Some Peculiarities of Positioning in Satellite Radio Navigation Systems

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***Abstract*- Earlier authors presented the first own results of research of positioning errors in radio navigation systems. They were received at specialized observation stations of Irkutsk Branch of Moscow State Technical University of Civil Aviation. This article is devoted to more detailed consideration of time variations of consumers' positioning errors. The found features can be used for increase of accuracy of positioning.**

***Keywords*- Satellite Radio Navigation; PPP; Positioning Error; Ionosphere; Total Electron Content; Ionospheric Correction**

I. INTRODUCTION

The problem of increase of accuracy in GNSS was and remains to be one of the most actual tasks. In the review [1] current situation in this area is in details described. We would like to pay attention to one more possibility of increase of the accuracy connected with one poorly studied phenomenon. This phenomenon consists in repeatability of temporary variations of an error of positioning in the next days. The phenomenon can have important practical applications.

The typical value of positioning errors in consumer single-frequency receivers is several meters as represented, for example, in [2]. High-quality geodesic devices and special techniques for solving a navigation problem including special models of ionospheric delay (so called PPP conception) enable to increase positioning accuracy to a decimeter level. The corresponding approaches are described, in particular, in the Work [3]. However such approaches can hardly be made use of in widely used conventional navigation devices. Thereby it is attractive to try using of some peculiarities of time variations of experimentally monitored positioning errors to increase accuracy of positioning in single-frequency equipment.

Our previous experimental studies revealed an interesting effect [4]. Receiver coordinate deviation from its true position is well-repeated during two or more following days. The effect is most expressed in time variations of antenna height. The effect has no relation to day variation of total electron content in the ionosphere with the interval of 24 hours. These fluctuations have shorter periods with specific duration of tens-thousands of seconds. It must be mentioned that measurements were performed by single-frequency navigation equipment. So we decided at first that the effect was related to time variations of electron concentration in the ionosphere. However, the results given below don't prove it.

II. EXPERIMENT RESULTS

Fig. 1 represents typical time variation of antenna height determined by a navigation receiver during two adjacent days. The data were received at a specialized observation station of Irkutsk branch of Moscow State Technical University of Civil Aviation in GPS navigation system. This and the other figures represent the determined antenna height *h* along the vertical axis. Only the relative variations of height are of interest, so only the measurement unit scale is represented along the vertical axis. The curves corresponding to two days are positioned one under the other with some vertical shift. The horizontal axis represents UTC in observation sessions during the adjacent days. The figure clearly shows that time variation has fluctuations of different time scales. Two classes are worth choosing among them: minor intensive short-period fluctuations with duration of tens of seconds and more intensive long-period variations with specific duration of thousands of seconds.

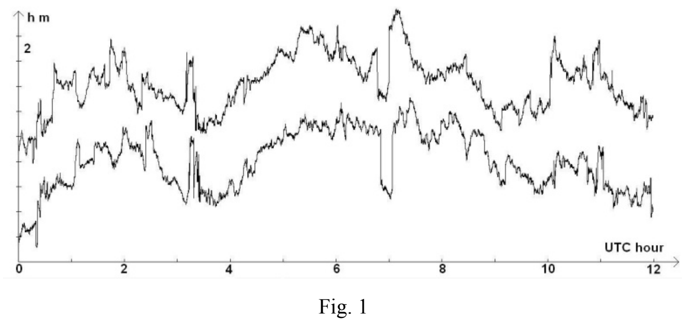

Fig. 1

The detailed analysis revealed an important property of fluctuations: their repetition during adjacent days has a time shift equal to four minutes. Figure 2 represents scaled-up fragments of time variation during adjacent days with this shift. The horizontal axis represents time *t* in minutes relative to the session start. The GPS satellite periods are 11 hours and 58 minutes, so the shift can be related to the repetition shift of the satellite constellation location.

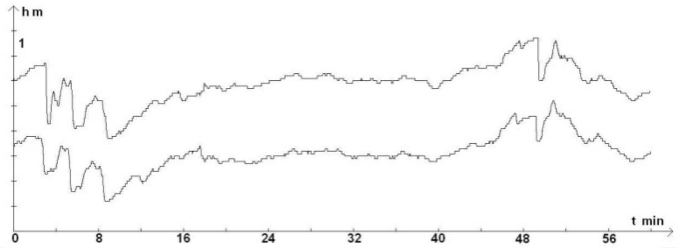

Fig. 2

At first we interpreted fluctuation repetition as a multipath effect which arises on reflecting satellite signals from landscape objects. Indeed, the multipath effect in stationary environment depends upon satellite constellation and repetition during adjacent days must have a time shift of 4 minutes.

