Chapter 37
Antenna Circular Rotation Method for Detecting Receiver Dynamic Positioning Accuracy

Haisong Jiao, Shentang Li, Haiqiang Yang, Liangjian Jiang and Lili Wang

Abstract The paper introduces circular rotation testing system by which GPS receiver's dynamic performance can be examined, analyzes the change rule of Doppler frequency shift caused by the circular rotation of antenna, compares the states of antenna circular rotation and the linear moving of airborne by investigating the Doppler shift and Doppler shift changing rate, then puts forward the basic method for detecting receiver dynamic positioning accuracy via antenna circular rotation to simulate the state of the airborne linear motion by investigating Doppler shift changing rate. As an example, by using a NovAtel RT2 GPS receiver, the paper gives accuracy analysis of the GPS receiver point positioning and carrier phase differential positioning under the condition of antenna circular rotation with the proposed method, and gives the Receiver's accuracy of point positioning and carrier phase differential positioning under different moving states as well. Finally, points out the application and popularization of the proposed method in detecting dynamic accuracy and tracking performance of Compass and GPS of other types.

Keywords Receiver · Dynamic accuracy · Circular rotation · Detection

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J. Sun et al. (eds.), *China Satellite Navigation Conference (CSNC) 2013 Proceedings*, Lecture Notes in Electrical Engineering 243,
DOI: 10.1007/978-3-642-37398-5_37,

37.1 Introduction

In view of GPS and Compass measurement receiver's high precision, it is difficult to find higher precision dynamic measuring equipment to examine their accuracy. Thus, the evaluation of receiver dynamic positioning precision has been difficult at home and abroad. At present, many domestic research institutes have been trying to study on this problem, the common method is to use the signal simulator for measurement dynamic simulation environment [1]. While, the cost of which is expensive and inconvenient to use. Furthermore, it can not simulate the real working environment, the test results are often in doubt as well. This paper presents a method using antenna circumferential rotation to detect and analyze the receiver dynamic positioning accuracy, trying to solve the difficult problem of receiver dynamic accuracy testing.

37.2 Design of Antenna Rotating Test System

37.2.1 Design Ideas

The receiver is mounted on the rotating platform, the antenna on the edge of rotating arm, continuously improve the antenna rotation speed by adjusting the motor, research the dynamic positioning accuracy by investigating the deviation of the dynamic positioning data relative to fixed position, by observing the receiver positioning and the change of Doppler shift of original measurements to study the receiver dynamic tracking performance [2].

37.2.2 System Consist

Antenna rotation test system, shown in Fig. 37.1, consists of a rotating platform test subsystem, differential reference station subsystem and the dynamic performance test subsystem.

Subsystem composition and function:

1. Rotating platform test subsystem mainly consists of a rotating platform (motor, rotating shaft, etc.), receiver (for recording), data transmission system and a photoelectric sensor. The main task of which is to simulate the operating state of receiver, to complete the measurement precision and tracking performance test under dynamic condition.
2. Differential reference station subsystem mainly consists of the receiver whose antenna is arranged at the reference point, the records with a laptop and data transmission radio. The main work of which is to record the original measurement data of the reference station and to transmit the differential information [3].

