Satellite System Engineering Methods and Practices Based on the Subject Chain Method

LIN Baojun, XIONG Shujie, LI Xiaoyue, LIN Xia

(Institution of Navigation Satellite, Innovation Academy for Microsatellites of Chinese Academy of Sciences, Shanghai 201203, China)

Abstract: At present, most satellite systems are designed as a hierarchy of subsystems. However, the subsystems with repetitive function in each subsystem are cumbersome. Thus, to overcome the shortage of the subsystem method and improve the inherent reliability of the satellite system, a new method based on the subject chain method is introduced. Based on the method, the satellite system is segmented into the control chain, the structure-thermal chain, the electronics chain and the payload chain. The inherent reliability of the satellite system is significantly enhanced, and the functional density is improved and the cost is reduced. Furthermore, the subject chain method has been successfully applied into the development for the first-launched Beidou global navigation satellite. The development cost and time are reduced markedly. In this paper, the core idea of the subject chain method and the description of four basic subject chains are also presented.

Key words: subject chain; inherent reliability; satellite system design; functional density

High lights:

- The background of first-launched new generation of Beidou global navigation satellite is introduced.
- The satellite system is firstly segmented by a new method called the subject chain method.
- The satellite systems is significantly enhanced, the functional density is improved and the cost is reduced by this new method.

中图分类号：V448 文献标识码：A 文章编号：2095-7777(2019)01-0046-06

DOI:10.15982/j.issn.2095-7777.2019.01.007

引用格式：林宝军，熊淑杰，李笑月，等. 基于学科链的卫星系统工程方法与实践[J]. 深空探测学报，2019，6（1）：46-51.

Reference format: LIN B J, XIONG S J, LI X Y, et al. Satellite system engineering methods and practices based on the subject chain method[J]. Journal of Deep Space Exploration, 2019, 6 (1) : 46-51.

Introduction

China has carried out multiple work in satellite quality control and productization in recent years [1-5], and the quality is promoted significantly. Although the utilizing reliability is enhanced, the inherent reliability, however, is still in need. Therefore, in the development of the first satellite of Beidou Global Navigation System, aiming at enhancing the inherent reliability as well as the functional density, we drew lessons from the achievements in satellite development [6-11], system engineering [12] and finally designed the satellite system based on our new method, the subject chain method, segmenting the system into various subjects instead of subsystems [1-3], the conventional way. We believe, with modern computer science and overwhelming satellite developing scale, this brand new-designed-method is more adaptable to meet the demands of the rapid development of aerospace engineering. We, a new team with the advanced design method, have successfully accomplished the satellite development in high performance and reliability, low cost and high functional density. In this process, we have some beneficial thought and exploration.

1 The Subject Chain Method

The core idea of the subject chain method is functional cohesion. By re-combing the traditional subsystem segmenting method from the top to the bottom, uniting similar terms and simplifying the quantity of like products, the possibility to make mistakes in the similar

收稿日期：2018-12-02 修回日期：2019-01-12

situation is reduced, and the system inherent reliability is enhanced. Moreover, the method also improves the functional density, decreases the volume and mass, and lowers the cost. From the management perspective, based on the subject chain method, the general department is significantly stressed and the hierarchies of the systems are reduced, in the meanwhile, the professional people work in their professional fields.

The conventional pattern, the large system to small subsystems pattern, is made by a hierarchy of subsystems, and each subsystem has a small headquarter. This pattern is usually used in the early years based on the weak computer calculation capacity and low level software to distract the calculation and complexity of the computer system. Although the miniaturization technology may reduce the sizes of facilities, a large amount of basic function is repetitive owing to the separation of subsystems. With the rapid development of electronic technique, a tiny computer on board is able to accomplish all the tasks of the whole satellite. Hence, cancelling the hierarchy is reasonable under this circumstance. Uniting the similar functional facilities and terminal equipment together not only can enhance the functional density and decrease the number of the facilities, but also lower the cost and simplify the management procedure. Above all, reducing the number of facilities may enhance the whole satellite's reliability under the same situation.

