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ABSTRACT Satellite positioning and satellite communications are in the midst of the intial selection phase of telemetry and control, looking for an advanced autonomous rendezvous system. This article summarizes basic requirements and processes associated with spacecraft rendezvous and docking as well as the composition of the U.S. global positioning system (GPS), the principles of positioning, precision, and difference principles, after which it sets out two types of relative motion equation forms. Making use of a combination of motion equation solutions, pure GPS, and difference GPS, it is possible to complete the entire guidance process of tracking spacecraft approaching target spacecraft. Moreover, it is possible to economize on such equipment as enormous ground telemetry and remote control, radars on board satellites, and so on, reducing sources of error. Simulation calculations verify that this design concept is feasible and accurate.

KEY TERMS Spacecraft rendezvous Spacecraft docking Spacecraft telemetry and control Global positioning system (GPS)

1 SUMMARY OF SPACE RENDEZVOUS AND DOCKING

Rendezvous and docking is one type of advanced process associated with astronavigational activities. It is a help in completing a good number of space missions--for example, carrying out assembly of large scale space structures (for which there is no way to launch them in one go); adding or replacing space station modules and other useful loads, experimental instruments, and equipment; recovery of products; periodic refueling and supplementation of provisions, equipment, and materiel on permanent space platforms and space stations; carrying out space matintenance and search and rescue missions, and so on.

Rendezvous refers to two or more spacecraft meeting each other in orbit in accordance with predesignated locations and times. Docking refers to the structural connecting of two spacecraft into one body after meeting each other in orbit. Talking from the point of view of aerodynamics and control, rendezvous and docking belong to the catagories of spacecraft orbital control and attitude control. Both in terms of theory and technological actualization, it is quite a complicated process.

As far as the realization of space rendezvous is concerned, it can possess different forms. Among those that have already been applied at the present time, there are those where people directly participate in operations in orbit (for example, the joint flight of Apollo and Union spacecraft) and those people complete from the ground by remote control. (for example, Peace space station). For the sake of cosmonaut safety as well as economic considerations, space rendezvous directly operated by people should be avoided. As far as rendezvous remotely controled by people from the ground are concerned, even if one opts for the use of relay satellites, such things as signal delays, electromagnetic interference, and so on, will still be produced. Advanced autonomous rendezvous systems will be the target a new generation of spacecraft will look for.

At the present time, the space rendezvous and docking which is normally opted for in utiliztions will go through the four phases of ground guidance, automatic guidance, approach, and docking. First of all, under ground control, tracking spacecraft complete some maneuvers. After that, on the basis of data associated with measurements by sensitive components on board satellites, tracking spacecraft are actively guided close along side target spacecraft. Finally, docking is implemented. To this end, it is necessary to have corresponding hardware equipment and software functions--for example, enormous ground telemetry and control systems, air-ground data transmission and communications, sensitive components on board satellites associated with different distances (for example, radar, pickup cameras, laser sensors, and so on). This type of telemetry and control method determines high cost, poor accuracy, and low reliability of rendezvous and docking systems at the present time. In regard to looking for new advanced autonomous rendezvous systems, it is necessary to opt for the use of new flight plans and telemetry and control methods. The satellite global positioning system (GPS) which is in the midst of being developed could possibly become the best telemetry and control tool in advanced autonomous rendezvous systems. /74

2 SATELLITE GLOBAL POSITIONING SYSTEM

The global positioning system (GPS) is the U.S. second generation satellite navigation system. It began testing in 1973. It has already been set up at the present time. It is capable of providing accurate, continuous, all weather position, speed, and time information associated with various types of vehicles, ships, personnel, aircraft, and spacecraft at several hundred kilometers altitude, in the vicinity of the surface of the earth. In godetic surveys, land navigation, maritime, aerial, and space navigation, GPS has already, or is in the process of obtaining, very good applications.

GPS is composed of three parts. The space portion is composed of 21+3 satellites distributed in six orbital planes at orbital altitudes of approximately 20000 km, transmiting navigational data to users. The ground portion includes monitoring and control stations, main control stations, and entry stations used in measuring the orbits of GPS satellites and doing calculations. In conjunction with this, ephereris as well as other data associated with satellites are calibrated, controled and completed by GPS management agencies. The user portion receives positioning results obtained on GPS receivers, and, in conjunction with that, process navigation data. Different users require receivers with different characteristics.

