GEODEZJA I KARTOGRAFIA
t. L, z.2 , s.61-74 (2001)

Jan Gocał
Michał Strach

Faculty of Mining Surveying
and Environmental Engineering
University of Mining and Metallurgy (AGH)
(30-059 Kraków, Al. A. Mickiewicza 30)

An initial assessment of the RTK GPS method as applied to monitoring of railway track geometry *

The paper presents a concept of application of the RTK-GPS technique to surveys of railway tracks. The concept was examined during an experimental survey performed over a 2 km long track section. The test survey confirmed functionality and sufficient accuracy of the RTK-GPS method as applied to railway track measurements aimed at track regulation.

INTRODUCTION

Classical methods, based on application of a theodolite, short linear scales (staffs and rulers with milimetre graduation) and simple devices for measurement of arc rises, are widely applied in surveying of railway tracks. On straight sections offsets of selected points of the real track axis from reference lines are measured, while for straight sections several kilometres long the reference lines form a traverse. In turn, the real shape of the track axis on transition curves and circular arcs of radii: $R < 300$ m, 300 m$<R<$2000 m and $R > 2000$ m, are determined on the base of rises measured with respect to chords (subtenses) of the length 10 m, 20 m and 40 m respectively, what means, that the measurement points on the rail are spaced by 5 m, 10 m and 20 m. Wire and optical device, or the „curvature corrector" produced by Matisa, which allowed a continuous measurement and recording of arc rises, were applied in offset measurements in the past. Now the measurements of rises are most often performed with the use of a theodolite and rulers, by the method of short or long chords. The method of short chords (Fig. 1) consists in reproduction, with a template (Fig. 2), of five consecutive points of the railway track axis. Rises are measured at points (*i*-1) and (*i*+1) with a theodolite centered over the point (*i*). In the next step the theodolite is centered over the point (*i*+1), point (*i*+3) is marked and the rises are measured at points (*i*) and (*i*+2). The method of long chords (Fig. 3) is especially suitable for

---

*The paper was prepared under the research project Nr. 9 T12 C 00318 financed by KBN (Committee on Scientific Research) in the years 2000 - 2003

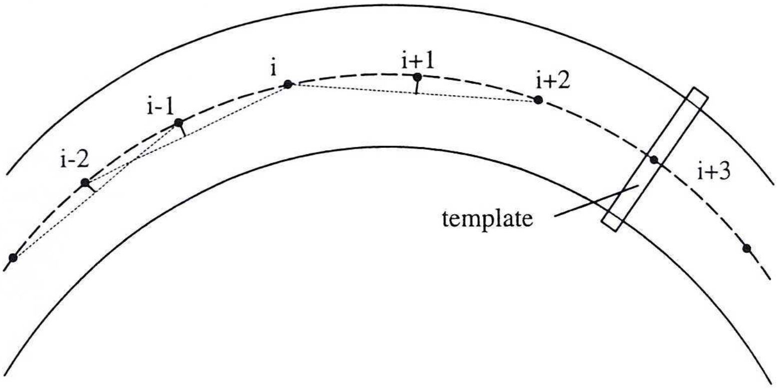

Fig.1

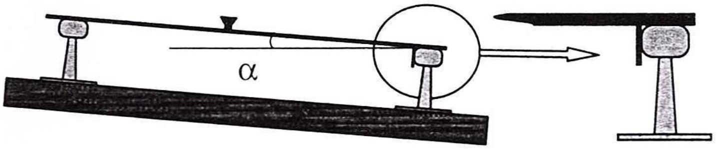

Fig. 2

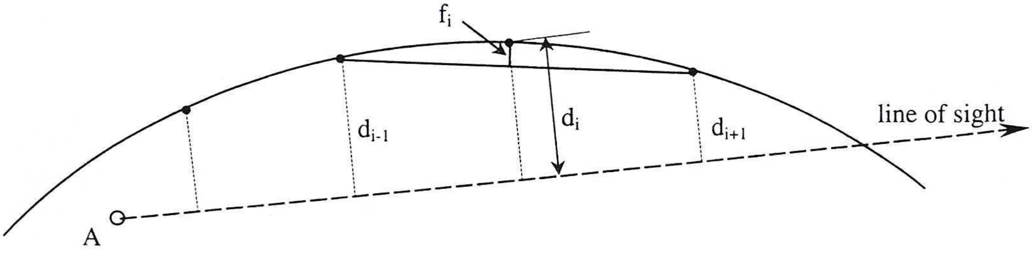

Fig. 3

measurement of rises along arcs of small curvature. The chord is realized by the line of sight of the theodolite centered over the point A and oriented along the rail. Distances d_i of points representing one of the track rails are measured with respect to the line of sight. On the base of distances d_i between points evenly spaced along the rail the rises are computed with the formula:

$$f_i = d_i - \frac{1}{2}(d_{i-1} + d_{i+1}) \tag{1}$$

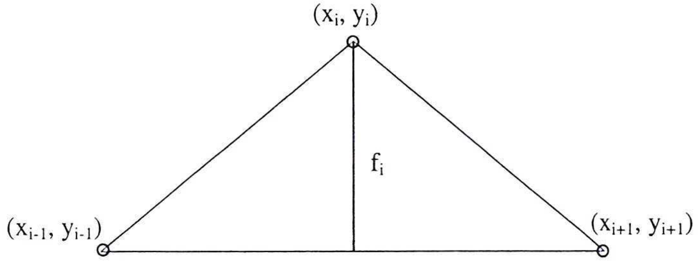

Fig. 4

The formula (1) can be also applied to computation of rises on the base of distances d_i of rail points from line joining two neighbouring regulation markers. The rises can be also computed when coordinates of three consecutive points of the track axis are known (Fig. 4). The following formula is then applied:

$$f_i = \frac{(x_{i+1} - x_{i-1})(y_i - y_{i-1}) - (x_i - x_{i-1})(y_{i+1} - y_{i-1})}{\sqrt{(x_{i+1} - x_{i-1})^2 + (y_{i+1} - y_{i-1})^2}} \tag{2}$$

Coordinates of the points representing the real track axis can be determined with the polar method from points of a precise control network established especially for the survey and for the determination of coordinates of the regulation markers placed along the track. It should be clearly stated, that the surveys of railway track performed for regulation purposes cannot be based on the local state control, as usually it does not fulfill the strict accuracy requirements. The control is at best sufficient for preparation of a digital map of the delineated stripe of railway grounds.