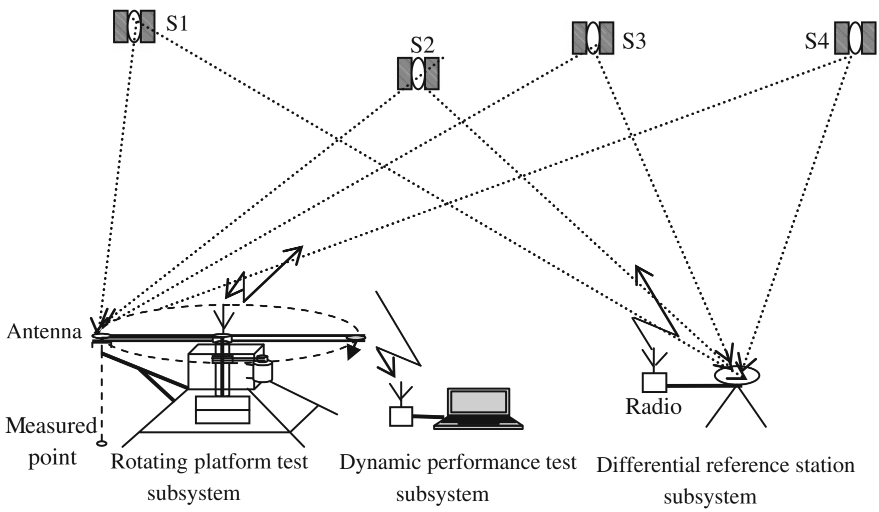

Fig. 37.1 Working scenario of antenna rotation test system

3. Dynamic performance test subsystem mainly consists of the laptop installed with dynamic test software, data radio to receive, process and display the real-time positioning information and original measurement information

37.3 Comparison of Antenna Circular Motion and Airborne Linear Motion State

37.3.1 Analysis of Doppler Frequency Shift Changes

37.3.1.1 Analysis and Test of Doppler Frequency Shift Caused by the Antenna Circular Motion

Set the disk center point is O, satellite S in ground projection point is E, EO connection with the disc for the intersection of A and C, B and D as the intersection point of circular and vertical line of AC that passes O, the angle between planar BDS and horizontal is θ ($\theta \leq 90°$), as shown in Fig. 37.2.

The Doppler frequency shift caused by relative motion of satellite and the target can be expressed as [4]:

$$f_d = f_s - f_r = -f_s \frac{V_R}{C} \tag{37.1}$$

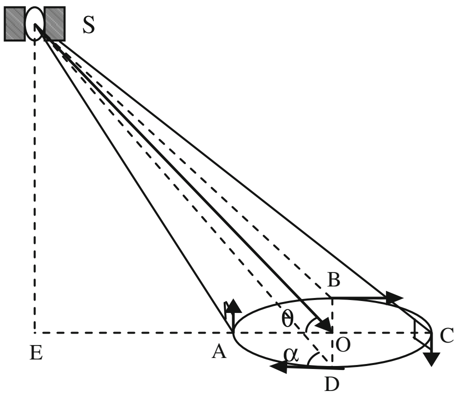

Fig. 37.2 Analysis diagram of Doppler frequency shift changes

where, f_s is the satellite transmitting frequency, f_r is the received satellite signal frequency, C is the velocity of light, V_R is the radial velocity of satellite and target's relative movement.

Suppose Satellite is stationary, namely the Doppler frequency shift is caused only by the antenna rotating, the GPS antenna line speed is V, the angle between the line SD and tangential component is α, then the radial velocity of D relative to satellite S is $V_R = V * COS\ \alpha$. When $\alpha > 90°$, the point D moves away from S, namely Doppler frequency shift is positive. When $\alpha < 90°$, the point is close to S, namely Doppler frequency shift is negative. When $\alpha = 90°$, $V_R = 0$, namely Doppler frequency shift is 0.

Let turntable arm rotate clockwise, the Doppler frequency shift caused by the antenna rotation is analyzed as follows:

1. From A to B, α increases from 90° to maximum gradually (obtuse angle). The radial velocity is reduced from 0 to negative maximum, Doppler frequency shift decreases gradually from 0 to positive maximum;
2. From B to C, α decreases from maximum to 90° gradually. The radial velocity is increased from negative maximum to 0, Doppler frequency shift decreases gradually from positive maximum to 0;
3. From C to D, α decreases from 90° to a minimum gradually f (acute angle). The radial velocity is increased from 0 to a positive maximum, Doppler frequency shift decreases gradually from 0 to a negative maximum;
4. From D to A, α increases from minimum 90° gradually. The radial velocity is decreased gradually from a positive maximum to 0, Doppler frequency shift increases gradually from a negative maximum to 0.

