INVESTIGATION OF PHASE CENTRE VARIATION OF THE GNSS ANTENNAE USING PORTABLE KINEMATIC TILTING DEVICE

Jan Cisak[1]; Yevgen M. Zanimonskiy[2]
[1] Institute of Geodesy and Cartography, Warsaw, Poland, jcisak@igik.edu.pl
[2] Institute of Radioastronomy, Kharkiv, Ukraine, zanimonskiy@rian.kharkov.ua

Abstract

A GNSS antenna can be characterized by phase centre offset and by phase centre variations (PCV) as a function of azimuth and elevation of the satellite signal. Absolute calibration of GNSS antennae at the place of its mount is becoming compulsory more and more frequently. The near-field effect is especially interesting for geodetic community for the establishment of new permanent GNSS stations and in precise geodetic fieldwork. The Institute of Geodesy and Cartography, Warsaw, Poland, has been involved in GPS antenna phase centre investigations since nineties of last century. In order to calibrate a variety of geodetic antennae and mounts, the field tests on short baselines in Borowa Gora Geodetic-Geophysical Observatory are having been conducted and elaborated.

A simple and portable prototype of the device for antenna calibration was constructed and investigated in the Institute of Geodesy and Cartography. A kinematic device has the advantage that possible local site scattering effects can be accounted for. The PCV measurements are conducted without the usage of a reference site. Different antennae types including choke-ring and Ashtech geodetic antenna were used in the experiments. Technical description and data processing scheme for PCV measurements are presented in the paper.

1. Introduction

For precise geodetic and geophysical applications the site position should be known at millimetre level of accuracy. The unknown shift of phase of the satellite signal recorded in the antenna system results in the systematic error reaching up to several millimetres. This means that the antenna itself and the bodies surrounding the antenna are modifying its electrodynamics properties. The configuration of the antenna system is thus unique for a site. At permanent GNSS stations, the electrodynamics properties of the antenna may become modified depending on weather conditions, dampness of the surrounding surface, or the amount of snow covering the antenna and snow in its vicinity (Niell, 1997; Ray, 2006). Elimination of the influence of these factors by modelling is not possible because of their complexity.

Experimental works with GNSS antennae designed for solving several different tasks have been carried out. The first task concerns a definition of parameters of the antenna under "ideal" conditions. The second one consists in defining how much the real conditions of the antenna arrangement differ from the "ideal" ones and what are the minimum set of requirements to the antenna installation site. The third problem, mostly relevant nowadays, is how to calibrate the antenna in real conditions on an installation site.

2. Phase centre changes due to different height of antenna mount

The antenna offset is defined as the average of phase centre locations relative to a physical reference point (antenna reference point - ARP). Unfortunately, the theoretical concept of phase centre as a mathematical point representing the intersection of all ranges measured from the satellites cannot be realized because the environment of the antenna distorts the properties of the incoming signals.

The calibration of geodetic GNSS antennae has become the subject of intensive research over the last 10 years. Different methods have been elaborated to determine the phase centre position and its variations in the “ideal” situation (Rothacher et al., 2002). Those methods are laboratory ones: anechoic chamber (Görres et al., 2006); NGS test field; (Mader, 1999) or used in special field conditions like the robot calibration system (Wübbena et al., 2006). Test field measurements represent the relative methods while anechoic chamber and robot systems give the absolute solution.

The necessity of absolute antenna calibration was reflected in the Resolution 1 of the EUREF 2005 Symposium in Vienna. http://www.euref-iag.net/html/resolutions.html#Viena The Institute of Geodesy and Cartography, Warsaw, has been involved in GPS antenna phase centre investigations since 1999 (Dobrzycka and Cisak, 2001).

High-accuracy GNSS observations can be affected not only by the antenna type but also by the height of the mount. The multipath far-field effects, i.e. reception of the reflected signal with a propagation difference larger than a few meters, may be reduced due to averaging over time. Near-field (scattering) effects in general cannot be reduced. Moreover, the multipath effects are practically absent at the high elevation angle of satellites. Scattering produces errors that vary insignificantly with elevation, so it is difficult to detect them under standard antenna calibration procedures.