Modern surveying methods, which should be applied to railway track surveys aimed at its regulation, have the character of the inegrated control networks. Coordinates of points in such networks are determined both on the base of static GPS surveys and the classical traverses, observed with precise electronic total stations. Density of location of the GPS and traverse points should be determined on the base of rigorous preanalysis under the assumption, that the r.m.s. error of position of the weakest traverse point should not exceed ±5 mm.

The latest achievements of the satellite GPS technique, and especially introduction into practice of the receivers equipped with radio modems, allow determination of point coordinates in real time. The measuremets are performed by the *stop and go* method, when the antenna rests at the surveyed point for 10-20 seconds, or with the kinematic method, where coordinates of the moving antenna are recorded every 0.1 second. These possibilities are brought by the RTK GPS (Real Time Kinematic GPS) method, actually widely introduced to engineering surveys. The evidence at hand allows statement to the effect, that the method fulfills all accuracy and usability requirements necessary for tu surveying of railway tracks.

Both methods: the polar and the RTK, allow determination of coordinates of points representing both straight and curvilinear sections of railway track in the same, homogeneous coordinate system, chosen for a line of arbitrary length. Coordinates of points are recorded in memories ot the electronic instruments, or in computers attached to them. They can also be transmitted automatically to the office computer, where regulation project for the railway track is prepared with the use of a specialized computer program. So both methods are by far more advantageous than the methods of measurements of point offsets with respect to reference lines in straight sections and arc rise measurements along the curvilinear sections, used up to date. The classical methods are troublesome, and data collected with them can be transferred into the computer only manually. So the polar and RTK methods should widely enter the everyday practice, provided the accuracies achieved can be accepted as sufficient for track regulation. A partial answer can be formulated on the base of our experimental surveys performed on a section of a railway line under exploitation.

1. *Characteristics of the construction of measurement carts*

In surveys of railway tracks, both with the polar or RTK method, there is need to identify and mark points representing the real axis of the track. For rapid restitution of the axis of an existing track the best is special measurement cart, which moves easily along the track and fits it in an unambiguous way. The measurement point of such cart can be placed in the track axis on a traverse beam, on a longitudinal beam right above the inner edge of one of the rails, or in an arbitrary place, provided its position with respect the track axis is known. A tribrach with circular bubble is attached at the measurement point. An EDM prism is placed into the tribrach for the surveying with the polar method or a GPS antenna for RTK surveys.

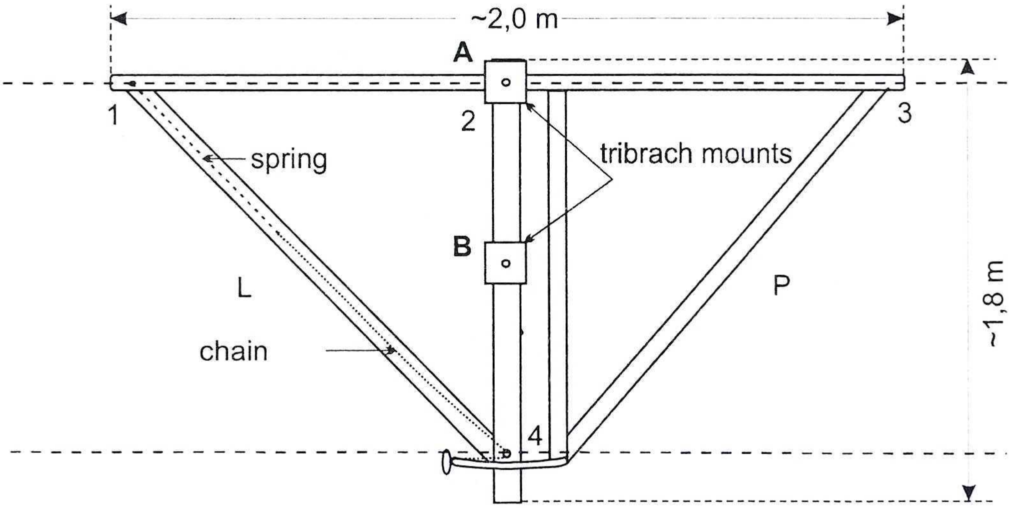

Fig. 5

The first, prototype cart was built on the base of the Matisa curvature corrector. The cart (Fig. 5) consists of two independent, rigid structures of a triangular shape: the left *L* and the right *R*, joined by a hinge at the point 2. At points 1, 2, 3 and 4 the wheels and pressure rolls are attached, while at points A and B are placed tribrachs used for mounting the prism or the GPS antenna (Fig. 6).

