Analysis of the Timing System Error of the Constellation Automatic Navigation

Lu Xiaochun Wu Haitao Li Xiaohui
National Time Service Center,
Chinese Academy of Sciences,
LingTong,Shaanxi, People's Republic of China, 710600

Chen Xiaozhong
Graduate University of Chinese Academy of Sciences,
Beijing, People's Republic of China, 100039

***Abstract*—System integrated clock (SIC) plays an important role in implementing the high-accuracy constellation automatic time synchronization and information exchange. In the establishment of SIC, error and noise are unavoidably introduced. In the paper, various error sources in the process are analyzed at first, and then an error-reduction method under the model of two-way plus common view time comparison is put forward and analyzed. Theory research and simulation experiment show that the constellation time synchronization error is below 10 seconds.**

key words: **automatic time synchronization , information exchange, error, two-way comparison, common-view comparison**

I. INTRODUCTION

By "High-accuracy constellation automatic time synchronization and information exchanging" is meant that, without the support of the control system on the earth for a long time, the navigation constellation satellite, through the two-way ranging between the satellites, data exchanging and the wave-filtering by the satellite processor, constantly adjusts the long-term predicted satellite ephemeris and clock parameters fed by the station on the earth, enables the constellation automatic time synchronization and automatic navigation for the users, and automatically maintains the basic structure of the constellation.

How to construct and maintain the system integrated clock in the implementation of the high-accuracy constellation automatic time synchronization and information exchanging is the prime purpose of the automatic time synchronization and information exchanging and the basis of automatic navigation.

The construction of the system integrated clock requires the comparison between the atomic clocks in the system. This involves the measurement of the clocks. Each clock can only be directly compared with the satellite clocks within the sight through the construction of inter-satellite communication links. The parameter relationship with the satellites out of the sight can only be established and constructed through satellite relay links and noise must be introduced in the linking process. Error and noise will also be introduced in the study of the time measurement between satellites, linking rules, format of the data telegram exchanging, comparison error processing and the inter-satellite linking. The major concern in the study of the constellation automatic time synchronization, information exchanging within the constellation and the construction of the system integrated clocks is how to analyze the effect of the errors on the accuracy and how to deal with the existing errors.

A qualitative analysis of the sources of errors in the high-accuracy constellation automatic time synchronization and information exchanging is made and the error-reduction method is proposed in this paper.

II. ANALYSIS OF ERROR SOURCE

According to its sources, error in high-accuracy constellation automatic time synchronization and information exchanging can be divided into several types .Such as:

· satellite clock error

· satellite ephemeris error

· error from the effect of the relative theory

· error from path transmission

· error from equipment channels

· noise

· measurement error

A. Satellite clock error

In the paper, constellation automatic synchronization is realized by the distance measurement between satellites, which is, in fact, a time measurement--distance measurement system. Therefore, automatic synchronization between satellites is closely connected with the satellite clock error.

Constellation clock is the system clock of navigation positioning for the users on earth, and it needs maintaining and renewing promptly in the automatic synchronization of navigation constellation. Here it is called system integrated clock (SIC) for short. SIC is constructed by the comparison between the atomic clocks within navigation satellite system and information exchanging. Satellite clock error refers to the deviation and floating of the navigation satellite original clock and SIC.

B. Satellite ephemeris error

Satellite ephemeris error refers to the deviation between the satellite space position given by the satellite ephemeris and the satellite actual position. Under the automatic navigation model, satellite clock synchronization and satellite ephemeris revision are achieved by transmitting distance measurement code and data through inter-satellite communication links.

Among the navigation systems at present, broadcasting satellite ephemeris belong to a kind of output forecasting ephemeris. Because a satellite is influenced by various dynamic forces in actual movement, error is certain to appear in the forecasting ephemeris. Hence, satellite ephemeris error is the prime error source of the users' navigation positioning. Apart from this, the users' positioning accuracy is also influenced by the geometric distribution of satellite constellation.

C. Error from the effect of the relative theory

The constellation of my research is moving in an orbit as high as about 20,000km, and the frequency deviation is caused by comparing satellite clock frequency and stationary atomic clock on earth with the influence of the relative theory in the narrow and broad sense. The frequency deviation brought about by satellite movement should not be ignored in automatic clock synchronization system.

Suppose the satellite is in the uniform motion in the round orbit. According to the relative theory in the arrow sense, an oscillator with the frequency of f0 is installed on the carrier with a flying speed of v. With the movement of the carrier, the frequency got by the observer on earth is about to change, and the changed value is

$$\Delta f_1 = -\frac{1}{2}\frac{v^2}{c^2} f_0$$

Here $v^2 = gR_m(\frac{R_m}{R_s})$ then

$$\Delta f_1 = -\frac{1}{2}\frac{gR_m}{c^2}(\frac{R_m}{R_s}) f_0$$

Among which, g is the acceleration of the earth's gravity. C is the light speed. Rm is the average radius of the earth. Rs is the average radius of the satellite orbit. As is shown, the frequency of the satellite clock is lowered, which means the satellite clock moves slower than the stationary atomic clock on earth.

