Research on Product Assurance Parallel Work of Spacecraft Control System

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Abstract. This paper mainly studies the practice of product assurance in the process of spacecraft control system development. Product Assurance of spacecraft control system has gone through a series of development processes. Because users have higher requirements for product assurance of spacecraft control system, based on modern quality management theory and combined with the reality of aerospace engineering, this paper presents a parallel research on product assurance based on spacecraft control system. Parallel research method is a systematic method, and its most basic working principle is the working principle of collaborative iteration. In this paper, the product guarantee parallel working model of spacecraft control system is presented, and the product quality of the control system is improved by the parallel research. According to the practice of product assurance parallel work in spacecraft control system, the correctness and validity of the method are confirmed.

Keywords: Control system · Product assurance · Parallel work

1 Introduction

Modern satellites usually use a series of product assurance methods to control the quality of satellites [1–3]. Normally, The product assurance of spacecraft control system goes through the serial development process of design, production, test and verification, etc. With the continuous improvement of spacecraft control system product assurance requirements, the output of control system is increasing and the pace of development is accelerating. Higher requirements are put forward for the product assurance of spacecraft control system.

That concurrent engineering can be used as a means of product assurance is a systematic approach. The processes include design, production, testing, assembly and other spacecraft control system manufacture processes (life cycle from design to on/off orbit operation), which are integrated in parallel with product assurance.

The most basic principle of parallel product assurance of spacecraft control system adopts the principle of "cooperative work" [4–6]. The concept of collaborative iteration implements on the process. Every product assurance process in spacecraft control system uses parallel iteration, which could help eliminating the risks during the development processes [7, 8].

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In this paper, a mathematical model is used to describe the product assurance of spacecraft control system. The evaluation models of parallel work for spacecraft control system are given.

2 Research on Spacecraft Control System Product Assurance

In the process of serial development of control system, the work of product assurance is often carried on. After the product assurance work in the design stage, the product assurance work in the production stage and test verification stage will be carried out. The serial engineering development model of product assurance is shown in Fig. 1 [9–11].

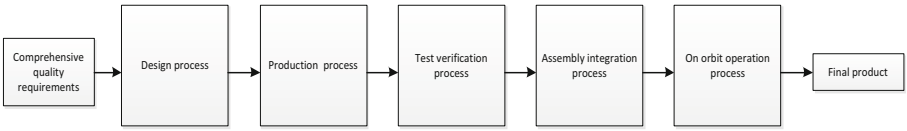

Fig. 1. Product assurance serial development model of spacecraft control system

The results of product assurance serial development may be open-loop. In parallel development mode, the production process, test verification process, assembly integration process and on orbit operation process feedback the design process. By comprehensively considerate the factors, which are the feasibility in production process, interface matching in test verification process, simulated assembly and the influence of plume in assembly integration process, the flight control process and on orbit fault plan in orbit operation process combined in the design process. Correct and adjust the problems and errors in the design process to improve it through the simulation of the follow-up development process.

The product assurance quality of spacecraft control system output is P, the product assurance quality of spacecraft control system in every process is P_i. The relationship is shown in Fig. 2. The design process is the first stage, the production process is the second stage. The test certification process is the third stage, and so on.

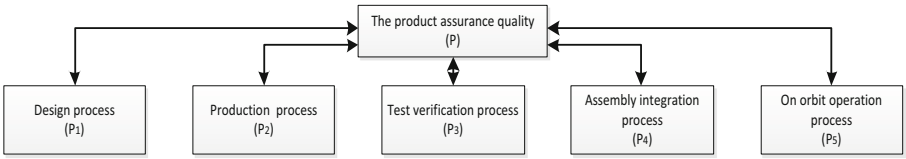

Fig. 2. Parallel development model of spacecraft control system

The product assurance results in test verification process, assembly integration process and on orbit operation process feedback to the production process, and so on.

As shown in Fig. 3, it is the simplified parallel product assurance development model of spacecraft control system.