Some years ago, when most of permanent GNSS tracking stations were established, the problem of the type of antenna mount has not been taken into consideration. It seems that scattering effects change the height of mean phase centre relatively to ARP at millimetre level. The changes are minimal when the antenna is placed on the tripod (Ray, 2006). The changes are significant and rather stable under different weather conditions when the antenna is located on the metal plate (Cisak and Zanimonskiy, 2006). Scattering of the phase and amplitude of the electromagnetic wave at the top of concrete pillar depends on the size of its upper surface, and in particular on the dampness of that surface

To detect elevation-dependent height errors of the antenna, test measurements were performed in Borowa Gora and Lamkowko Observatories in Poland. In summer 2006 the choke ring antenna was placed on a tribrach above the large (1 m × 1 m) concrete pillar. The elevation of the antenna reference point was changed from 0 up to 78 cm.

Torrid summer provided us with the chance to perform measurements with a dry as well as an artificially moistened top to the concrete pillar. The heights of the site obtained as a result of GPS solutions using two reference stations BOGO and BOGI from “dry” and “wet” conditions of the top of pillar differ slightly more then one millimetre.

On the other hand in winter 2006/2007 changeable weather during two consecutive weeks of observations randomised the influence of scattering signals. The variations of height errors vs. antenna elevation were difficult to discern from random ones.

In the next group of experiments the antennae (choke-ring and Ashtech geodetic) have been placed on a concrete pillar with diameter of the top of about 0.5 m only. The variations of antenna phase centre height relatively to ARP occurred insignificant and rather random in this case.

At the same time the similar experiments were performed with antennae placed on the wooden tripod (without any scattering or reflecting surfaces) as well as on the top of the pillar covered by metal plate like those used on some permanent GNSS stations. There was no significant or systematic trend of “apparent” height vs. antenna elevation above the tripod. The phase centre variations vs. antenna elevation over metal plate are distinguishable and stable under weather changes . These variations range within 5 mm; they differ for both GPS frequencies and their combinations.

The authors suggest that the application of the third frequency in the GPS satellite and design of special antennae for near rock placement are the ways to solve the "near-field problem".

The test of the property of choke-ring antenna placed near the ground was performed in Borowa Gora Observatory in May-June 2007. The antenna was situated on different elevations on the grassy meadow. 24-hours sessions were used at the each elevation reiterated three times in accordance to randomised plan of experiments. Some results of this test are shown in Figure 1.