What's more, according to the relative theory in the narrow sense, the frequency f0 of the oscillators located in different positions of the same distance is changed because of the different gravity positions. Because the satellite clock is located in a relatively high gravity position, the gravity frequency deviation value is

$$\Delta f_2 = \frac{gR_m}{c^2}(1 - \frac{R_m}{R_s}) f_0$$

With the influence of the relative theory in the broad and narrow sense, the changing frequency value of satellite clock is

$$\Delta f = \Delta f_1 + \Delta f_2 = \frac{gR_m}{c^2}(1 - \frac{3R_m}{2R_s}) f_0$$

As is shown, the frequency of the satellite clock is quicker than that on earth according to the observer on earth. For the convenience of the users' positioning and timing and the reduction of this influence, the satellite clock standard frequency should be lowered. Because the movement of the earth, the change of the satellite orbit altitude and the change of the earth's gravity field, the influence of this relative theory is not a constant. Therefore, a minor error exists after the above revision. Its influence to the satellite clock is

$$\delta t^{j} = -4.443\times 10^{-10} e_s \sqrt{a_s} \sin E_s(s)$$

Among which, es is the eccentric rate of the satellite orbit, as is the longer radius of the satellite, and Es is the angle of the near point.

While the automatic constellation is studied, frequency deviation to the users on earth caused by the effect of relative theory is deducted from the standard frequency of the star-carried atoms at first. Then the frequency deviation from the relative theory on both broad and arrow sense caused by the relative movement and interaction of gravity of different satellites is taken into consideration. This kind of frequency deviation is a very important error source, which can be reduced by software in data processing.

D. Error from the path transmission

The constellation of my research is located as high as 20,000km in the atmosphere, and the signals transmission is conducted in ionosphere and the electro-magnetic layer. Ionosphere is formed by the interaction of solar radiation and the atoms and molecules in the atmosphere of the earth. In the middle and low altitude, the ion energy is produced by the longer electro-magnetic radiation of solar short waves, that is, the ultraviolet radiation and X-ray radiation. Solar energy particles (protons ad electrons) also play an important role I polar zone. Ionosphere is an area where the radio transmission is greatly influenced by the number of free electrons in the earth's atmosphere.

Magnetic layer is a cavernous layer like the head and tail of the comet, which is formed by the removal of solar wind and the deformation of the earth's magnetic field under the interaction of solar wind and earth's magnetic field. Magnetic layer is filled with thin layer of plasma, which is mainly composed of protons, electros and a small amount of helium particles ad neutral hydrogen particles. Magnetic pressure is larger than atmospheric pressure and the movement of plasma is completely controlled by the earth's magnetic field.

The distance between satellites is measured by radio waves in satellite automatic navigation. The distance measurement error is caused by the additional time delay brought about by the radio wave transmission in magnetic layer and ionosphere. To revise this time delay, double frequency transmission system is adopted. The delay error of the ionosphere is

$$\delta\rho = \frac{A}{f^2}$$

Among which A is a constant, f is the wave-carrier frequency of the signal transmission. If two wave-carrier transmission systems are adopted, then the ionosphere time delays of two wave-carriers f1and f2 are respectively

$$\delta\rho_1 = \frac{A}{f_1^2}$$

$$\delta\rho_2 = \frac{A}{f_2^2}$$

Suppose ρ 0 is the signal transmission distance after the removal of ionosphere delay, and ρ 1and ρ 2 are the false inter-satellite distances measured by the measurement distance code in inter-satellite automatic synchronization, then

$$\rho_0 = \rho_1 + (\frac{f_2^2}{f_1^2 - f_2^2})(\rho_1 - \rho_2)$$

$$\rho_0 = \rho_2 + (\frac{f_1^2}{f_1^2 - f_2^2})(\rho_1 - \rho_2)$$

E. Error from equipment channel

The transmission error of inter-satellite automatic synchronization links consist of three types: channel delay error, cable transmission error ad discrepancy error of the receiving channel and sending channel.

Channel delay error refers to the measurement error of the satellite sending equipment and the receiving equipment. The error is a system error, which can be got on earth before sending the satellite. According to the measurement means at present, the accuracy of measurement can be as high as 0.5ns.

Cable transmission error refers to the transmission delay brought about by the channel connection cable. This error is also a system error, which is related to the cable length and character, and its measurement accuracy can be as high as 0.2ns.

The discrepancy error of the receiving channel ad sending channel is caused by the discrepancy of different satellite sending and receiving channel delays. It is a random error and can be got by the experiment on earth, with an accuracy as high as 0.3ns.