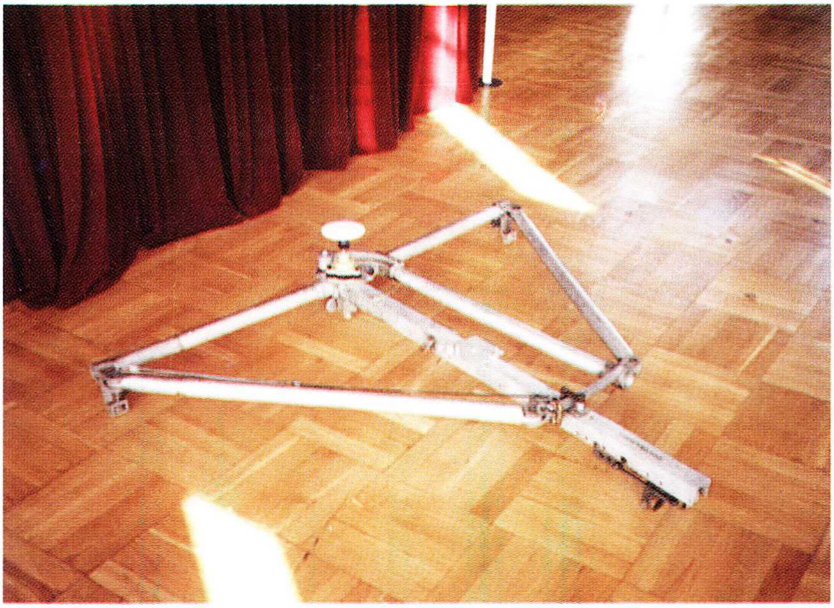

Fig. 6

Fig. 7

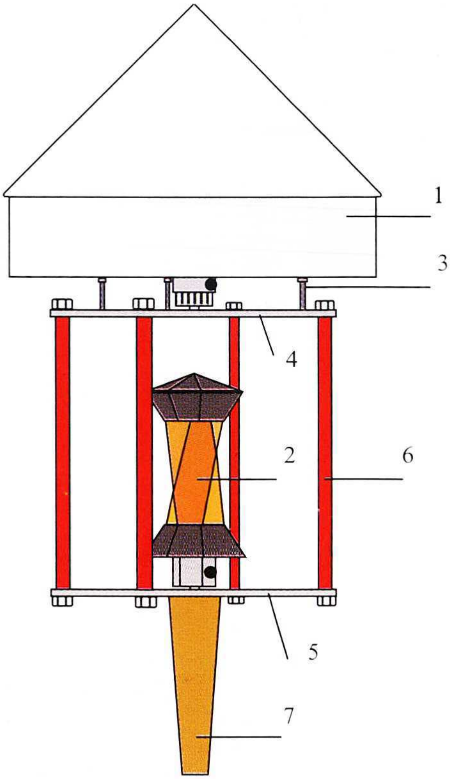

Fig. 8. Design of the head of observation pillar, 1 – choke-ring GPS antenna, 2 – 360° EDM prism, 3 – antenna supports, 4 – antenna platform, 5 – EDM prism platform, 6 – suppots, 7 – conical joint.

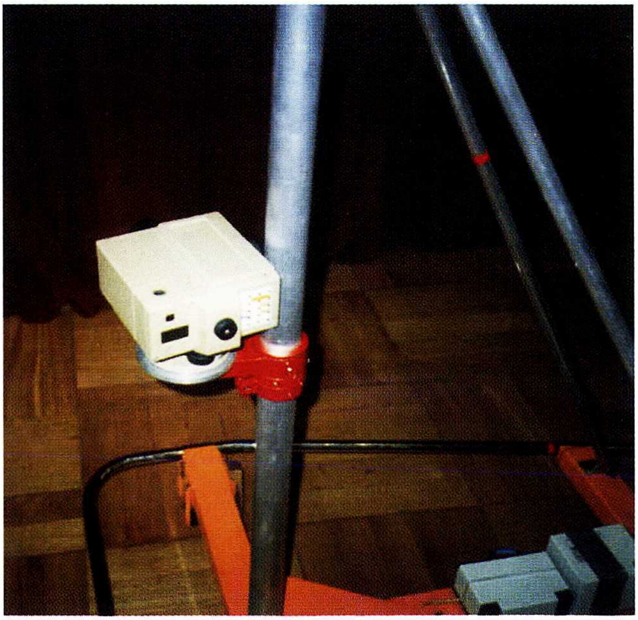

Fig. 9

It was found during the experimental surveys, that the cart works properly and can be easily removed from the track when a train approaches. The hinge joint of the triangles and a chain with spring allow smooth ride of the cart along the curvilinear sections of the track, with the stable pressure to one of rails maintained. Among odds was the relatively low position of the GPS antenna, what resulted in noisy or obstructed signal even in places with no natural, terrain obstructions.

The next, improved version of the measurement cart (Fig. 7) was built on the base of a typical electronic multipurpose track gauge meter TEC-1435, typically equipped with several sensors and a digital recorder. These gauges allow measurement of the covered distance, gauge and superelevation of the track. On the short arm of the track gauge meter, which rests on the rail with two rolls, a cylindrical support is mounted, strengthened by two additional stiff struts. The measuring head (Fig. 8), equipped with GPS antenna and EDM prism, is fixed at the top of the support by a conical joint, which guaratees unambiguous placement. The support also bears a movable platform with standard tribrach, where the distancer DISTO or the electronic level NA3003 (Fig. 9) can be mounted.

The measurement cart in its multipurpose version allows track surveying in every terrain conditions. In presence of close high obstructions the measurements are performed with a precise electronic polar station by the 3D polar method, while in the open areas – with GPS RTK. But, due to the specific accuracy characteristics, the RTK technique gives only 2D information on track position. Heights have to be determined by geometric levelling with the electronic level placed on the cart. In turn the DISTO is used for determination of distances from the track axis to the obstructions situated along the track. These distances are indispensary for control of the clearance gauge during preparation of the track regulation project. The registered data pertaining to the actual track gauge and superelevation allow on-line computation of corrections to the as-measured positions of track axis points. The corrections are due to fact, that both the GPS antenna and EDM prism, as well as DISTO or the NA3003 are situated on certain height above the monitored rail.

2. *Results of introductory experimental surveys*

The introductory experimental surveys were performed on a chosen, about 2000 m long section of railway track. Close to the track three reference points (Fig. 10) were monumented, coordinates of which were determined by static GPS with the accuracy of ±2 mm. A traverse with sides 150–250 m long and total length of 1800 m was run between the GPS points. A rigorous analysis proved, that positions of the traverse points are determined with r.m.s. error less than ± 5 mm.

Points representing the real track axis and placed every 10 m were surveyed. Measurement cart built on the base of the Matisa curvature corrector, two GPS receivers Leica System 300 and a precise total station TC2002 were used. The surveys were performed with the RTK *stop and go* method. The reference station was placed at the middle GPS control point, while the rover was moved to consecutive points with the measurement cart, which carried also the GPS antenna mounted on it. The occupation of every point usually took not more than 15 seconds. Longer occupations were decided in proximity of single or dense horizon obstructions, where it was necessary to wait for longer time in order to achieve assumed coordinate quality (CQ) parameter.