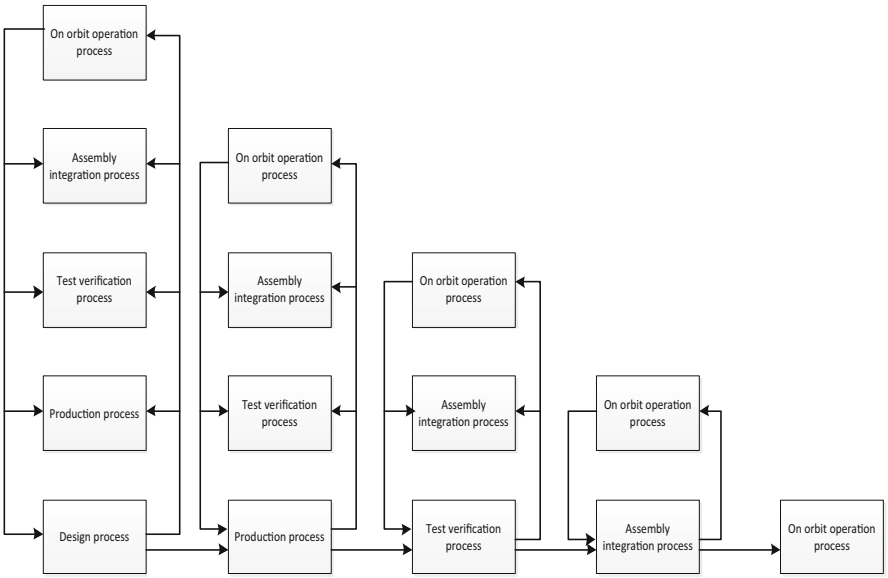

Fig. 3. Simplified parallel product assurance development model of spacecraft control system

Product guaranteed gain of spacecraft control system at each stage is ΔP_i. Feedback product guaranteed gain coefficient of spacecraft control system at each stage is σ_i [11].

$$\sigma_1 = \frac{P_1 + \Delta P_1}{P_1} \quad \sigma_2 = \frac{P_2 + \Delta P_2}{P_2} \quad \sigma_3 = \frac{P_3 + \Delta P_3}{P_3}$$
$$\sigma_4 = \frac{P_4 + \Delta P_4}{P_4} \quad \sigma_5 = \frac{P_5 + \Delta P_5}{P_5} \tag{1}$$

Parallel development process is a series of processes such as production process, which improves the overall quality of design process to $K_1^5 = P_1 \cdot \sigma_1 \cdot \sigma_2 \cdot \sigma_3 \cdot \sigma_4 \cdot \sigma_5$, Where $\sigma_1 \cdot \sigma_2 \cdot \sigma_3 \cdot \sigma_4 \cdot \sigma_5 \geq 1$. The comprehensive quality improvement of parallel process is K_n^m, among them, n is the stage that needs to modify and feedback, m is the stage to modify.

After parallel process, the latter process is a comprehensive iteration of the previous process. The quality of the product assurance in each stage of spacecraft control system is K_i. The quality of the product assurance in design process of spacecraft control system is:

$$K_1 = P_1 \cdot \sigma_1^1 \cdot \sigma_2^2 \cdot \sigma_3^3 \cdot \sigma_4^4 \cdot \sigma_5^5 \tag{2}$$

After synthesis, the gain of product assurance quality in parallel process design stage is:

$$\Delta P_1 = P_1 \cdot \sigma_1^1 \cdot \sigma_2^2 \cdot \sigma_3^3 \cdot \sigma_4^4 \cdot \sigma_5^5 - P_1 \tag{3}$$

The gain coefficient of product assurance quality in parallel process design stage is:

$$\varepsilon_1 = \frac{P_1 \cdot \sigma_1^1 \cdot \sigma_2^2 \cdot \sigma_3^3 \cdot \sigma_4^4 \cdot \sigma_5^5 - P_1}{P_1} = \sigma_1^1 \cdot \sigma_2^2 \cdot \sigma_3^3 \cdot \sigma_4^4 \cdot \sigma_5^5 - 1 \tag{4}$$

The gain coefficient of product assurance quality in parallel process production stage is:

$$\varepsilon_2 = \frac{P_2 \cdot \sigma_2^1 \cdot \sigma_3^2 \cdot \sigma_4^3 \cdot \sigma_5^4 - P_2}{P_2} = \sigma_2^1 \cdot \sigma_3^2 \cdot \sigma_4^3 \cdot \sigma_5^4 - 1 \tag{5}$$