The Doppler frequency change shift caused by the relative movement of a certain GPS satellite and the turning antenna and the reference station is shown in Fig. 37.3, The Doppler frequency shift change caused only by the GPS antenna turning is shown in Fig. 37.4, where the satellite movement is canceled out.

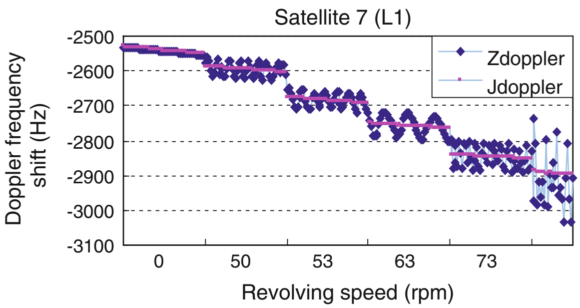

Fig. 37.3 Doppler frequency shift of antenna and reference station relative to satellite

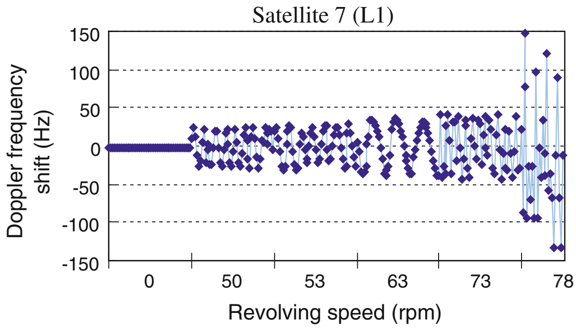

Fig. 37.4 Doppler frequency shift caused only by GPS antenna turning

As shown in Figs. 37.3, 37.4, with the GPS antenna rotating, the Doppler frequency shift caused by the antenna circular motion is changed periodically. Moreover, with the increase of rotation speed, the Doppler shift frequency caused by antenna rotation increases accordingly.

37.3.1.2 Analysis of Doppler Frequency Shift Caused by Airborne GPS Motion

The NovAtel GPS receiver is commercial receiver, which uses a carrier phase locked loop for carrier tracking, a code delay locked-loop for code tracking. At present the aircraft speed varies from tens of meters per second (helicopter) to 250 meters per second or so (fighter, transport models ranging), which belongs to the low and middle dynamic range. The Doppler frequency shift change received by airborne GPS and reference station (nearly to turn the corner section) is shown in Fig. 37.5; Figure 37.6 shows Doppler frequency shift change caused only by the movement of plane relative to the GPS satellite.

Analysis: It can be got from Figs. 37.5, 37.6 that, the range of Doppler frequency shift caused only by aircraft movement is about ±700 Hz (The turning section for a maximum of ±1000 Hz). On the receiver under static condition, Doppler frequency shift caused by the motion of the satellite lies in ±4.5 kHz, the range of Doppler shift frequency caused by turntable rotation is ±100 Hz. If we

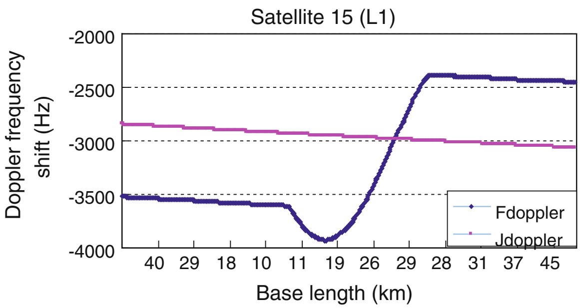

Fig. 37.5 Doppler frequency shift of airborne GPS and reference station relative to satellite