Therefore, we divide the satellite system into the structure-thermal chain, the electronics chain, the control chain and the payload chain, the four subject chains, as Fig. 1 depicts. On one hand, the four subject chains are responsible for the satellite top-level design, and also they face the terminal equipment directly. The satellite's structure part and the thermal part are both the guarantee parts for the whole satellite, and these two parts are closely related. So we combine these two parts together as the structure-thermal chain. The main basis of the structure-thermal chain is mechanical engineering such as CAD, CAE and thermal analysis. The attitude control part, the orbit control part and the solar panel control part of one satellite play the control role. They offer the appropriate attitude, orbit and pointing for the payload, energy, measurement and control subsystems. So these three parts compose the control subject chain. The control subject basis is system dynamic, control science and engineering etc. Other functional parts in the platform are all closely related to electronics, including energy, measurement and control, driving control, power distribution, satellite affair management and data processing. These functional parts are combined together as one subject chain, the electronics chain. The subject basis is electronics, computer science, and software design. In that the payloads function independently, the payloads compose the payload chain. The four subject chains accomplish all the functions of the satellite, achieving the function cohesion at the top level, uniting similar terms and enhancing the functional density. Also, the separate design for platforms and payloads not only guarantees the commonality of platform, but also provides flexibility for the platform design to meet the payloads changes. Thus, the separate design is able to enhance the extensible capacity of the platforms and meet the payloads upgrade demand in the future.

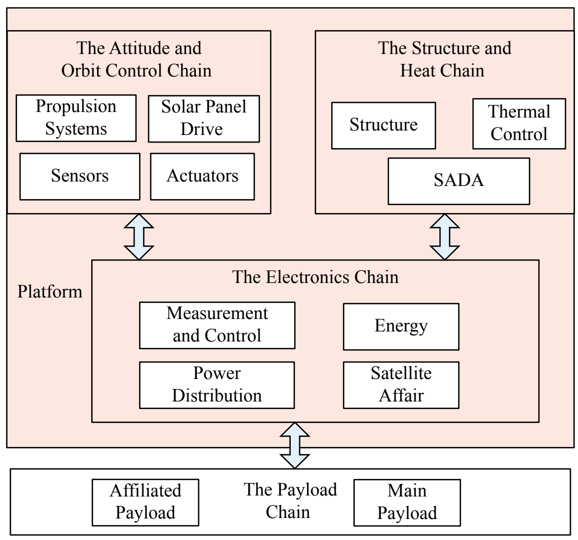

Fig. 1　Composition of the satellite system

Every subject chain is able to optimize the satellite from the top level to the components level. The optimization is more efficient owing to breaking down the hierarchy of subsystems.

2　The Structure-Thermal Chain

The structure-thermal subject chain offers the satellite reasonable configuration, equipment layouts and suitable thermal environment and makes the equipment, including the facilities and components as a whole. It guarantees the satellite to endure all kinds of dynamic and thermal environment through the tests, transportation and launch.

The structure-thermal subject chain is not only in charge of the layout design, the design of the primary and secondary structure, the physical structure design, and the integrated satellite thermal design, but also faces the thermal design of all the facilities. On one hand, the thermal design for every facility can be designed based on the optimal principle of the whole satellite. On the other hand, the resources of the whole satellite can be arranged reasonably. Thus, satellites have more room to choose the standard and mature products, which lessens the research workload of the suppliers. For instance, thermal powers of the fixed amplifier chips are usually high for the global navigation system satellite. So we allocate more weight resources for the thermal paths of the fixed amplifiers. And then the thermal control by thermotubes and radiating surfaces becomes easily. Due to the extendibility of the payload missions and the antenna installed on the earth-facing surface, the earth-facing panel needs a demanding design and the high heat radiation of the payloads also needs to be taken into account. To solve these issues, the platform and payloads are isolated into two separate cabins which can easily adapt to the variation of the payloads missions. Moreover, the antenna are installed across the two cabins, which ensures that the antenna phase center goes through the center of the mass, and then the orbit can be determined precisely. As Fig. 2 shows, our satellite is designed as a cuboid, and the long side face is set as the radiating surface. Obviously, under the same volume, the cuboid design provides larger radiation area for the satellite than the cube design and thus the cuboid design is able to meet the high demand of the payloads thermal radiation.

