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The Usage of Continuous Engineering Approaches in the Adaptation of the RK-SM-MKA Receiving Complexes for Installation on Board the Meteor-M No. 2-1 and 2-2 Spacecraft

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Abstract. The paper gives the results of using the system engineering methods, more precisely, continuous engineering, its relatively new trend, when performing the adjustment of the search and rescue onboard complex for the Meteor-M type spacecraft. The article offers the description of the method for project management aimed at adaptation of the search and rescue complex (item RK-SM-MKA) for installation on board of the Meteor-M No. 2-1 and No. 2-2 spacecraft. The results of its application are also discussed.

It is shown, that building of a separate unit for interface transformation made it possible to install the onboard radio complex as soon as possible, within the scheduled time before the spacecraft launch.

Keywords: system engineering, project management, V-diagram, life cycle phases, continuous verification, continuous engineering

Introduction

To date, we can state that Moore's law is still being implemented, that is, the number of transistors in processors increases twofold every two years. The natural consequence of this law is the ever-increasing complication of products for various purposes, which utilizes the increasing capabilities of the electrical, electronic, and electromechanical (EEE) parts.

At present, the complexity of space technology products has also grown significantly. In addition, the product requirements are constantly increasing in terms of reliability, active life, etc. In some other countries, the 1970-ies were the starting point of the development of the approaches of system engineering [1] (which are now being gradually introduced in Russia), rigidly regulating the phases of the life cycle of the product creation in conjunction with the control procedures of each stage, as well as the verification and validation of the output products, as a part of the design process of products for various purposes. Special visual programming environments and object programming languages [2] are formed that simplify the process of system design of products or the creation of complex systems.

Based on this foundation, many additional approaches are already being developed that make it possible to improve the efficiency of solving problems arising in the design of new products. Within the framework of the present paper, it is proposed to consider the application of "continuous engineering" [3, 4] approaches to the adaptation of the search and rescue complex RK-SM-MKA (Modernized Rescuing Radio Complex for Small-Sized Spacecraft) for its installation on the spacecraft of the "Meteor-M" series.

Continuous engineering (CI) offers methods for the development of enterprises for the successful development of innovative products with ever-increasing complexity and connectivity, taking into account the current (or ever-changing) requirements of the consumer and the market. CI is not a general replacement for system engineering approaches or existing project management techniques. In the framework of CI methods, key project management approaches are being revised through the introduction of activities such as continuous verification, the unblocking of engineering knowledge, and the strategic reuse of the results of previous development projects.

The RK-SM-MKA complex is designed for reception and processing of COSPAS-SARSAT beacon signals [5, 6] and was originally developed for installation on the Sterkh and Obzor-OA spacecraft, which, in accordance with the international obligations of the Russian Federation under the COSPAS-SARSAT [7] program, were to be launched into the orbit, forming the basis of the Russian low-orbit segment. Due to the termination of the Sterkh and Obzor-O projects in 2015, it was decided to install the RK-SM-MKA on board the Meteor-M spacecraft No. 2-1 and 2-2, provided that the aforementioned devices were launched no later than 2017 or 2018.

Taking into account the fact that the time for adaptation of the complex for spacecraft launch was extremely limited, it was suggested to use the "Continuous Engineering" approaches to plan the works on this project, which allows providing a timely delivery of equipment to the head enterprise.

Thus, within the framework of the present work, we propose a description of the methodology for managing the adaptation of the RK-SM-MKA equipment for its installation on board the Meteor-M No. 2-1 and 2-2 spacecraft, and discuss the results of its application.

Continuous engineering

Currently, a system approach to the design of complex products, known as "system engineering", is widely used. Within the framework of the "system engineering" approach, all aspects of product development are considered from the very beginning of the design process and are consistently applied for continuous improvement of the created product [1].

Obviously, during the adaptation of a product originally intended for another spacecraft, taking into account the requirements of the new spacecraft platform, it is necessary to start the design process from the very beginning: to revise and change (if necessary) the basic requirements for the product. However, in this case, it becomes clear that, perhaps, it will be necessary to implement a full cycle of reworking of the complex, which will require considerable time and financial resources.

The well-known modern physicist Stephen Hocking said: "Intelligence is the ability to adapt to change." Accordingly, it is necessary to find such an approach to the product development process, which would at least not reject the changes at various stages of product design [3].

Such an approach called "continuous engineering" was introduced by IBM in 2014. It was viewed by the