However, this interpretation was declined after synchronous observations at two distant observation stations. Figure 3 represents time variations of antenna heights at two observation stations with the approximate distance of 4 km between them. Thereby, the stations have quite different environment. The figure shows that distant stations have good correlation of long-period variations of antenna heights. Short-period fluctuations are absent. Thus, short and minor intensive fluctuations of antenna heights are actually caused by the multipath effect. Variations with time duration of thousands of seconds are not related to the multipath effect.

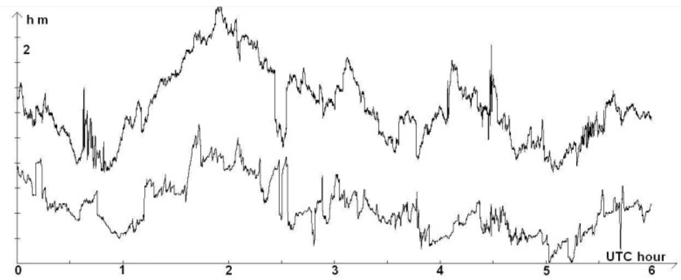

Fig. 3

Then a time variation of antenna height of one of the IGS observation stations was analyzed. We used data in the form of navigation and observation RINEX-files. The navigation problem was solved with the aid of GPStk Toolkit (program RINEXPVT) [5, 6]. Fig. 4 was formed similar to Fig. 1 for one of the middle-latitude IGS stations. It also clearly shows repetition of time variations of antenna height during adjacent days. So it proves that the described peculiarity has a global, not local character.

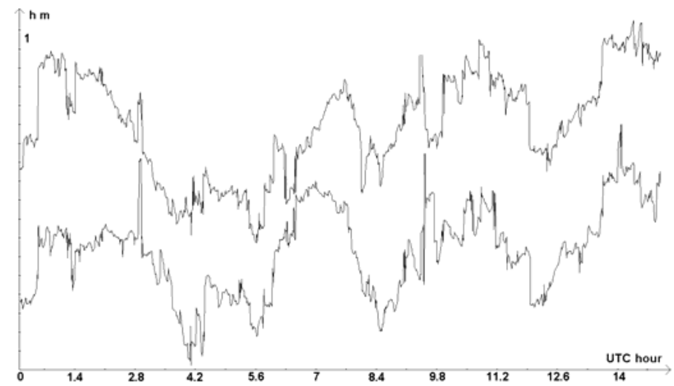

Fig. 4

To explain the revealed effect we hypothesize that the reason of the described phenomenon is repetition of satellite positioning error during adjacent days. To verify this we used the program RINEXPVT at GPS Toolkit again. This program enables to solve a navigation problem by means of standard navigation RINEX-files and the files of refined ephemerides (SP3-files). Fig. 5 represents fragments of day variation of a determined height at one session for an IGS station. The upper curve corresponds to the data of standard navigation RINEX-files. The lower curve corresponds to the data of refined ephemerides. It can be seen that the use of refined ephemerides doesn’t eliminate the specified variations. Thereby, the specified variations are not related to satellite coordinate errors.

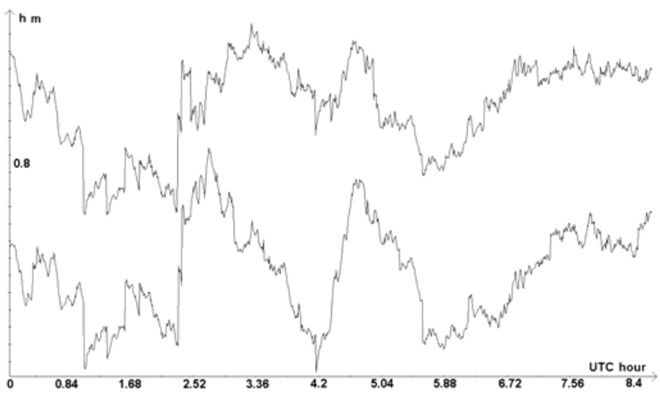

Fig. 5

The use of IGS station data enables to study positioning error repetition for observation points having a significant distance between them. Fig. 6 represents time variations of heights for two middle-latitude IGS stations. The stations have a distance of 7 degrees longitude between them (approximately 600 km). The figure shows that positioning error repetition takes place and doesn't have any significant time shift.