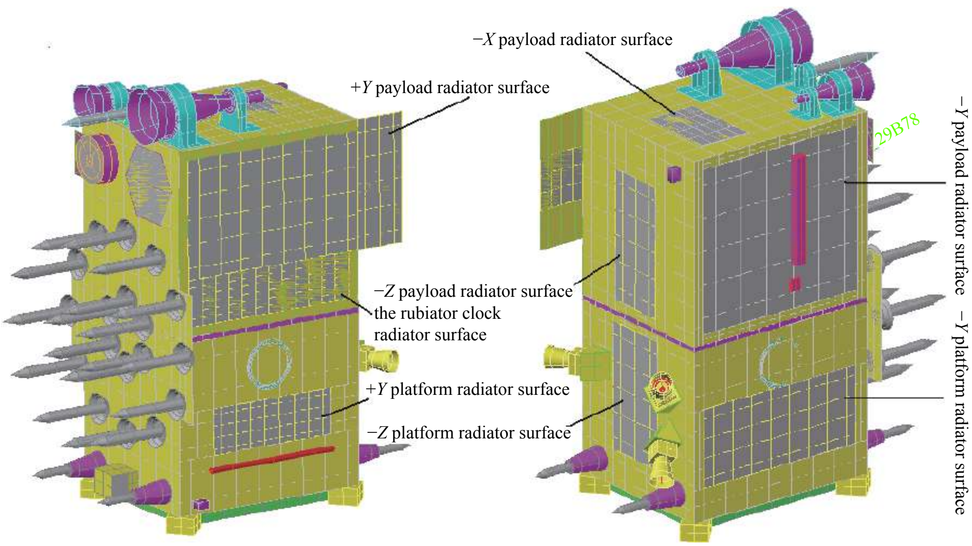

Fig. 2 Sketch map of main and extended radiating surface

As shown in Fig. 3, the satellite crosswise flight attitude can make larger fixing area on both positive and negative earth-facing surfaces, the positive and negative Z faces. Therefore, the design is able to meet the high demand of the antennae location (including the payload antennae, the measurement antennae, the control antennae and inter-satellite links antennae), the demand of the electromagnetic compatibility design, and also the demand of the payloads-mission extendibility. The two smallest surfaces are designed as the two flying surfaces, the positive and negative X faces. This is because the positive and negative X faces don’t need too much area for equipment installation and heat radiation, and the influence of outer heat flux during the orbital period is also weak in the meanwhile.

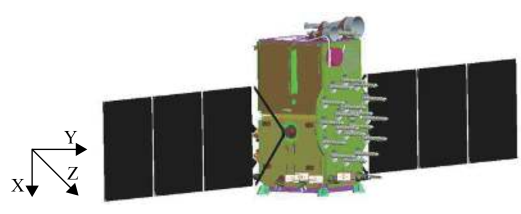

Fig. 3 The flight sketch map of the Navigation Satellite

With the revised parts, the configuration is optimized significantly. Thanks to utilizing the mature products, performance of the satellite is improved, cost is reduced sharply and handsome income is provided for suppliers.

3 The Control Chain

Based on the theory of control science and engineering, the control subject chain is formed by all the control parts in a satellite. Specifically, the chain is composed of the attitude measurement units, the attitude control units, the thrusters and no private computers are included. Moreover, the function of the chain is to keep the satellite attitude stable and accomplish the tasks of the attitude maneuver as well as orbit control and etc.