Making use of GPS C/A code signals, it is possible to obtain "standard positioning service" accuracies, that is, position errors inside 100 meters. Speed errors are at 0.1m/sec. Time errors are at 100 nanoseconds. With regard to situations where positioning accuracy requirements are even higher--for example aircraft entering airfields to land, missile guidance, space shuttle guidance, satellite and space station orbital determination, and so on, it is possible to opt for the use of difference type GPS. This makes use of two GPS receivers operating at the same time. After going through appropriate processing, it is possible to eliminate system errors, causing positioning accuracies to rise to around 5 meters. If one again opts for the use of carrier wave phase differences, accuracies can reach to around 1 meter. With regard to satellite or space station positioning as well as rendezvous and docking, this is a very good means of telemetry and control.

3 RELATIVE MOTION EQUATIONS ASSOCIATED WITH SPACECRAFT RENDEZVOUS

Assuming that target spacecraft make circular orbit or near circular orbit flights and that coordinate system oxy is firmly connected to them (see Fig.1), then, the relative motions of tracking spacecraft and target spacecraft can use the equations set out below to make approximate descriptions[1]:

$$\begin{cases} \ddot{x} - 2\omega y = a_x \\ \ddot{y} + 2\omega x - 3\omega^2 y = a_y \\ \ddot{z} + \omega^2 z = a_z \end{cases} \tag{1}$$

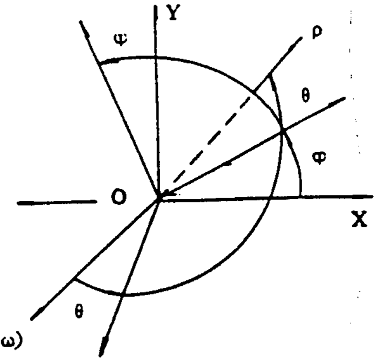

Fig.1 Orbital Coordinate System

In this, ω is the orbital angular velocity of target spacecraft. ax , ay , and az are thrust and interference force acceleration components associated with tracking spacecraft. The relative motion equation set above can also be written in polar coordinate form:

$$\begin{cases} \ddot{\rho} - \rho\dot{\theta}^2 - \rho(\omega + \dot{\varphi})^2\cos^2\theta - \rho\omega^2(3\sin^2\varphi\cos^2\theta - 1) = a_\rho \\ \rho\ddot{\varphi} + 2\dot{\rho}(\omega + \dot{\varphi}) - 2\rho(\omega + \dot{\varphi})\dot{\theta}tg\theta - \frac{3}{2}\rho\omega^2\sin 2\varphi = a_\varphi/\cos\theta \\ \rho\ddot{\theta} + 2\dot{\rho}\theta + \frac{1}{2}(\omega + \dot{\varphi})^2\sin 2\theta + \frac{3}{2}\rho\omega^2\sin 2\theta\sin^2\varphi = a_\theta \end{cases} \tag{2}$$

In this, ρ is relative distance; θ is the included angle oxy associated with line of sight and orbital planes; φ is the phase angle of line of sight in orbital planes.

In order to obtain analytic solutions for equation sets (1) or (2), it is also necessary to put forward further simplified conditions with regard to equation sets. The results are, therefore, not able to accurately describe spacecraft motions and are not able to handle completion of rendezvous missions. /75

4 GPS APPLICATIONS

Research clearly shows that the coverage of GPS with regard to medium and low orbit satellites and spacecraft as well as its feasibility is adequate. It is capable of providing position, speed, attitude, and time information for spacecraft rendezvous processes, making rendezvous become accurate and simple. This article is only limited to discussing GPS positioning applications

4.1 Single Unit GPS Applications

Direct applications of single GPS units are capable of giving 100 meter accuracies--adequate to take tracking spacecraft and guide them to within a range of 10 - 100 km from target spacecraft. This type of direct autonomous orbital determination is capable of saving on ground remote control stations, making orbital corrections in almost real time. Eliminating delays associated with information going back and forth between satellites and the ground saves on ground data processing. Increasing the independence of satellites, at the same time, also reduces various types of errors associated with traditional telemetry and control systems--for example, electric wave propogation, spin of the earth, polar movements, fluctuations in gravity fields, telemetry and control station position errors, and so on.

4.2 Position Difference GPS Applications

Position difference makes use of two GPS receiver units operating at the same time not far from each other (for example, 400 km or less). It eliminates system errors and raises positioning accuracy. Normally, C/A code positioning is capable of reducing errors from 100 meters to 5 meters. Assuming that the GPS position vector on target spacecraft is XR and the postion vector for tracking spacecraft is XU, then, position coordinates associated with relative motion in equation (1) are capable of being precisely specified by GPS as:

$$[X, Y, Z] = X_U - X_R \tag{3}$$

Reference information XR is broadcast from target spacecraft to tracking spacecraft. Difference positions are completed on the tracking spacecraft. Different from the normal significance of difference, the reference station here is set on the target spacecraft with the result that it pertains to relative position. In order to compensate for the inadequacy of difference GPS positioning speed being low, it is possible to take GPS positioning and combine it with solutions in regard to equation (1).