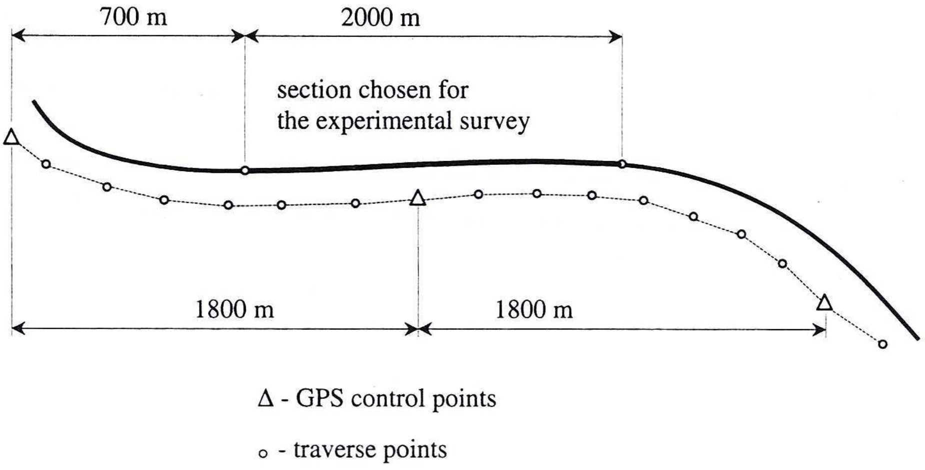

Fig. 10

In the next step after the RTK-GPS survey the whole track section was surveyed independently again with the polar method. This time the GPS antenna was replaced by the EDM prism. The cart was positioned at consecutive track axis points, while the precision electronic total station TC2002 occupied in sequence the traverse stations.

As the result two sets of coordinates of track axis points were obtained; one of them originated from the RTK measurements, while the second one came from the polar method survey. As the observations were performed in two independent measurement cycles, with independent positioning of the cart, it was decided not to compare the coordinates directly, due to ambiguous identification of the along-the-track coordinate component. Instead it was resolved, that one can compare distances d_{GPS} and d_{TC} of points having the same name/number from regression lines (theoretical track axes) given by equations:

$$\begin{aligned} y_{\mathrm{GPS}} &= a_{\mathrm{GPS}}x + b_{\mathrm{GPS}} \\ y_{\mathrm{TC}} &= a_{\mathrm{TC}}x + b_{\mathrm{TC}} \end{aligned} \tag{3}$$

The abovementioned distances of points from the regression lines are computed with the formula:

$$d_i = \frac{y_i - ax_i - b}{\sqrt{1+a^2}} \tag{4}$$

Since the angle between the lines (3) is negligibly small, there is no need to transform GPS coordinates and TC coordinates into one common system and the distances can be compared directly by computation of their differences:

$$\Delta d_{\mathrm{GPS-TC}} = d_{\mathrm{GPS}} - d_{\mathrm{TC}} \tag{5}$$

Several outlying observations were found in the set (5) of differences computed for all points observed at the 2 km long section of the track. All of them originated at points with

Table 1

Nr [km]	Nr [Lp]	d GPS	d TC	d(GPS-TC)	Nr [km]	Nr [Lp]	d GPS	d TC	d(GPS-TC)
1260	2	-0.0438	-0.0242	-0.0196	1760	52	0.0157	0.0030	0.0127
1270	3	-0.0322	-0.0236	-0.0086	1770	53	0.0220	0.0068	0.0152
1280	4	-0.0232	-0.0145	-0.0087	1800	56	0.0137	0.0127	0.0010
1290	5	-0.0165	-0.0091	-0.0074	1810	57	0.0259	0.0169	0.0089
1300	6	-0.0014	-0.0001	-0.0013	1820	58	0.0359	0.0215	0.0144
1310	7	0.0107	0.0059	0.0048	1830	59	0.0408	0.0248	0.0160
1320	8	0.0041	0.0026	0.0015	1840	60	0.0344	0.0255	0.0090
1330	9	-0.0006	-0.0061	0.0055	1850	61	0.0375	0.0314	0.0061
1340	10	-0.0149	-0.0159	0.0009	1860	62	0.0341	0.0303	0.0038
1350	11	-0.0298	-0.0188	-0.0110	1870	63	0.0356	0.0298	0.0058
1360	12	-0.0135	0.0029	-0.0164	1880	64	0.0326	0.0239	0.0087
1370	13	-0.0077	0.0011	-0.0087	1890	65	0.0277	0.0177	0.0100
1380	14	-0.0008	0.0132	-0.0140	1900	66	0.0236	0.0166	0.0069
1390	15	0.0094	0.0215	-0.0121	1910	67	0.0160	0.0104	0.0056
1400	16	0.0209	0.0233	-0.0024	1920	68	0.0201	0.0063	0.0138
1410	17	0.0190	0.0188	0.0002	1930	69	0.0123	0.0040	0.0083
1420	18	0.0141	0.0136	0.0006	1940	70	0.0037	-0.0021	0.0057
1430	19	0.0181	0.0188	-0.0007	1950	71	0.0015	-0.0021	0.0036
1440	20	0.0235	0.0191	0.0044	1960	72	-0.0011	-0.0079	0.0068
1450	21	0.0161	0.0231	-0.0070	1970	73	-0.0045	-0.0098	0.0053
1460	22	0.0047	0.0197	-0.0150	1980	74	-0.0079	-0.0146	0.0067
1470	23	-0.0020	0.0111	-0.0131	1990	75	-0.0212	-0.0243	0.0030
1480	24	-0.0101	0.0045	-0.0146	2000	76	-0.0312	-0.0321	0.0009
1490	25	-0.0014	-0.0025	0.0011	2010	77	-0.0210	-0.0244	0.0034
1500	26	0.0029	0.0037	-0.0008	2020	78	-0.0148	-0.0218	0.0070
1510	27	0.0092	0.0067	0.0025	2030	79	-0.0061	-0.0094	0.0033
1520	28	0.0070	0.0054	0.0016	2040	80	0.0073	0.0021	0.0052
1530	29	-0.0045	0.0023	-0.0068	2050	81	0.0182	0.0143	0.0039
1540	30	-0.0054	-0.0025	-0.0029	2060	82	0.0269	0.0235	0.0034
1550	31	-0.0209	-0.0140	-0.0069	2070	83	0.0355	0.0272	0.0083
1560	32	-0.0116	-0.0143	0.0028	2080	84	0.0412	0.0375	0.0038
1570	33	-0.0069	-0.0125	0.0056	2090	85	0.0489	0.0438	0.0051
1580	34	-0.0074	-0.0079	0.0005	2100	86	0.0517	0.0458	0.0059
1590	35	-0.0095	-0.0095	0.0000	2110	87	0.0500	0.0472	0.0028
1600	36	-0.0079	-0.0068	-0.0011	2120	88	0.0457	0.0449	0.0008
1610	37	-0.0071	-0.0081	0.0011	2130	89	0.0413	0.0391	0.0022
1620	38	-0.0114	-0.0092	-0.0022	2140	90	0.0330	0.0327	0.0003
1630	39	-0.0090	-0.0089	-0.0001	2160	92	0.0276	0.0191	0.0086
1640	40	-0.0021	-0.0068	0.0047	2170	93	0.0106	0.0060	0.0046
1650	41	-0.0071	-0.0127	0.0056	2180	94	-0.0045	-0.0058	0.0013
1660	42	-0.0091	-0.0161	0.0069	2190	95	-0.0298	-0.0204	-0.0094
1670	43	-0.0172	-0.0261	0.0089	2200	96	-0.0287	-0.0230	-0.0057
1680	44	-0.0295	-0.0346	0.0051	2220	98	-0.0048	-0.0007	-0.0041
1690	45	-0.0262	-0.0324	0.0062	2230	99	0.0192	0.0244	-0.0052
1700	46	-0.0159	-0.0216	0.0057	2240	100	0.0317	0.0369	-0.0051
1710	47	-0.0158	-0.0183	0.0025	2250	101	0.0369	0.0422	-0.0053
1720	48	-0.0063	-0.0149	0.0085	2260	102	0.0385	0.0455	-0.0070
1730	49	-0.0065	-0.0118	0.0053	2270	103	0.0403	0.0429	-0.0026
1740	50	-0.0022	-0.0053	0.0032	2280	104	0.0324	0.0315	0.0008
1750	51	0.0029	-0.0034	0.0063	2290	105	0.0097	0.0080	0.0017