The task of the control subject chain is to design the overall scheme, choose the suitable sensors and the actuating mechanism, configure these facilities and design the control modes and algorithms. The specialist majored in control are responsible for these tasks and therefore the tasks can be handled professionally. Because the attitude control scheme and the orbit control scheme are not designed separately anymore, the thruster control scheme can be designed more optimally. As the Fig. 3 shows, not only can the new optimal four-thruster control scheme simplify the system and improve the reliability significantly, but also can simplify the pipe installation and then lessen the pressure of the layouts.

In hardware, the chain is faced with the sensors and actuators directly, which means faced with the demand level. Based on the system optimization principle, the facilities are chosen by the parameters in index, performance and ripeness and then the control mode and algorithm are designed according to the chosen facilities. The structure and thermal design is taken charged by the structure and thermal subject chain and the relevant hardware interface design, the data collection design, the drive control design, and the relevant algorithms programming are taken charged by the electronics chain. With the arrangement, it is avoided that the staff in various field like control, electronics, software and etc. have to be involved in the attitude and orbit control subsystem.

Moreover, we emphasize that every facility is designed for its professional function. For example, wheel suppliers don’t focus on their wheels’ layouts, but their performance；star sensors’ suppliers mainly concentrate on the star identification and the attitude computation, who do not think about the sensors’ fault diagnosis；thruster suppliers are charged for valves, pipelines, tanks and thrusters, and the temperature of tanks and the valves on-off state are controlled by the electronics subject chain. Due to this principle, for one we simplify the system significantly and also the pressure of the suppliers is lessened. In fact, most of the suppliers just have perfect knowledge in their main filed. Therefore, the work arrangement based on the principle not only makes full use of the general departments’ advantage which has strong abilities in mechanics, electrics, thermology and software, but also the suppliers for each part are able to concentrate on their skilled fields——that is to say “strong generals, professional branches”.

4 The Electronics Chain

The electronics subject chain consists of the subject of electronics, computers and software. As few slave computers are set for the chain, the chain is able to accomplish plenty of work together, such as satellite operating management, attitude and orbit control, thruster on-off control, up and down data management in measurement and control system, power supply control, temperature acquisition and thermal control. In addition, the chain is also able to accomplish the function of system reconstruction and recovery in the state of the fault diagnosis and to provide the guarantee condition for payload in the aspect of power, telemetry, control, data transfer and thermal control.

As is shown in Fig. 4, the electronics subject chain is responsible for all the work in the hardware and software aspect. Specifically, the chain manages the entire configuration for all the software and hardware, and collects, manages and shares all of the data together. As for the chain in our satellite, according to the domestic engineering situation, the chain designed in our satellite is comprised of only four electronic devices—one on-board computer, one data terminal device, one main distributor and one auxiliary distributor which accomplish the satellite operating management, power supply management, drive control and data management. There are three reasons why only four devices are equipped. First, with the development of computer science, one computer is able to accomplish all the tasks that had to be managed by a few computers before, so only one on-board computer can simplify the system structure and improve the system reliability. Second, one distributor used in the platform power supply and drive control is able to unify the separate terminal devices as one device. Thus, the device, more reliable and simplified, is solidified without considering the varied tasks, which contributes to improve the product maturity. Third, the data terminal device and the auxiliary distributor are set for the standard power distribution interface and the data interface of payloads. The data terminal device separates the data of payloads with those of platform and the auxiliary distributor provides the various power distribution interfaces. These two devices provide more reliable and standard interfaces for payloads and are able to adapt to the updated states of the payloads easily.