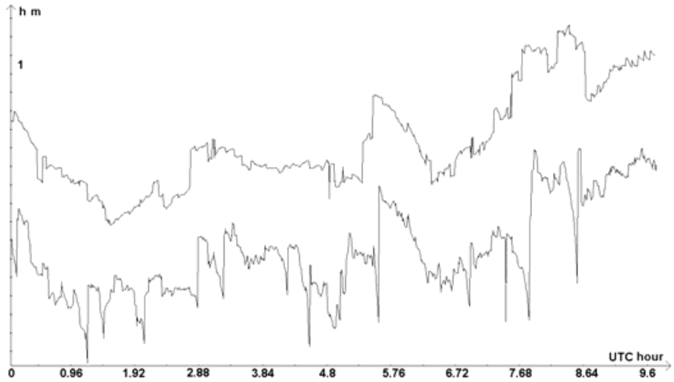

Fig. 6

Similar results were achieved for two middle-latitude IGS stations with the distance of 7 degrees latitude between them (approximately 900 km). The results are represented in Figure 7.

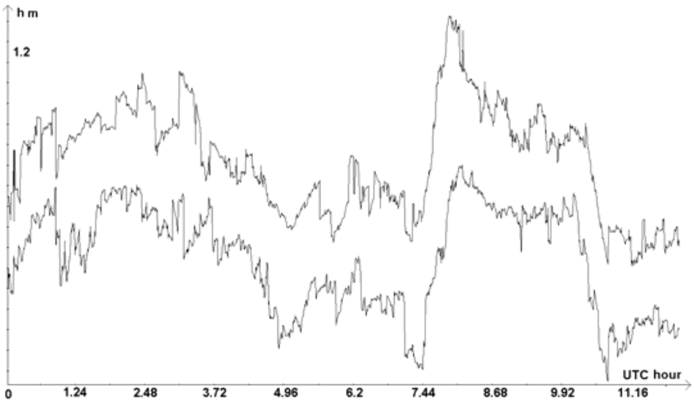

Fig. 7

Taking into consideration the correlation of the Earth's radius and satellite orbit height we can assert that the IGS stations engaged in the research use the same constellation for solving a navigation problem. It can be assumed that positioning error variations are related to the constellation of satellites which are used in solving a navigation problem.

The influence of a constellation configuration on an antenna height determination error was researched as follows. The PRSolve program at GPS Toolkit has a property which enables to choose specific satellites to solve a navigation problem. At an appointed session of an IGS station two calculations with different constellations were performed. The constellations were made up of five satellites, one of those was common, the others satellites did not repeated. The results of calculations are represented in Fig. 8. The upper portion demonstrates height variations during adjacent days for the first constellation, the lower one for the second. It can be seen that variations during a day take place but the character of repeated variations for different constellations is not the same.