Nr [km]	Nr [Lp]	d GPS	d TC	d(GPS-TC)	Nr [km]	Nr [Lp]	d GPS	d TC	d(GPS-TC)
2300	106	-0.0231	-0.0182	-0.0050	2510	127	0.0111	0.0167	-0.0056
2310	107	-0.0211	-0.0261	0.0050	2520	128	0.0170	0.0167	0.0003
2320	108	-0.0197	-0.0181	-0.0016	2540	130	0.0060	0.0055	0.0005
2330	109	-0.0129	-0.0085	-0.0044	2550	131	-0.0043	0.0007	-0.0050
2340	110	-0.0007	-0.0010	0.0003	2560	132	-0.0027	-0.0006	-0.0021
2350	111	-0.0518	-0.0535	0.0018	2570	133	-0.0048	-0.0012	-0.0036
2360	112	-0.0716	-0.0714	-0.0002	2580	134	-0.0027	-0.0024	-0.0003
2370	113	-0.0963	-0.0923	-0.0041	2590	135	-0.0064	-0.0044	-0.0020
2380	114	-0.0977	-0.0979	0.0001	2600	136	-0.0114	-0.0058	-0.0057
2390	115	-0.0802	-0.0823	0.0021	2620	138	-0.0107	-0.0070	-0.0037
2400	116	-0.0618	-0.0605	-0.0013	2630	139	-0.0076	-0.0075	0.0000
2410	117	-0.0388	-0.0369	-0.0019	2640	140	-0.0085	-0.0040	-0.0044
2420	118	-0.0177	-0.0158	-0.0019	2650	141	0.0054	0.0033	0.0021
2430	119	-0.0112	-0.0124	0.0013	2660	142	0.0013	0.0078	-0.0065
2440	120	-0.0167	-0.0154	-0.0013	2670	143	0.0074	0.0109	-0.0035
2450	121	-0.0152	-0.0160	0.0008	2680	144	0.0060	0.0121	-0.0061
2460	122	-0.0103	-0.0035	-0.0068	2690	145	0.0117	0.0139	-0.0022
2470	123	0.0027	0.0016	0.0011	2700	146	0.0146	0.0131	0.0015
2480	124	0.0044	0.0099	-0.0055	2710	147	0.0141	0.0163	-0.0022
2490	125	0.0061	0.0141	-0.0080	2720	148	0.0169	0.0186	-0.0018
2500	126	0.0075	0.0177	-0.0102	2730	149	0.0041	0.0200	-0.0159