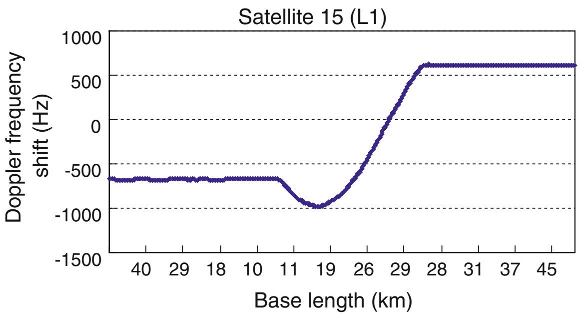

Fig. 37.6 Doppler frequency shift caused by airborne GPS moving

verify the receiver precision only by Doppler frequency shift, the dynamic range of the measurement via turntable is low. In comparison with Doppler frequency caused only by the motion of the satellite on the receiver under static condition. The variation range of Doppler shift caused by the aircraft motion is not big, If the double difference positioning accuracy of GPS receiver under static condition is very high, which is verified, then the linear change of Doppler frequency caused by aircraft moving uniformly in a straight line will not affect the dynamic positioning accuracy of airborne receiver.

37.3.2 Analysis of Doppler Frequency Shift Change Rate

The Doppler frequency shift change rate caused by GPS antenna's circumferential rotation (one revolution) relative to a certain satellite is shown in Fig. 37.7. Figure 37.8 for the Doppler frequency shift change rate caused by the airborne GPS antenna movement (intermediate for turning) relative to satellite No. 15.

Analysis: It is shown in Fig. 37.7 that, the minimum scope of Doppler frequency change rate caused by GPS circular motion is within 250 Hz/s under the rotation condition (53 RPM). In Fig. 37.8, the Doppler change rate caused by airborne GPS in uniform motion (V = 220 m/s) is within a range of about 2 Hz/s, the maximum of which is 20 Hz/s at turning section. Thus, by investigating the

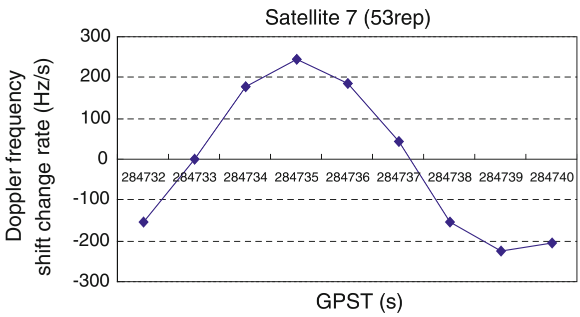

Fig. 37.7 Doppler frequency shift change rate caused by GPS antenna turning

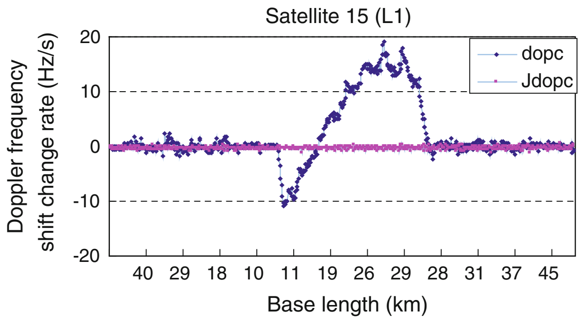

Fig. 37.8 Doppler frequency shift change rate caused by airborne GPS moving

Doppler frequency change rate, the method can fully simulate and detect receiver positioning accuracy under high dynamic conditions.

37.4 Positioning Precision Detection of GPS Receiver Under Dynamic Circular Motion Conditions

37.4.1 Detection and Analysis of GPS Single Point Positioning Accuracy

Test method: Let the receiver record or transmit the real time single point positioning data PRTKA (or GPGGA), the ground station then receives and displays the deviation curve of the data through GPS dynamic measurement precision test software in real time. Figure 37.9 shows real-time point positioning deviation relative to a fixed point on different speed conditions.