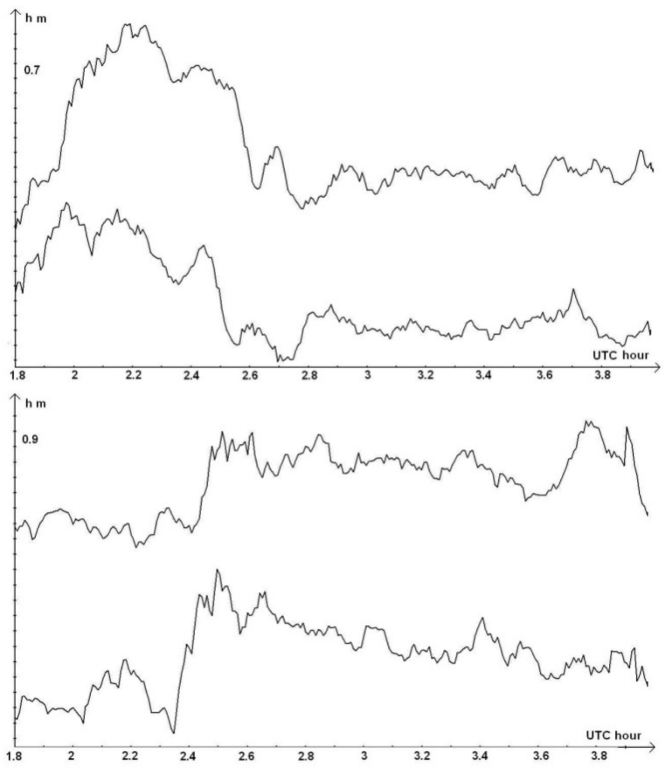

Fig. 8

In addition to the latest research at a specialized observation station of Irkutsk Branch of Moscow State Technical University of Civil Aviation, the measurements were performed with the use of GPS and GLONASS navigation systems. The results are represented in Fig. 9. In the figure, similar to the previous one, time changes of the determined height during adjacent days are represented. The upper portion demonstrates the result for GPS, the lower one for GLONASS. Repetition of time variation of the height is also available. And this repetition is also different for the two systems. For GLONASS system time variation during the following day is shifted for an hour and a half compared to the previous one. It corresponds to the satellite period of the Russian navigation system.

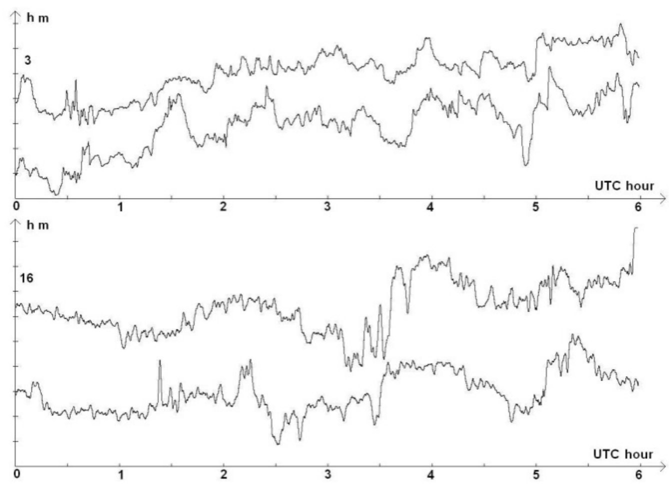

Fig. 9

III. CONCLUSIONS

So, the performed research shows steady repetition of positioning error variation during adjacent days with specific time scales from tens to thousands of seconds. The repeated variations are probably related to the space segment of satellite navigation systems and have no direct relation to the navigation receiving equipment, their landscape environment, nor conditions of radio signals propagation.

At the moment we can't propose a reasonable hypothesis about the origin of the described repeated variations. One of the aims of the present article is attracting attention of specialists to the search of hypotheses. The importance of the problem is obvious as understanding the reasons of positioning error repetition opens the ways of its eliminating.

The revealed peculiarity of time variations of positioning errors can be used to increase the accuracy of a consumer's coordinate determination. There is an analogy with the differential operation mode of GPS system (DGPS) [7]. In this mode the current errors of determination of three coordinates are defined at the basic station with the known coordinates. Then the errors as a correcting parameter are continuously transmitted to consumers in the given area through specialized ground or satellite communication links.

The following technique of use of positioning error repetition during adjacent days can be suggested. When being smoothed the day variation of errors is registered at a basic station. The corresponding file of numerical data is formed and made available in the Internet or transmitted to a cellular operator. The next day a consumer downloads once the file from the Internet or receives it through cellular links. Then the corresponding errors are subtracted from the current calculated coordinates. In this way the considerable amount of current positioning errors is compensated. This time-differential operation mode is likely less efficient as compared to a differential one, but it is easier and less expensive. In this case there is no need to use specialized radio channels and the day's amount of transmitted information is considerably reduced. The suggested technique could be the most convenient for consumers using mobile devices with built-in navigation receivers having an access to cellular communication and the Internet. It is they for whom it is the simplest way to organize data download with the correcting information.

This work was executed with support of the Ministry of Education and Science of the Russian Federation (agreement №8388).

ACKNOWLEDGMENT

The authors thank T. Portnova for assistance in manuscript preparation.

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