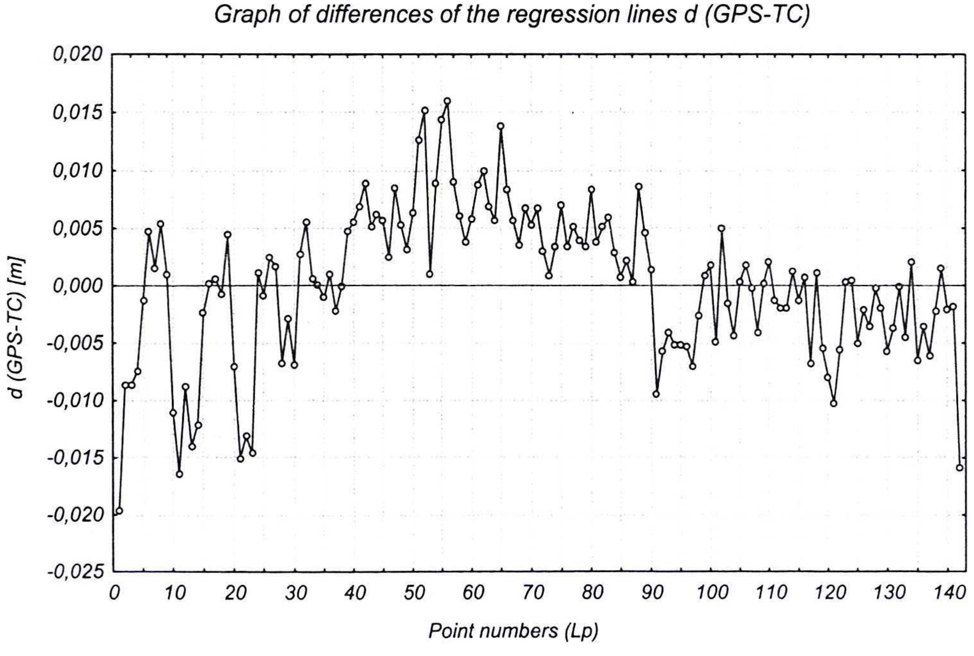

Fig. 11

Table 2

Nr [km]	Nr [Lp]	f GPS	f TC	f (GPS - TC)	Nr [km]	Nr [Lp]	f GPS	f TC	f (GPS - TC)
1260	2	0.0019	0.0072	-0.0052	1760	52	0.0035	0.0014	0.0021
1270	3	0.0014	-0.0045	0.0059	1810	57	0.0011	-0.0002	0.0013
1280	4	0.0012	0.0019	-0.0007	1820	58	0.0028	0.0007	0.0020
1290	5	-0.0052	-0.0024	-0.0028	1830	59	0.0059	0.0014	0.0045
1300	6	0.0026	0.0021	0.0005	1840	60	-0.0050	-0.0028	-0.0022
1310	7	0.0099	0.0049	0.0050	1850	61	0.0034	0.0037	-0.0003
1320	8	-0.0010	0.0029	-0.0038	1860	62	-0.0026	-0.0003	-0.0023
1330	9	0.0050	0.0005	0.0045	1870	63	0.0024	0.0029	-0.0004
1340	10	0.0003	-0.0040	0.0043	1880	64	0.0010	0.0001	0.0009
1350	11	-0.0165	-0.0136	-0.0029	1890	65	-0.0004	-0.0027	0.0023
1360	12	0.0055	0.0124	-0.0069	1900	66	0.0018	0.0027	-0.0009
1370	13	-0.0006	-0.0074	0.0068	1910	67	-0.0062	-0.0012	-0.0050
1380	14	-0.0017	0.0013	-0.0031	1920	68	0.0063	-0.0009	0.0073
1390	15	-0.0007	0.0038	-0.0045	1930	69	0.0004	0.0020	-0.0015
1400	16	0.0071	0.0033	0.0038	1940	70	-0.0034	-0.0032	-0.0002
1410	17	0.0015	0.0004	0.0011	1950	71	0.0003	0.0031	-0.0028
1420	18	-0.0046	-0.0055	0.0009	1960	72	0.0004	-0.0021	0.0025
1430	19	-0.0008	0.0026	-0.0034	1970	73	0.0000	0.0016	-0.0015
1440	20	0.0068	-0.0020	0.0088	1980	74	0.0053	0.0026	0.0027
1450	21	0.0021	0.0039	-0.0018	1990	75	-0.0018	-0.0010	-0.0008
1460	22	-0.0025	0.0028	-0.0053	2000	76	-0.0107	-0.0082	-0.0025
1470	23	0.0007	-0.0011	0.0018	2010	77	0.0021	0.0027	-0.0006
1480	24	-0.0090	0.0002	-0.0091	2020	78	-0.0013	-0.0052	0.0039
1490	25	0.0024	-0.0070	0.0094	2030	79	-0.0025	0.0004	-0.0029
1500	26	-0.0011	0.0017	-0.0028	2040	80	0.0013	-0.0003	0.0016
1510	27	0.0045	0.0023	0.0022	2050	81	0.0012	0.0016	-0.0004
1520	28	0.0049	0.0009	0.0040	2060	82	0.0000	0.0028	-0.0029
1530	29	-0.0055	0.0009	-0.0065	2070	83	0.0016	-0.0034	0.0050
1540	30	0.0077	0.0035	0.0042	2080	84	-0.0010	0.0021	-0.0031
1550	31	-0.0132	-0.0059	-0.0073	2090	85	0.0025	0.0023	0.0003
1560	32	0.0025	-0.0011	0.0036	2100	86	0.0024	0.0003	0.0021
1570	33	0.0027	-0.0015	0.0042	2110	87	0.0014	0.0019	-0.0006
1580	34	0.0009	0.0033	-0.0024	2120	88	0.0000	0.0019	-0.0018
1590	35	-0.0020	-0.0023	0.0003	2130	89	0.0021	0.0004	0.0017
1600	36	0.0004	0.0021	-0.0017	2170	93	-0.0009	-0.0006	-0.0003
1610	37	0.0027	-0.0001	0.0029	2180	94	0.0053	0.0015	0.0039
1620	38	-0.0036	-0.0007	-0.0029	2190	95	-0.0140	-0.0064	-0.0076
1630	39	-0.0024	-0.0010	-0.0014	2230	99	0.0061	0.0067	-0.0006
1640	40	0.0063	0.0042	0.0021	2240	100	0.0039	0.0038	0.0001
1650	41	-0.0016	-0.0013	-0.0002	2250	101	0.0019	0.0010	0.0008
1660	42	0.0032	0.0035	-0.0003	2260	102	-0.0001	0.0031	-0.0032
1670	43	0.0022	-0.0008	0.0030	2270	103	0.0052	0.0046	0.0005
1680	44	-0.0082	-0.0057	-0.0026	2280	104	0.0078	0.0065	0.0013
1690	45	-0.0038	-0.0046	0.0008	2290	105	0.0054	0.0014	0.0040
1700	46	0.0054	0.0040	0.0014	2300	106	-0.0182	-0.0094	-0.0088
1710	47	-0.0050	-0.0001	-0.0049	2310	107	0.0004	-0.0084	0.0088
1720	48	0.0051	0.0002	0.0049	2320	108	-0.0028	-0.0008	-0.0020
1730	49	-0.0024	-0.0018	-0.0005	2330	109	-0.0029	0.0011	-0.0040
1740	50	-0.0004	0.0024	-0.0028	2340	110	0.0335	0.0318	0.0018
1750	51	-0.0041	-0.0024	-0.0018	2350	111	-0.0165	-0.0184	0.0018

Nr [km]	Nr [Lp]	f GPS	f TC	f (GPS - TC)	Nr [km]	Nr [Lp]	f GPS	f TC	f (GPS - TC)
2360	112	0.0026	0.0016	0.0010	2550	131	-0.0063	-0.0019	-0.0044
2370	113	-0.0124	-0.0081	-0.0042	2560	132	0.0020	-0.0004	0.0023
2380	114	-0.0100	-0.0112	0.0012	2570	133	-0.0023	0.0003	-0.0026
2390	115	-0.0005	-0.0033	0.0029	2580	134	0.0031	0.0004	0.0027
2400	116	-0.0024	-0.0009	-0.0015	2590	135	0.0007	-0.0003	0.0010
2410	117	0.0010	0.0013	-0.0003	2630	139	0.0021	-0.0021	0.0043
2420	118	0.0078	0.0094	-0.0017	2640	140	-0.0078	-0.0020	-0.0058
2430	119	0.0064	0.0033	0.0031	2650	141	0.0095	0.0015	0.0080
2440	120	-0.0037	-0.0012	-0.0025	2660	142	-0.0054	0.0007	-0.0061
2450	121	-0.0018	-0.0070	0.0051	2670	143	0.0039	0.0010	0.0029
2460	122	-0.0043	0.0039	-0.0082	2680	144	-0.0037	-0.0003	-0.0034
2470	123	0.0060	-0.0016	0.0077	2690	145	0.0014	0.0013	0.0001
2480	124	0.0000	0.0021	-0.0021	2700	146	0.0018	-0.0020	0.0039
2490	125	0.0002	0.0004	-0.0001	2710	147	-0.0017	0.0004	-0.0021
2500	126	-0.0012	0.0024	-0.0037	2720	148	0.0083	0.0005	0.0077
2510	127	-0.0012	-0.0005	-0.0006	2730	149	0.0082	0.0007	0.0075