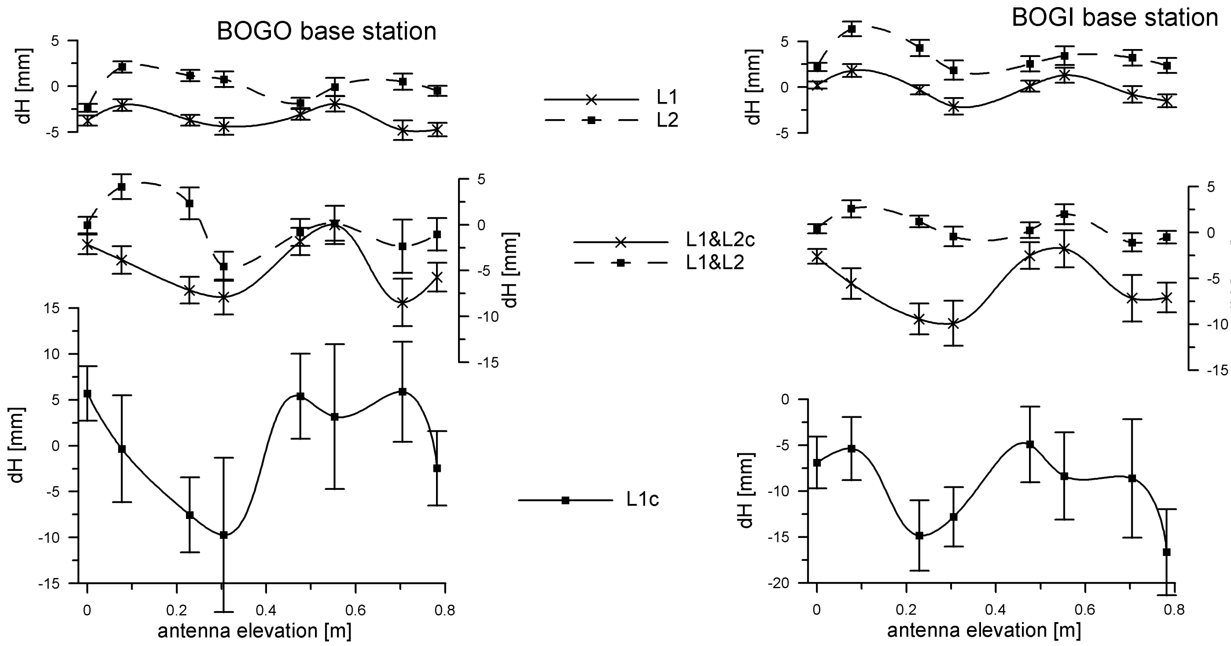

Fig.1. The apparent variations of the height of mean phase centre relatively to ARP (L1, L2 and combinations) vs. antenna elevation. Observations with antenna placed near the ground. Two reference stations were used

It should be emphasized that near-field effects have different phases and slowly differing amplitude for carrier signals at both frequencies. This is the one of the reasons of different results of measurements with different carrier combinations (Fig. 1). Variations for single frequency solutions are within 5 mm and rather regular. Variations for the iono-free combination (L1c) are about five times larger. Observed variations slightly depend on the reference station used in the experiment.

The results obtained indicate that the location of the antenna at the elevation of several decimetres above a soil is the worst for geodetic applications.

3. Antenna calibration device

A project on the development of GNSS antennae calibration technology, taking into account the parameters of local conditions, was established as a continuation of the previous investigations by the Institute of Geodesy and Cartography, Warsaw. A prototype of the device for antenna calibration was constructed. In this kinematic instrument the test antenna is mounted on the rocking lever (Fig. 2). First test measurements were already performed in Borowa Gora and Lamkowko Observatories in Poland.

Using the antenna-tilting device it is possible to determine the mean phase centre offset as well as the PCV in a real multipath and scattering situation. Algorithms and data processing schemes are very similar to those used for absolute antennae calibration with robot device. Differences in the results arise due to continuous angular movement (tilting) of antenna instead of the discrete tilting of robot carrying antenna. In this situation one may use the simple filtering procedures for extraction of sinusoidal variations of antenna position and carrier phases. Parameters of mechanical movement of ARP are being measured by means of a special sensor. The swing period of the pendulum-like device in the same plane lasts 30 seconds. Complete investigation of antenna parameters needs two sets of measurements with axial rotation of antenna on 90º.

Phase centre offset is being measured with the use of a reference site, whose antenna does not need a precise or absolute calibration. On the other hand, PCV may be measured in a single site mode with the use of between satellites carrier differences.

Fig. 2. Investigation of the Leica choke-ring antenna before its installation at the permanent GPS station LAMA

Dependence of PCV vs. apparent zenith angle "antenna-satellite" as well as the scheme of transformation of modulation of an apparent angle to the modulation of measured distance "satellite-antenna" are shown in Figure 3.

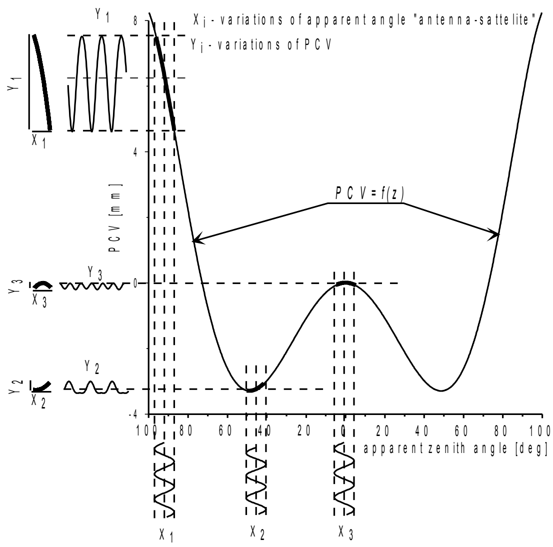

Fig. 3. PCV vs. apparent angle "antenna-satellite" and the scheme of transformation of modulation of angle onto modulation of apparent distance "satellite-antenna"