In general, with the subject chain concept introduced, the satellite general departments are able to have access to the terminal units, so the middle links are taken out and the flat management method can be applied. The general engineers are able to involve themselves in the forefront of each subject chain, and therefore the units' performance can be acquired accurately. The engineers then can modify the units design in the view of the satellite performance improvement. Finally, the control ability of general departments can be improved greatly through the process. Moreover, general departments not only have a basic knowledge of the index of the devices, but are able to acquire the satellite performance including the units' accurately, which makes strong general departments. In addition, for every terminal unit's suppliers, as part of work in mechanics, electrics and thermology has been undertaken by general departments, the suppliers just need provide the core and standard products rather than take nonstandard and customized work into consideration. The method makes the professional devote themselves in their professional fields, and also the suppliers are able to develop their products in low labor costs, which makes the strong branches.

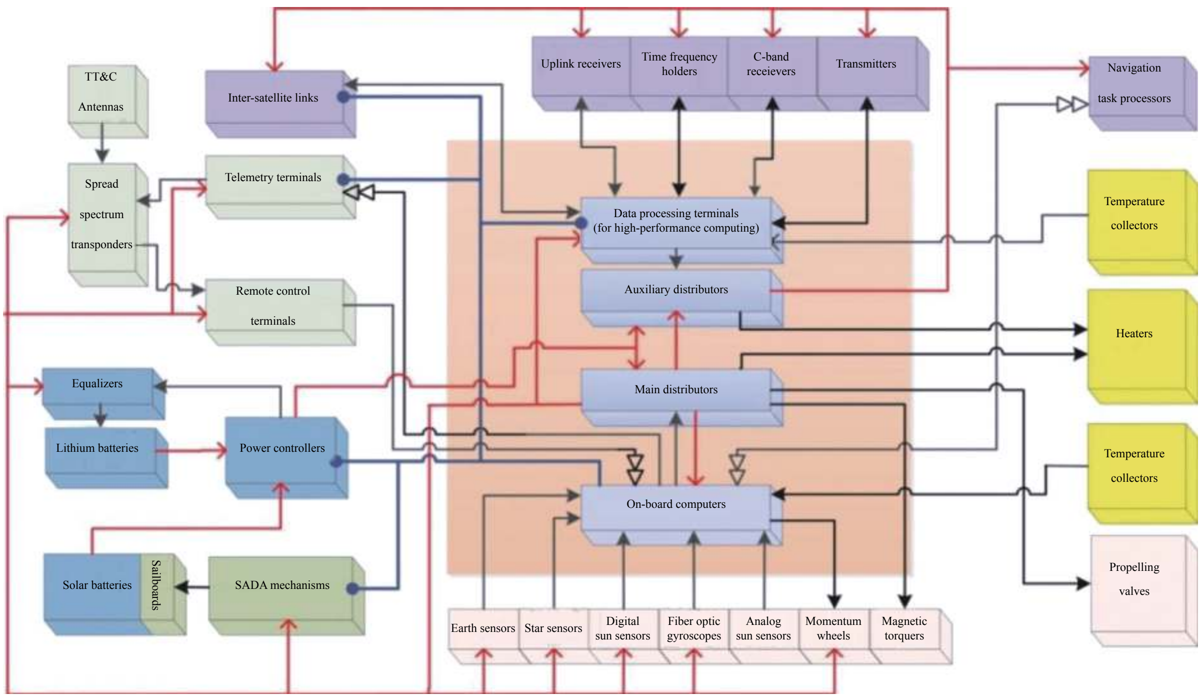

Fig. 4 The electronics subject chain

5 The Payload Chain

The payload chain includes the main payloads and the attached payloads, varying with the different missions. As for our navigation satellites, the platform and payloads are in the separate cabin. The heat insulation design is applied in the two cabins and the layouts of these two cabins are designed separately. Besides, the platform provides standard interfaces for mechanics, electrics and thermology.