4.3 Pseudo Range Difference GPS Applications

Pseudo range difference makes use of GPS measured pseudo ranges, and it is not necessary to solve for positions. In this way, it is then possible to save on signal processing time and increase positioning speed. By the same token, this is relative positioning. Assuming that the pseudo range from target spacecraft to gPS satellite is RR , tracking spacecraft pseudo range is RU . Because of this, the relative distance between the two spacecraft can be expressed as

$$\rho = R_U - R_R \tag{4}$$

As far as this type of method is concerned, precise specification of relative distances is very simple and convenient. Then, making use of GPS angular measurement functions, it is possible to make a rapid solution with regard to equation (2).

5 SIMULATIONS AND CONCLUSIONS

This article carried out simulations of certain low orbit spacecraft rendezvous processes. Tracking spacecraft orbital parameters were:

Hemi major axis: $a = 6706.221$ km,
Eccentricity: $e = 0.024578$,
Orbital angle of inclination: $i = 65°$,
Ascending node right ascension: $\Omega = 30°$,
Perigee angular distance: $\omega = 50°$.

Target spacecraft selected the same orbital plane as tracking spacecraft and circular orbits with the same periods. Simulation processes were the entire approach process from distances of 100 km to 10 meters. Option was made for the use of position difference added to dynamics model (1).

Simulations were divided into two types of case:

1. There is one iteration of positioning by difference GPS every 60 seconds. During the period of two iterations of positioning, positions are precisely determined from dynamics model (1). Calculation results are seen in Fig.2. In it, /76 a is the actual orbit. c is the orbit calculated purely from dynamics equations (1). b is the orbit using difference GPS+dynamics model at this location.

2. There is one iteration of positioning by difference GPS every 10 seconds. During the period of two iterations of positioning, there is still precise determination of positions from dynamics model (1). Calculation results are seen in Fig.3.

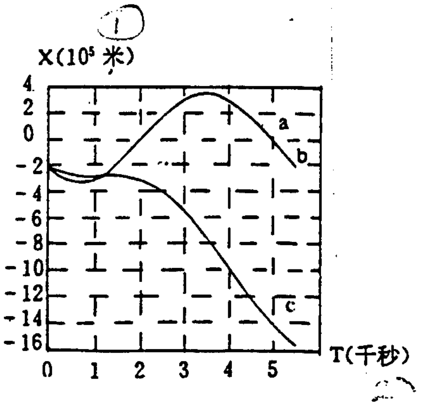

Fig.2 X Direction Error

Key: (1) Meters (2) Thousand Seconds

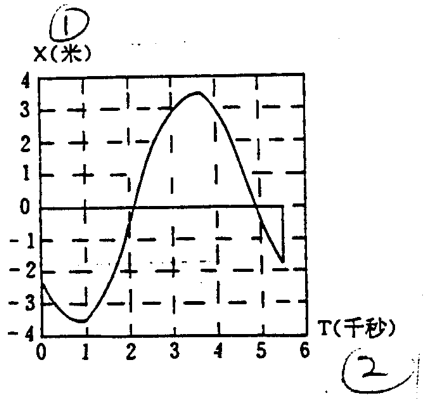

Fig.3 X Direction Error

Key: (1) Meters (2) Thousand Seconds

Results clearly show that errors associated with orbit c precisely specified by pure dynamic model get constantly larger as a function of time. They are capable of reaching a few hundred kilometers. After the addition of GPS difference positioning, errors rapidly diminish. Moreover, the higher GPS positioning speeds are, the higher the accuracy of orbit determinations also are. The precisions of the second type of method are capable of reaching 300 meters or less (z axis at 1 meter or less). Of course, the simulations here do not consider the influences of corrected signal propogation times.

Through this research work, it is possible to know that satellite positioning system GPS is capable of being an advanced autonmous space rendezvous system to provide synchronous position, speed, attitude, and time information. Using GPS positioning, it is possible to complete the entire process of tracking spacecraft, from changing orbit, homing toward target spacecraft and approaching. Moreover, option is made for the use of completely different methods of orbital determination up to now, saving on ground telemetry and control sections. This then is not only economizing on personnel strength and materiel. Moreover, it reduces the sources of errors which telemetry and control equipment carry with them. During the homing phase, use is made of difference GPS to replace original radar systems and laser sensors. Equipment is simple. The amount of software processing work on board satellites is small. Accuracies are high. This is the first telemetry and control system selected for a new generation of rendezvous systems.

This article only researched design concepts and simulations associated with GPS position data to carry out spacecraft rendezvous and docking. Further research work should concentrate on comprehensive applications of GPS position, speed, attitude, and time information, in conjunction with this, causing the engineering of it as early as possible.

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