Similar figures explain the principle of signals transferring in various electronic devices. Analogue of transfer function of a device is the dependence of PCV on apparent zenith angle z_i, i.e. PCV = $f(z_i)$. Commonly speaking the output signal consists of harmonics of an input signal. The amplitude of basic harmonic, on frequency of modulation of an angle, is proportional to an inclination - the first derivative, and the second harmonic, on the double frequency of modulation - is proportional to the curvature - the second derivative.

Directional derivatives have been calculated on the basis of measured modulation of “antenna – satellite” distance:

$$\delta y_i = \left[\frac{dy}{dz_i} \delta z_i(t) - \frac{d^2 y}{dz_i^2} \frac{1}{2} (\delta z_i(t))^2 \right] + \varepsilon_i(t)$$

δy_i - modulation of satellite – antenna distance at satellite elevation angle z_i ;

$\frac{dy}{dz_i}, \frac{d^2 y}{dz_i^2}$ - first and second derivatives of phase centre pattern dependent on elevation in the vicinity of z_i;

$\delta z_i(t)$ - modulation of “apparent” elevation angle

$$\delta z_i = \left(\psi(t) \sin(A - A_{tilt}) \cos z_i + \frac{1}{2} \psi^2(t) \sin z_i \right)$$

$\psi(t)$ - angle of antenna tilting at the kinematic tilting device

$$\psi(t) = \psi_0 \sin\left(\frac{2\pi t}{T} \right)$$

ψ_0, T - amplitude and period of antenna tilting, t – time, A – azimuth of satellite;

A_{tilt} - azimuth of antenna tilting axis, $\varepsilon_i(t)$ - errors dependent on time.

Recording GNSS signals of continuously moving satellites (zenith and azimuth vary in time), provides an opportunity to determine derivatives (in the plane of antenna tilting) of the dependence of PCV on zenith angle and azimuth in corresponding points.

Choke ring antennae as well as newly designed geodetic antennae, (Kunysz, 2006; Krantz et al., 2001) have no obviously visible dependence of PCV vs. azimuth. For such types of antennae the layout chart of zones of measurement of PCV variations as variations of carrier phases of signals of observed satellites is shown in Figure 4.

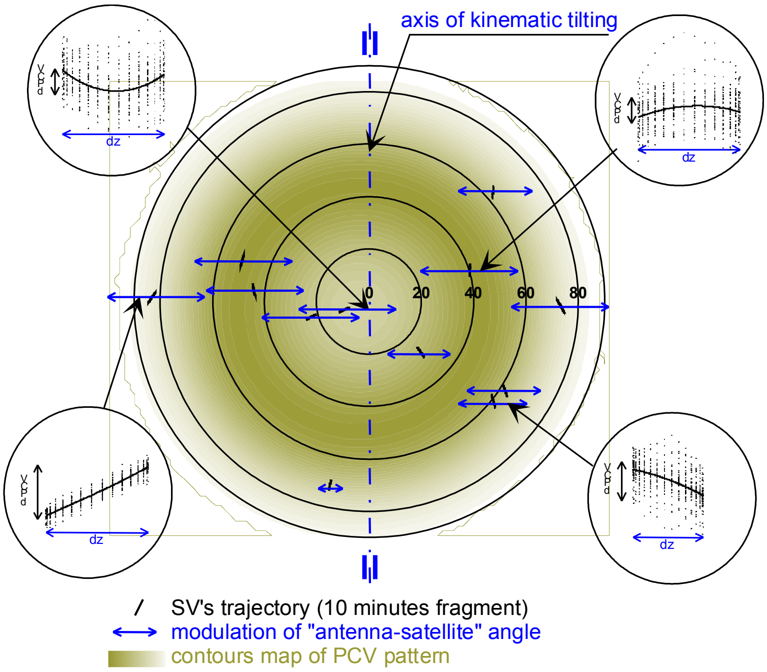

Fig. 4. 10-minutes trajectories of satellites in polar coordinates "zenith angle-azimuth", as well as modulation of an apparent angle at tilting (for all observed satellites) and modulation of distance the "satellite-antenna", interpreted as modulation of PCV (for four satellites with characteristic angular coordinates) on a background of a contour map of PCV model

Similar layout chart on the background of 3-D view of PCV pattern is shown in Figure 5.