Differences of rises computed from point coordinates determined with the polar method and GPS-RTK

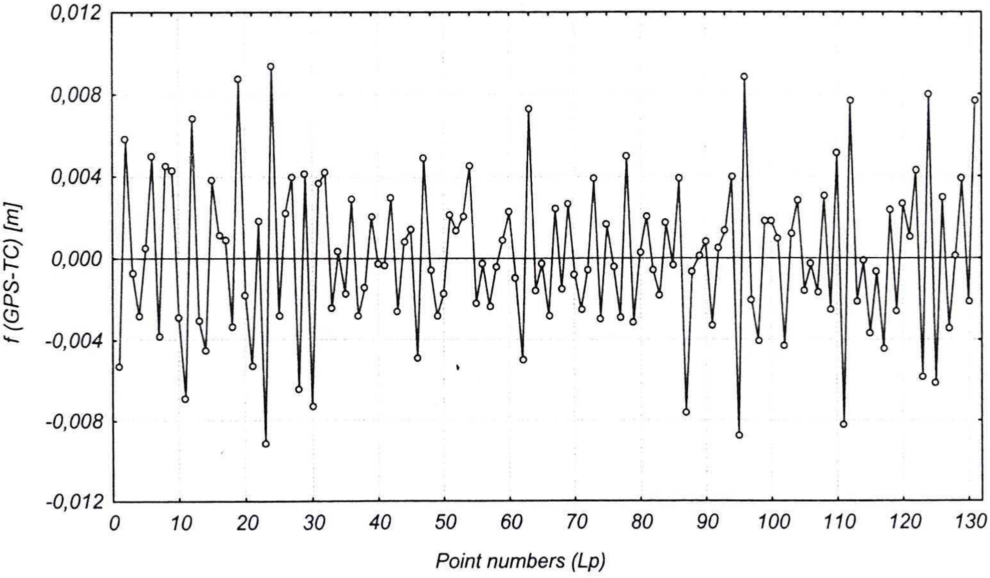

Fig. 12

horizon unsuitable for GPS surveys, i.e. in vicinnity of separate high obstructions (7 points) and in the area of dense obstructions (50 points at one end of the section). Among the 57 outliers one difference reached +94.8 mm and the remaining ones were within the range from –39.4 mm to +26.4 mm, with the r.m.s. value equal to ±17.2 mm. The differences (5) were recomputed again with the outliers excluded, results of this computation are shown in the Table 1, while Fig. 11 contains their graphical presentation.

Coordinates of points representing the real axis of the track were also used for computation of rises. The formula (2) was applied both to the RTK and polar method data. Differences of rises computed with the formula:

$$\Delta f_{\text{GPS-TC}} = f_{\text{GPS}} - f_{\text{TC}} \tag{6}$$

are listed in the Table 2 and represented in a graphical form on Fig. 12.

Sets of the Δd and Δf differences were analyzed with the software STATISTICA v.5.5 PL. Histograms created for the differences of offsets from the regression lines (Fig. 13) and for the differences of rises (Fig. 14) allow to conclude, that the differences have normal distribution $N(\mu, \sigma)$.

The parameters of such distribution are: displacement μ as the average value of offset and scale σ, a number characterizing the dispersion of collected data from the expected value μ. The displacement μ is the mean value of the deviation Δd or Δf in given sample data. Values of μ close to zero mean, that the deviations Δd, Δf are not influenced by a systematic factor and the standard deviation σ can be computed on their base. A confirmation of the absence of a systematic factor can be achieved by testing the hypothesis that the average values $E(\Delta d)$ or $E(\Delta f)$ are equal to zero at the assumed significance level, for example $\alpha = 0.05$. When the hypothesis H_0: $\mu = 0$ is accepted, it is understood, that the average value is contained in a given, symmetric confidence interval on the level $(1 - \alpha) = 0.95$ % , centered at zero, and then on the base of the deviations Δd and Δf the standard deviations $\sigma_{\Delta d}$, $\sigma_{\Delta f}$ are computed. In the reverse case the standard deviations are computed on the base of deviations reduced for the systematic factor $(\Delta d - \mu_{\Delta d})$ and $(\Delta f - \mu_{\Delta f})$. Results of the statistical analysis of the differences Δd given in Table 1 and of the differences Δf listed in Table 2 are shown in Table 3.

CONCLUSIONS

The surveys of the rectilinear railway track section proved the full applicability of the prototype measuring cart built on the base of the Matisa curvature corrector. The design of the cart allows unambiguous determination of track axis and marking of points measured with the use of EDM prism, when the polar method is applied, or the GPS antenna during RTK surveys. Results of surveys obtained at the 1500 m long track section confirmed advantages of the RTK method as applied to measurements for railway track regulation purposes. Despite the use of a prototype measurement cart, outdated GPS receivers and standard GPS antennas, satisfactory values of accuracy parameters pertaining to determined coordinates of points representing the real track axis, were obtained. These parameters are the standard deviations, listed in the Table 3, which encompass together errors of point coordinates determination with the polar

Table 3

Values of statistical parameters [mm]		
Variable	Δd	Δf
Sample size	142	131
Mean	0.1	0.0
R.m.s.error of the mean	0.5	0.3
Confidence level – 95.00 %	-0.9	-0.6
Confidence level + 95.00 %	+1.2	+0.7
Minimum value	-19.6	-9.1
Maimum value	+16.0	+9.4
Standard deviation	6.5	3.8

