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A new attitude pointing design for Venus spacecraft

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ABSTRACT

For Venus exploration, a Venus spacecraft is expected to keep its digital transmission antenna pointing towards the Earth for ultra-long-distance and low-bit-rate transmission. Fixed heat-dispersing surfaces are also expected to maintain the temperature inside the spacecraft, which is closer to the Sun than the Earth's orbiter. This paper addresses a new attitude pointing design scheme for Venus spacecraft just by placing the antenna irregularly on the spacecraft, which is beneficial to transmitting data from Venus to Earth and holding the temperature against the Sun. Unlike other Venus spacecrafts employing two or three antennas to transmitting data, such as Venus Express (ESA) and AKATSUKI (JAXA), the present scheme aims to reduce the number of transmission antennas to only one and to set the fixed surfaces as thermal radiators. Two detailed strategies during the flight operation are proposed in this paper to drive the attitude manoeuvres to keep the only antenna pointing to the Earth all the time and to switch the radiator to the suitable surface in specified intervals.

1. Introduction

With the development of space technology, human activities have been gradually expanded to Venus and other planets in the Solar System to investigate the planetary environment, the origin and evolution of universe as well as other scientific research. Unlike the orbiters around the Earth, the spacecraft flying by Venus experiences more heat radiated from the Sun and more extreme constraints to communicate with ground stations on the Earth. Thus, a practical attitude pointing scheme is required to meet all the spacecraft's demands on solar energy, temperature control, data transmission, and so on.

Several Venus spacecrafts with different attitude pointing schemes were launched in previous decades, such as Pioneer Venus [7], Galileo spacecraft [2], Venera [6], and Magellan (Venus Radar Mapper) [4], which were expected to transmit few data to ground station in short working lifetime. Thus, their antennas were designed to point to the Earth only when needed. Recently, due to the increase in the amount of data transmission and the lifetime, Venus Express (ESA, 2005) [1,8] and AKATSUKI (JAXA, 2010) [3,5] employed several antennas pointing to the Earth all the time to avoid the data-recording memory overflow.

Venus Express developed from Mars Express carries two digital transmission antennas, as shown in Fig. 1. However, AKATSUKI carries three antennas, the high-gain antenna of which acts as the main transmission one, as shown in Fig. 2. Both the axes of solar panels of Venus Express and AKATSUKI are expected to be perpendicular to the Venus's revolution plane and are also oriented towards the Sun to maintain the incident angle close to 90°, i.e., the solar panel of Venus Express is equipped along the axis normal to Surfaces A and C, denoted as Axis A–C. An advantage of the attitude pointing scheme used by Venus Express and AKATSUKI equipment is to fix the only surface as thermal radiator during their lifetimes. However, two or more antennas may increase the weight, and lower the reliability of the spacecraft as well.

Generally, the Venus spacecraft for exploring the space environment carries a variety of detection equipments and produces a significant amount of measuring data. However, the interplanetary data transmission results in considerable loss after travelling an ultra-long distance. Hence, a low bit-rate downlink transmission is preferable for Venus spacecraft to transmit these measuring data, which requires the antenna pointing towards the Earth all the time or at most of its lifetime. Even for the imaging mission, the occupation time of adjusting the attitude to image Venus is quite slight compared with the rest of pointing the attitude to Earth. From the viewpoint of spacecraft design methodology, the moving or high-power equipments are undesirable by the spacecraft platform with limited ability, such as the telecommunication antenna. Furthermore, an effective approach to cope with the heat generated by the closer distance from the Sun is to embed the radiating components on one or two fixed surfaces. Therefore, the fixed radiators are beneficial to cooling the temperature inside the spacecraft.

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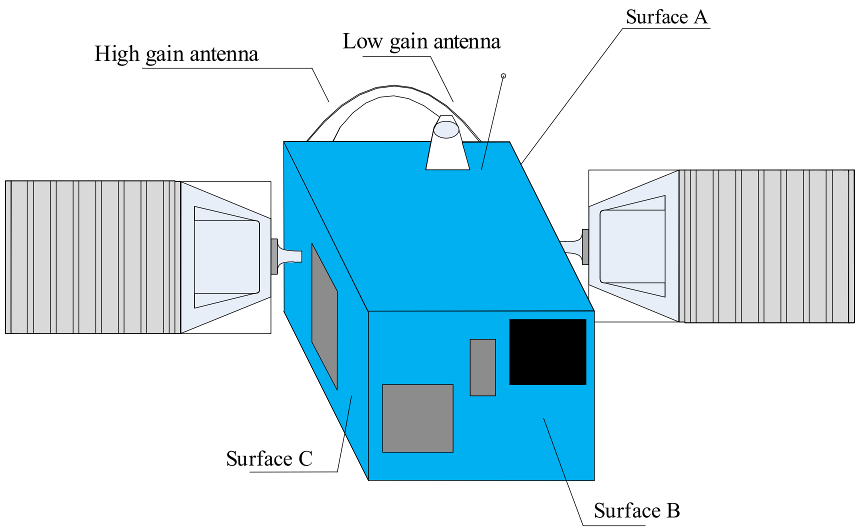

Fig. 1. Geometry configuration of the ESA's spacecraft, Venus Express [8].