F. Noise

The noise of satellite automatic synchronization system consists of the exterior type and the interior type. The interior noise is produced because of the receiving equipments themselves(including the aerial and the transmission line), which has a statistical character of hot noise (Gauce noise).The exterior noise is originated in the noise and disturbance in the background of cosmos ad the atmosphere of the earth. It is a non-Gauce noise and has a pulse character.

Among the distance measurement signals, the ratio of signal and noise is worsened with the appearance of noise. As a result, the measurement accuracy is influenced.

G. The measurement error

Measurement error refers to the error produced while the receiving equipment is conducting inter-satellite distance measurement, which mainly consist of :

.The receiving equipment positioning extracting error

.PLL measurement error

.FLL measurement error

.DLL measurement error

III. ERROR REDUCTION METHODS

There are always system error and random error in information transmission. Error reduction methods are one of the main concerns of high-accuracy constellation automatic synchronization and information exchanging technology.

A. Introduction

An error reduction method under the model of two-way plus common view comparison among the atomic clocks with the constellation is proposed, for the improvement of SIC accuracy and the realization of high-accuracy constellation automatic synchronization and information exchange technology.

Two-way comparison refers to a process during which two separate satellites A and B, installed with a sender and a receiver respectively, send direct sequence frequency magnified signals to each other. The respective measurement formula is got by the false code measurement.

The clock error is got by information exchange in communication links, on order to achieve clock synchronization. The two-way comparison method can effectively remove the error from the communication links of the two satellites, and improve the synchronization accuracy of the inter-satellite clocks.

Common view comparison refers to a process during which a satellite(i) is sending distance measurement signals which can be received by the other satellites within the sight. In the case, these satellites are called common view satellites compared to the satellite (i). By common view comparison, time delay errors of the common view satellites' receiving channels can be removed partially to improve the synchronization accuracy between satellite clocks.

B. Inter-satellite links working model

Inter-satellite links work in two models. One is the time comparison model and the other is the communication model.

Under the time comparison model, every satellite should conduct the inter-satellite two-way plus common view time comparison in the branch net. Every satellite within the constellation is supposed to send and receive distance measurement signals, for the coordination of which, TDMA is adopted. The distributed time interval length of every satellite is 1s.It takes 24 satellites 24s to finish a period of the satellite sending distance measurement signal process within the constellation. After a period of 24s time comparison, constellation inter-satellite links enter into the communication model.

Under the communication model, agreement suitable for the constellation satellite environment is used to manage the communication links and send and receive the data.

C. Error reduction methods

The establishment of SIC relies on the clock error of all the satellites within the constellation, that is, the clock error between any two satellites among 24s. Two-way plus common view atomic clock time comparison is adopted to effectively reduce the satellite clock error.

Suppose only two-way time comparison is adopted, as is show in picture 1. The clock error got by the system will consist of the magnified transmission error produced by the links' transmission. The ultimate transmission will be as high as $(\sqrt{2})^8 = 16\sigma 1$.

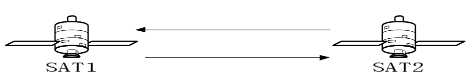

Figure 1 two-way comparison links

Therefore common view time comparison is also adopted to remove the transmission error between satellites out of sight.

The three satellites within sight are shown in picture 2. Suppose satellite 2 and satellite 3 can not be seen, but both of them can see satellite 1.

By adopting common view comparison, the time delays of the receiving channels and the transmission errors of satellite 2 and satellite 3 can partially be remove

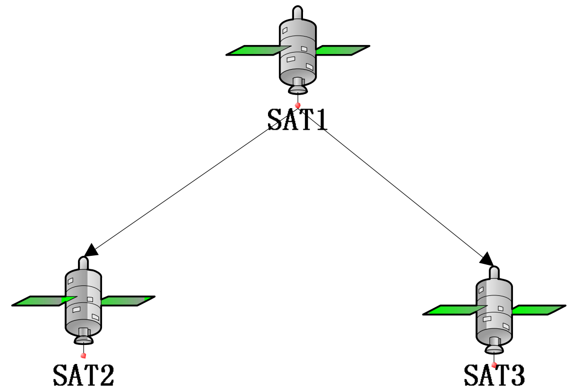

Figure 2 common view comparison links

To the whole constellation, the ultimate remaining error of the whole system in the worst situation is $\sigma_{max} = (\sqrt{2})^6 \sigma_2 = 8\sigma_2$ (Abut 8ns). However, many circular paths are constructed by the common view comparison with every circle within the other circles. The actual system error is far less than σ max, which is sufficient for high-accuracy constellation automatic time synchronization.

IV. CONCLUSION

How to construct the SIC is the prime purpose of the automatic time synchronization and information exchanging as well as the basis of automatic navigation. The major concern in the study of the constellation automatic time synchronization, information exchanging within the constellation and the construction of the system integrated clocks is how to analyze the effect of the errors on the accuracy and how to deal with the existing errors. The two-way plus common view comparison as an error reduction method put forward in the paper sets a good example for the constellation automatic synchronization study. Other error reduction methods will be of further concern in the future.

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