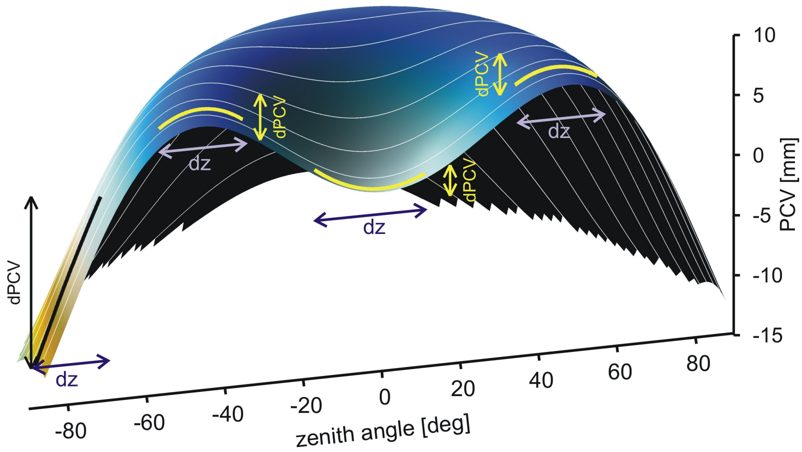

Fig. 5. Results of measurements of PCV modulation for four satellites in 10-minute session on the background of 3-D view of model of PCV of choke-ring antenna

The plots of modulation of PCV at various zenith angles of satellites may be put together, as a "puzzle". Thus average PCV values was adjusted in the manner that at z = 0 PCV = 0 (Fig. 6).

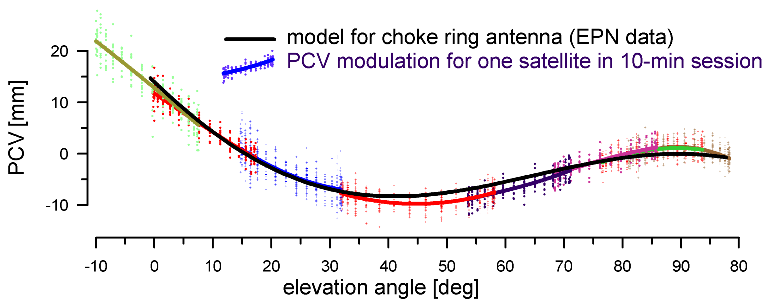

Fig. 6. PCV vs. zenith angle drawn up on the basis of 30-minute session of the observations of 8 satellites (points and fragmentary lines). A black continuous curve shows the model for the choke ring antenna (according to EPN data)

Discrepancy between the experimental data and model of PCV will be investigated at the next stage of work with antenna calibration device.

4. Conclusions and future works

- The uncertainty of the measured height of site due to the scattering of the electromagnetic waves on the top of the concrete pillar may reach 1-2 mm;
- The effect of scattering at the top of the concrete pillar is unstable and depends on humidity of the pillar;

- Scattering on the metal surface, found under antenna at some permanent GPS stations, gives significant and stable in time, change of the measured height of site up to 5 mm;
- The most stable results were obtained in the absence of disseminating surfaces near the antenna, namely for the installation of antenna on a standard wooden geodetic tripod at height of approximately 1.5 m above a grass-covered ground;
- The measurements executed with the antenna located on the elevation ranging from several centimetres up to half a metre above a soil, have yielded the most unstable results with variations of the measured height at the level of 1-2 cm for iono-free combination;
- Investigation of antennae in real conditions of installation, that is, "in situ", should be carried out. This would allow for testing the stability of scattering of satellite signals and multipath and, in case of stable conditions, there could be a calibration conducted "in situ";
- The development of the kinematic tilting device should be continued and a final method of calibration should be elaborated.

Acknowledgements

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