This paper provides a new attitude pointing scheme for Venus spacecraft by placing the antenna irregularly on the platform to lower the difficulty of developing or manufacturing the spacecraft. This innovative scheme overcomes the existing deficiencies of other Venus spacecrafts like Venus Express and AKATSUKI, and reduces the number of equipped antennas to the only one with two optional surfaces as the radiator. Moreover, two detailed strategies during the flight operation are raised to drive the attitude manoeuvres to keep the only antenna pointing to the Earth and to switch the radiator during the lifetime.

2. Attitude pointing scheme when placing antenna regularly

According to the attitude pointing scheme when placing the data antenna regularly, Venus Express reaches its minimum number of two antennas. In this section, the detailed strategy for attitude pointing is presented to point the antenna to the Earth and to keep its radiator away from the Sun.

As shown in Fig. 1, Venus Express carries two digital transmission antennas, which are front and back mounted respectively. The large high-gain antenna handles long-distance data transmission and the small low-gain antenna handles relatively short distance data transmission. It is Fig. 3 that demonstrates the attitude pointing strategy of Venus Express for different phases of cruise, data transmission, and detecting or imaging. Obviously, the occupation time of detecting and imaging Venus can be ignored by the lifetime. Early in the mission when Venus is relatively close to the Earth and the radiator of Surface C is opposite to the Sun, the spacecraft will rely on the low-gain antenna to transmit exploration data. As the distance between the Venus and Earth increases, a 180° attitude manoeuvre around Axis A–C is implemented and the high-gain antenna is used for data transmission while Surface C is still maintained against the Sun. After the spacecraft passes over the Earth–Sun–Venus collinear position, the incident angle on Surface C gradually increases from negative to positive, which may require a 180° attitude manoeuvre around the axis of the high-gain antenna to drive Surface C against the Sun. And then the spacecraft will keep this attitude until the end of its lifetime, as shown in Fig. 2. In addition, the moments of attitude manoeuvre can be yielded numerically from the intersection angle between the Venus–Sun and Earth–Sun vectors, i.e., the key of the this strategy is solved from the ephemeris of the Sun, Earth and Venus, which is varying so slowly that the moments can be computed on the ground and then be sent to the spacecraft by uplink telecommunication.

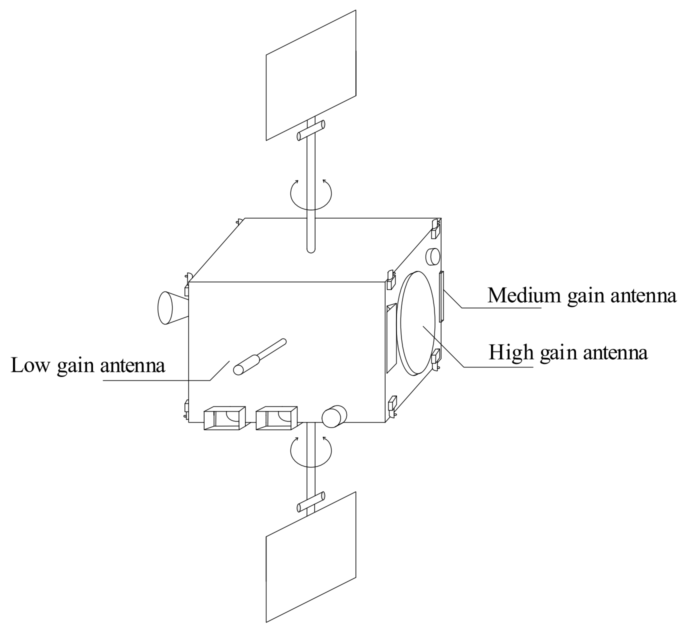

Fig. 2. Geometry configuration of the JAXA's spacecraft, AKATSUKI [5].

According to the scheme, the incident angle of solar panels is approximately 90° to obtain as much electrical supply as possible, and the radiating components embedded on Surface C are successful in cooling the temperature because the only radiator, i.e., Surface C is far away from the Sun during the lifetime. However, the two antennas will cost more mass, power and reliability.

3. Attitude pointing scheme when placing antenna irregularly

3.1. Antenna equipped irregularly on spacecraft

Similar to the scheme of Venus Express, the axis of the solar panel in this scheme is perpendicular to Venus's revolution plane and points towards the Sun to maintain an incident angle close to 90°. Both Surfaces B and C marked in Fig. 4 embed the radiating components to act as the optional radiator which can be switched by the lower device, and the only antenna is equipped irregularly against Surface B. The irregular intersection angle between the antenna axis and the normal line of Surface B is denoted by θ ($°0 < \theta < 90°$), as shown in Fig. 4.