The gain coefficient of product assurance quality in parallel process test verification stage is:

$$\varepsilon_3 = \frac{P_3 \cdot \sigma_3^1 \cdot \sigma_4^2 \cdot \sigma_5^3 - P_3}{P_3} = \sigma_3^1 \cdot \sigma_4^2 \cdot \sigma_5^3 - 1 \tag{6}$$

The gain coefficient of product assurance quality in parallel process assembly integration stage is:

$$\varepsilon_4 = \frac{P_4 \cdot \sigma_4^1 \cdot \sigma_5^2 - P_4}{P_4} = \sigma_4^1 \cdot \sigma_5^2 - 1 \tag{7}$$

The gain coefficient of product assurance quality in parallel process orbit operation stage is:

$$\varepsilon_5 = \frac{P_5 \cdot \sigma_5^1 - P_5}{P_5} = \sigma_5^1 - 1 \tag{8}$$

After parallel engineering, integrated product assurance quality improvement for spacecraft control system is:

$$\begin{aligned} K &= P \cdot (\sigma_1^1 \cdot \sigma_2^2 \cdot \sigma_3^3 \cdot \sigma_4^4 \cdot \sigma_5^5) \cdot (\sigma_2^1 \cdot \sigma_3^2 \cdot \sigma_4^3 \cdot \sigma_5^4) \cdot (\sigma_3^1 \cdot \sigma_4^2 \cdot \sigma_5^3) \cdot (\sigma_4^1 \cdot \sigma_5^2) \cdot \sigma_5^1 \\ &= P \cdot \sigma_1^1 \cdot \sigma_2^3 \cdot \sigma_3^6 \cdot \sigma_4^{10} \cdot \sigma_5^{15} \end{aligned} \tag{9}$$

The gain coefficient of spacecraft control system product assurance in parallel process is:

$$\varepsilon = \frac{P \cdot \sigma_1^1 \cdot \sigma_2^3 \cdot \sigma_3^6 \cdot \sigma_4^{10} \cdot \sigma_5^{15} - P}{P} = \sigma_1^1 \cdot \sigma_2^3 \cdot \sigma_3^6 \cdot \sigma_4^{10} \cdot \sigma_5^{15} - 1 \tag{10}$$

3 Product Assurance Work Evaluation of Spacecraft Control System Developed in Parallel

According to the experience of spacecraft model development, taking the control system of scientific research satellite as an example, there are at least three iterations and optimizations in each stage. Each iteration will have an impact on the product development cycle.

The parallel development can adopt the methods of hardware and software generalization, modularization and serialization. Promoting the engineering and systematization of spacecraft control system development more scientifically, it provides the theoretical basis for the improvement of product assurance of spacecraft control system. The concurrent engineering simulation diagram is shown in the Fig. 4.

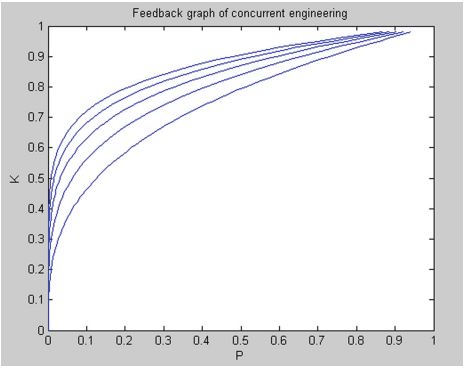

Fig. 4. Feedback graph of concurrent engineering

4 Conclusion

Usually, the development stage of spacecraft control system goes through scheme stage, pattern stage, preliminary sample stage and normal sample stage. Through parallel development model for product assurance of spacecraft control system, design process, production process, test verification process, assembly integration process and on orbit operation process are iterated and optimized. Through parallel development, the development stage can be reduced and the pattern stage and preliminary sample stage can be complained. The development stage of spacecraft control system goes through the scheme stage, preliminary sample stage and normal sample stage. Under the condition of ensuring quality of spacecraft control system, the development cycle is shortened from 5 to 4 years. The advantages are that the cost of rework and repetition

of the process is reduced, development cycle is shortened and the efficiency is greatly improved.

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