Accuracy analysis: As seen from Fig. 37.9, with the increasing of rotation speed, the dynamic point positioning deviation increases gradually, which is from 5 to 30 m or so. The increasing of the observation noise leads to the gradual increasing of Random deviation, which indicates that the GPS receiver point positioning is greatly affected by the circular motion environment. In the Figure, the deviation value is for

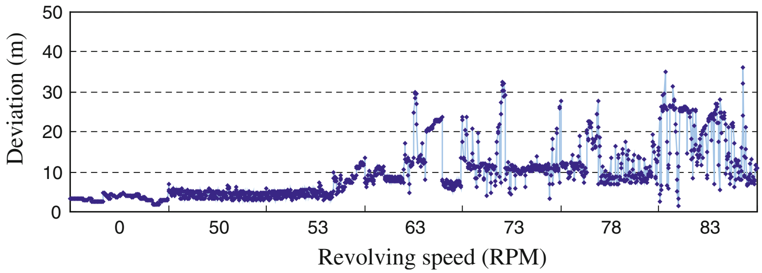

Fig. 37.9 Point positioning deviation on different rotation speed conditions

the distance the antenna away from a certain fixed point during real time rotating (In this test, the antenna from the shaft center distance is 0.99 m).

37.4.2 Detection and Analysis of Dynamic Positioning Accuracy of Carrier Phase Differential Data

37.4.2.1 Accuracy Detection

Test method A: Reference receiver and the GPS receiver on turntable record RGEB (the original measurement data) and REPB (satellite ephemeris) simultaneously, change the rotating speed, by afterwards processing via double difference processing software, the deviation from a fixed point can be got, the values of which reflect the dynamic data accuracy. Figure 37.10 shows the deviation of double difference carrier phase data relative to a fixed position on conditions of different rotating speed (from static until not positioning).

Test method B: Reference receiver transmit difference data (RTCAOBS and RTCAREF) to the receiver on turntable in real time, the receiver on turntable then process the data and send out the result, the ground radio station receives the double differential positioning data and displays the deviation curve of the received data by Dynamic Measurement Precision Test software in real time.

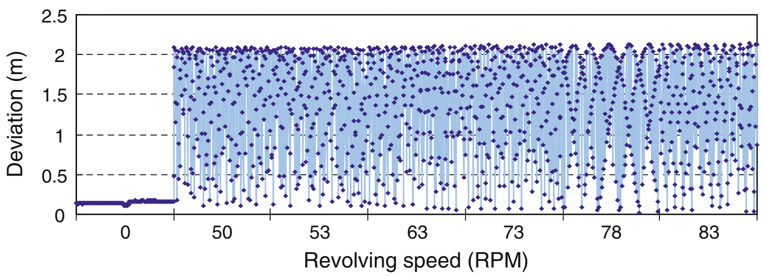

Fig. 37.10 Carrier phase differential positioning deviation on different rotation speed conditions

37.4.2.2 Accuracy Analysis

Below, taking rotation speed of 78 rpm as an example to analyze the actual position of the receiver antenna at each moment. Due to the max sampling rate of the receiver is 4 times/s, the analysis interval is 0.25 thereby. Table 37.1 and Fig. 37.11 show the corresponding relationship between each positioning time and actual position of the circular rotating antenna.

Theoretical analysis: As can be seen in Table 37.1 and Fig. 37.11, when the rotation speed is 78 rpm, the antenna is located adjacent to position on the

Table 37.1 Corresponding relationship between each epoch and actual position of rotating antenna

Numerical order	Record epoch (second)	Number of bars per second (bar)	Location in chart (bar)	Mark in chart
1	0	–	1	O
2	0.25	19.5	19.5	①
3	0.5	39	39	②
4	0.75	58.5	58.5	③
5	1	78	18	④
6	1.25	97.5	37.5	⑤
7	1.5	117	57	⑥
8	1.75	136.5	16.5	⑦

