scale coefficient of the instrument-reflector system, which are given by the producer company, are –30 mm and 1, respectively. According to test results in table 7 and table 8, the zero addition value of the instrument-reflector system of Topcon GTS 701 electronic tacheometer is –19 mm. These values mentioned above are the values changed. According to the results in table 7 and 8, the phase difference functions of the controlled instruments are drawn as below by taking their unit lengths into consideration (Figure 3).

GENERAL REMARKS AND CONCLUSION

The calibration values of electromagnetic distance measurements, which are given by their own firms, can lose their currency in time. The calibration errors remain as a permanent error and they can not to be eliminated by a least square adjustment process. They also cause model errors. Especially calibration parameters have to be controlled before deformation measurements, which require high precision. Otherwise someone makes a mistake in the determination of the size of the deformation. So, the calibration parameters of electromagnetic distance measurements have to be determined by an EDM calibration baseline, which are devoted and scaled for this aim. When table 5 is investigated, it is shown that root mean square errors of distances determined by GPS are changing between ±0.20 mm and ±0.60 mm. Thus, the obtained accuracy shows that the scaling of an EDM calibration baselines by GPS is possible.

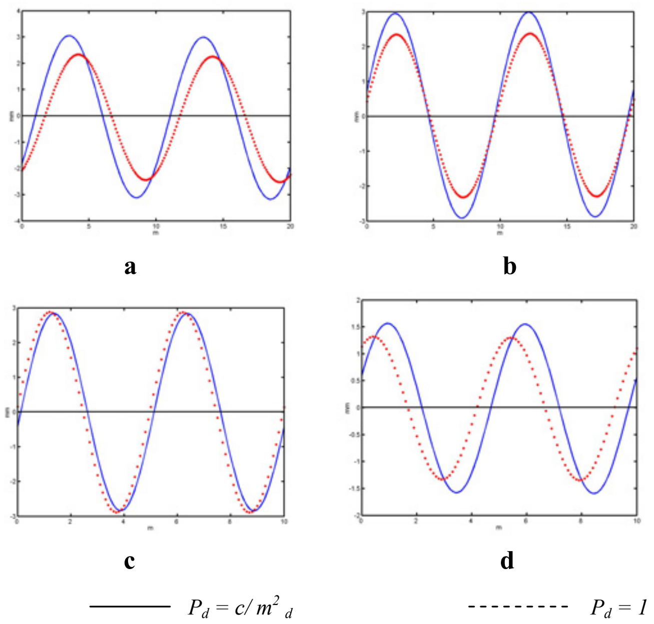

Fig. 3. The phase difference measurement functions of electronic tacheometers **a)** for Sokkısha SET2(u=10m) **b)** for Topcon GTS229(u=10m) **c)** for Sokkıa Power SET2000(u=5m) **d)** for Topcon GTS701(u=5m)

In this study, technical specifications of the established EDM calibration baseline and scaling of this baseline by GPS have been explained. The zero addition, scale coefficient, and phase difference measurement functions of Sokkisha SET 2, Topcon GTS 229, Sokkia Power SET 2000 and Topcon GTS 701 have been determined by using this baseline. According to the test results obtained for different weight models, it can be said that the zero addition is changed 95% in confidence for Topcon GTS701. Henceforth, the determined parameters have to be taken into consideration for later applications to be done by these instruments.

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