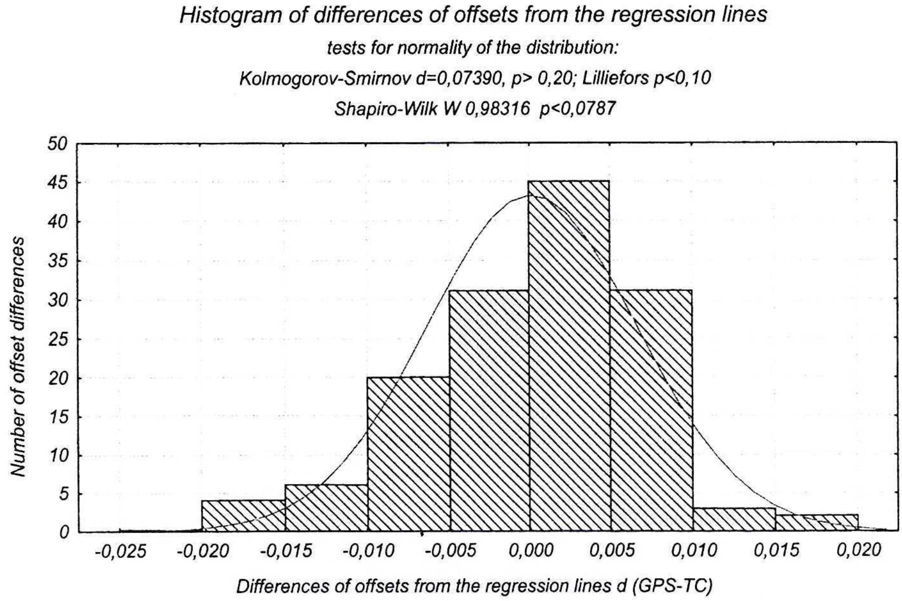

Fig. 13

method and the RTK, errors in the identification of the points observed independently with the two methods, and errors of the reference points. In result one can expect, that the standard deviations of differences $\Delta d_{GPS\text{-}TC}$ (±6.5 mm) and $\Delta f_{GPS\text{-}TC}$ (±3.8 mm) will be less for surveys performed with the specialized measurement cart based on the track gauge meter TEC–435 and modern GPS receivers Leica System 500 equipped with choke-ring antennas. It is expected, that the proposed changes in hardware will result in significantly lesser vulnerability of the

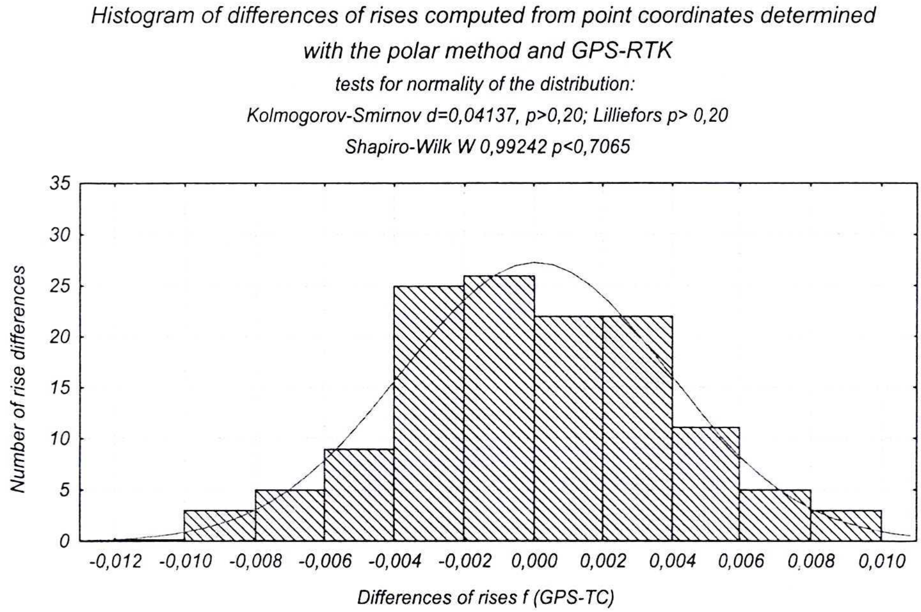

Fig. 14

GPS system to satellite signal distortion and obstruction. On the base of results of surveys made on the last 500 m of the railway track section used in the experiment (Fig. 10) one can conclude, that in presence of high terrain obstacles the RTK method is deceptive and produces data of insufficient accuracy. In such areas the survey should be performed by the polar method, with the use of precise electronic total stations.

REFERENCES

[1] Gmyrek J., Gocał J., *Charakterystyka dokładnościowa zintegrowanej osnowy kolejowej*. Półrocznik AGH, Geodezja t.5, z.1, 1999r

[2] Gogoliński W., Uznański A., *Badanie geometrii osi torów kolejowych techniką RTK GPS*. Półrocznik AGH, Geodezja t.5,z.1,1999r.

[3] Instrukcja D19 o organizacji i wykonywaniu pomiarów w geodezji kolejowej, Warszawa, 1992r

[4] Praca zbiorowa, *Geodezja inżynieryjna*, t.3, PPWK , Warszawa.

Received May 6, 2001
Accepted August 8, 2001

Jan Gocał
Michał Strach

Wstępna ocena przydatności metody RTK GPS w pomiarach inwentaryzacyjnych torów kolejowych

Streszczenie

W artykule przedstawiono koncepcje wykorzystania techniki satelitarnej RTK GPS do pomiarów inwentaryzacyjnych torów kolejowych. Według tej koncepcji wykonano badania doświadczalne na dwu kilometrowym odcinku linii kolejowej. Badania potwierdziły funkcjonalną i dokładnościową przydatność metody RTK GPS do prac związanych z regulacją torów kolejowych.

Ян Гоцал
Михал Страх

Предварительная оценка пригодности метода RTK GPS в инвентаризационных измерениях железнодорожных путей

Резюме

В статье представлена концепция использования спутниковой техники RTK GPS для инвентаризационных измерений железнодорожных путейю. Согласно с этой концепцию выполнены опытные исследования участков железной дороги длиной два километра каждый. Опытные измерения подтверждают функциональную и точечную пригодность метода RTK GPS в работах связанных с регулированием железнодорожных путей.