Note Assum set 1 revolution = 60 bars, then: 78 rpm= 78 bar/s

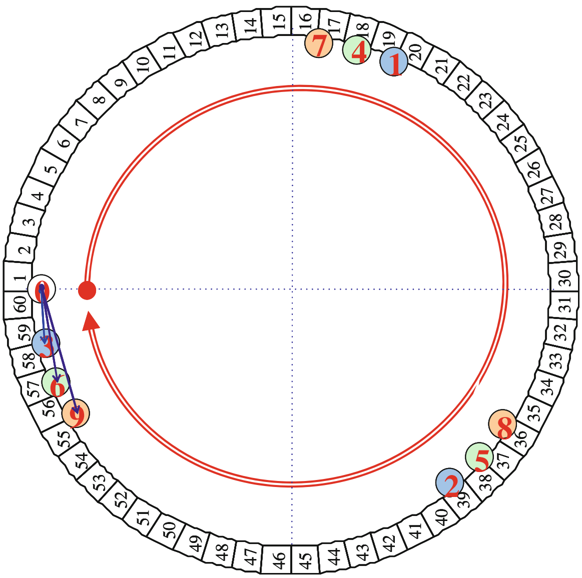

Fig. 37.11 Aided analysis diagram of positioning accuracy on circular rotation conditions

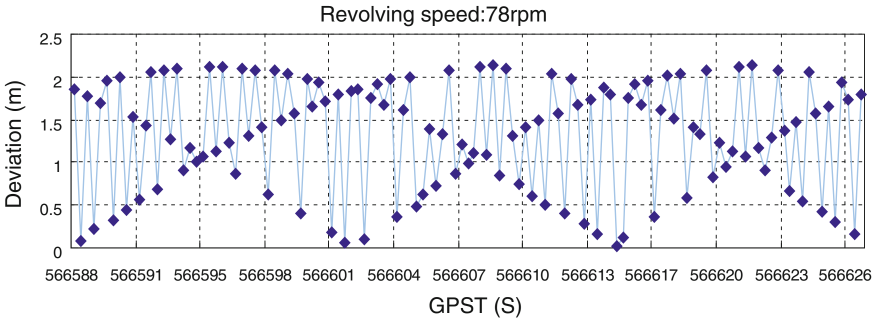

Fig. 37.12 Deviation of carrier phase differential data relative to fixed point on rotation conditions

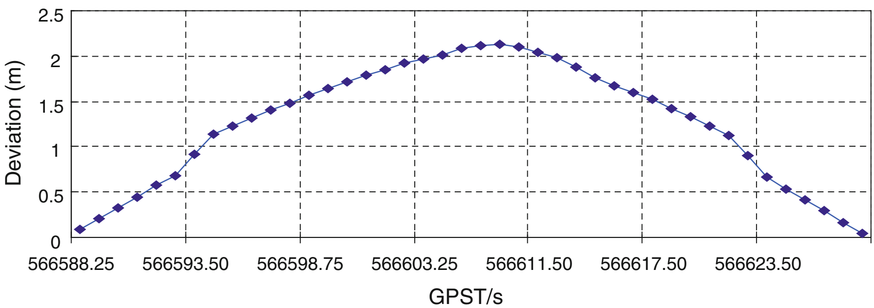

Fig. 37.13 Deviation of carrier phase differential data relative to fixed point on rotation conditions

turntable every 0.75 s and counterclockwise postponed. With the increase of rotation time, the distance between antenna's current position and initial position increases from the scale range 60 to 31 and decreases from the scale 30 to 1.

Figures 37.12, 37.13 for the position deviation curve of the GPS receiver on turntable away from a fixed point by the post carrier phase difference processing. Figure 37.12 for recording interval of 0.25 s of the differential data position deviation, Fig. 37.13 for the interval of 0.75 s.

Conclusion can be drawn from the above analysis, when the rotating speed is 78 rpm, the accuracy of GPS dynamic carrier phase differential data is high, the circular motion trajectory of antenna can be accurately plotted to a degree of centimeter precision level. It can be seen from Fig. 37.10, the accuracy of carrier phase differential dynamic data changes little with the increase of antenna rotation speed, which further indicates that dynamic measuring precision of the present system is high and fully meet the mission accuracy requirements.

37.5 Conclusions

Besides the application in verifying GPS or Compass user machine dynamic positioning precision and dynamic tracking performance, the rotating test platform can be applied not only to examine and check before acceptance the afterwards difference processing software's performance of dynamic solution, ambiguity and cycle-slip detection and repair ability as well, but also to test the anti-jamming ability of the receiver under dynamic conditions, etc.

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