6 Conclusion

The subject chain method has been successfully applied in the first-launched Beidou global navigation satellite which operates in the orbit of inclination 55°, semimajor axis 42 164 km. The satellite holds a RNSS C-band navigation payload, an L-band navigation payload and inter-satellite links. The mass of the satellite containing the weight of the propulsion fuel is just 848.5 kg, the output power is 2 200 W, and the expected lifespan of the satellite is 10 years. Due to the application of the subject chain, the function density of the satellite is improved significantly, the development cost is saved and the development period is reduced sharply in which only 1 251 days were spent from the project approval to the satellite launch and only 33 days were taken from entry to the satellite center to launch. The satellite was successfully launched from Xichang at 21:52:26, Mar. 30th 2015. Up to now, nearly 3 years the satellite functions well and no unexpected interruption has occurred. The design is of great reference value in engineering application and for other satellites' design.

References

[1] YUAN Y. Engineering of aerospace products[M]. Beijing：Chinese Astronautics Publishing House, 2011.

[2] JIE S, ZHAO W S, YANG Z. Key technologies of modular design of micro-spacecraft facing micro-spacecraft family[J]. Journal of Harbin Institute of Technology, 2007, 39(12): 1908-1911.

[3] FU X X, HUA B L, SHENYUAN H. Satellite engineering[M]. Beijing：Chinese Astronautics Publishing House, 2004.

[4] LAFON T. JASON L. lessons learned from the development and 1 year in orbit[J]. Acta Astronautica，2005，56 (1–2) : 45-49.

[5] BONNEVILLE R. GEOSTEP: A gravitation experiment in Earth-orbiting satellite to test the Equivalence Principle[J]. Advances in Space Research，2003，32 (7) : 1367-1372.

[6] DECHEZELLES J J, HUTTIN G. Proteus: A mutlimission platform for low earth orbits[J]. Air & Space Europe，2000，2 (1) : 77-81.

[7] JACKSON B, CAMPBELL J. The subsystemless satellite–a new design paradigm for the next generation of small satellites[C]// 12 th AIAA/USU Conference on Small Satellites. USA: AIAA, 1998.

[8] GALEAZZI C. PRIMA: A new, competitive small satellite platform[J]. Acta Astronautica，2000，46 (2–6) : 379-388.

[9] ORII T, ONO T, AOYAMA J I, et al. Development of versatile small satellite[J]. Acta Astronautica，2002，50 (9) : 557-567.

[10] DRIBAULT L, DURTESTE C. The LEOSTAR platform design and validation[J]. Air & Space Europe，2000，2 (1) : 82-85.

[11] BERGER G. A smallsát approach to large missions[J]. Acta Astronautica，1996，39 (9–12) : 993-999.

[12] FROSCH R A. A new look at systems engineering[J]. IEEE Spectrum，1969，6 (9) : 24-28.

作者简介：

林宝军（1963– ），男，研究员，主要研究方向：航天器总体设计，空间科学，导航、制导与传感技术。

通信地址：上海市浦东新区海科路99号4号楼（201203）

电话：（021）50735060

E-mail：linbaojun@aoe.ac.cn

基于学科链的卫星系统工程方法与实践

林宝军，熊淑杰，李笑月，林夏

（中科院微小卫星创新研究院 导航卫星研究所，上海 201203）

摘　要：目前，绝大多数的卫星系统都是按照分系统来设计的，这种方法的弊端在于分系统内部重复的功能模块对整星而言是冗余的。因此，为了摒除按照分系统设计的卫星系统缺点以提高系统可靠性，我们设计了一个全新的卫星系统，其基于学科功能链。按照学科功能链，我们将卫星系统划分为控制学科链、结构热学科链、电子学学科链、载荷学科链，显著提高了卫星系统的性能、可靠性和功能密度，同时有效降低了研制成本，缩短了研制周期。最终，基于学科链的卫星系统已成功应用于北斗导航全球系统的首发卫星上。本文阐述了基于学科链设计的核心思想和四个主要的学科链内涵。

关键词：学科链；内部可靠性；卫星系统设计；功能密度

[责任编辑：高莎，英文审校：朱恬]