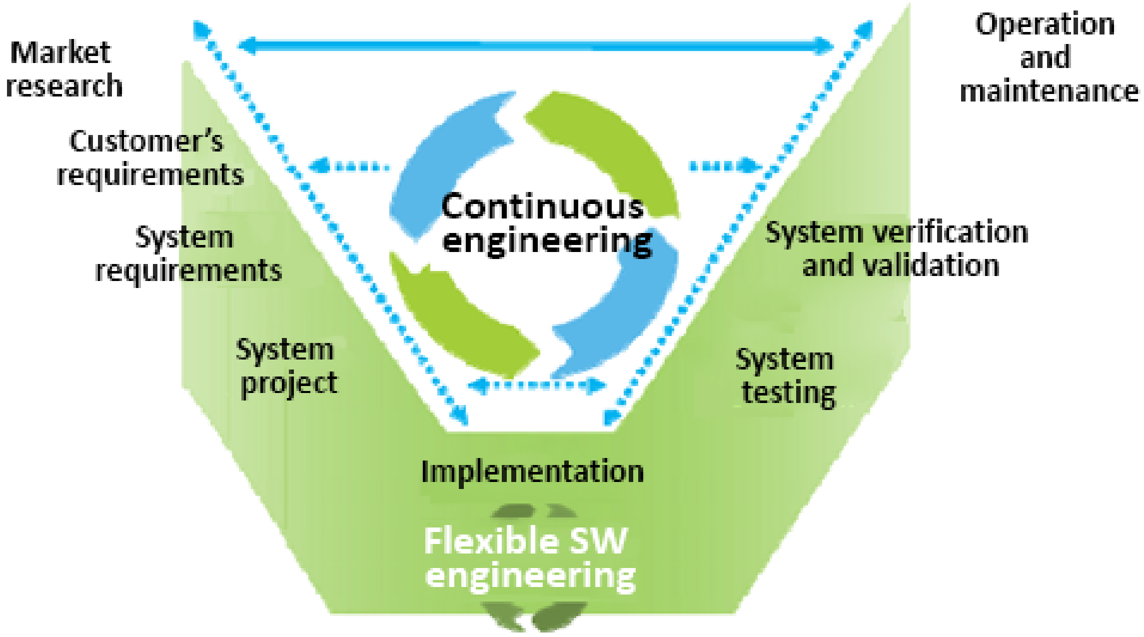

Fig. 1. V-diagram in the representation of CI [3]

specialists of the corporation as the enterprise's ability to create complex electronic products in the interests of the development of approaches and implementation of the Internet of things (IOT) concept [4]. "Continuous engineering" was based on IBM's over 25-years of experience of offering solutions within the framework of the concept of system engineering and the development of software for various manufacturers, including manufacturers from the aerospace industry [8].

CI represents the logical development of approaches to system engineering. It preserves the focus on the system, the levels of abstraction and the basic processes that form the basis of system engineering, but adds a new perspective on how the actions are interconnected [3].

In the framework of continuous engineering, the V diagram of the product or system development process (Figure 1) is no longer a consecutive series of steps; on the contrary, it involves performing actions that are performed iteratively (and most probability in parallel) through the entire product development process, and connects actions and interconnections between engineering, operational and marketing data [3].

The main idea of the CI is to reduce the distance between the current development plans and the current (or newly arising) requirements imposed on the product.

As already mentioned above, the fundamental difference of the CI approaches from the traditional approaches to product design is their focus on the constantly changing requirements for the product, as the commercial success of the product is substantially determined by market requirements that are subject to serious variations. Applying the methods proposed as a part of the CI, it would be possible to change the design of the product in a timely manner if there arises a discrepancy between the technical implementation of the product and its requirements in the process of the continuous verification process.

In order to be maximally ready for constant changes in requirements, a mechanism was proposed (and its advantage is that it does not go beyond the "system engineering" approaches) for reusing the developed products or their components. Moreover, such an approach can be extremely effective for adapting existing products to the changed conditions of their use.

A simple example, given in [3]. If the software product in the product "B" subsystem performs almost the same functions as in the "A" subsystem, it may seem that you just need to copy the program code of the "A" product and modify it to meet the requirements for the product "B" subsystem. At first glance, the proposed mechanism for accomplishing the task will speed up the process of adaptation.

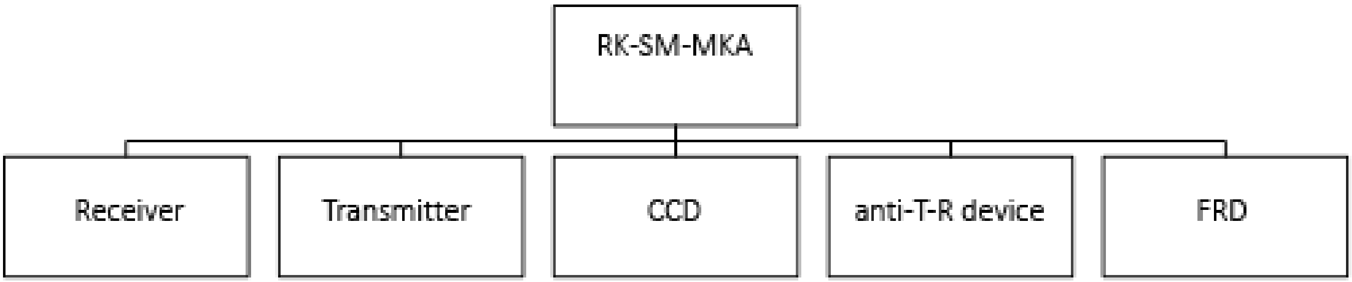

Fig. 2. Structural diagram of the RK-SM-MKA complex

However, if the product code “A” is simply copied and adapted for use in the product “B”, the latter product acquires a modified code, and all verification tests with this software will be performed as part of the product “B” verification. One cannot just assume that the results of verification of the product “A” code apply to the product “B”, because the product “A” code has been changed. Moreover, if a defect in the product “A” code is found, it will be difficult to determine whether this defect has been eliminated in the product “B” code or vice versa, without carrying out the corresponding work to correct the software of each of the products. That is, in any case, it is necessary to carry out work to eliminate this defect twice. Consequently, the effectiveness of this solution is clearly low.

It is from this point of view that it is more efficient to go by borrowing previously created products. If, while developing the subsystems of the product “A”, it is known that the subsystems of the product “B” require approximately the same functionality, one can create technical or design solutions in such a way that the product “B” uses parts of the product “A” design systematically, that is including requirements, test programs, software and other elements, without modifications. In this case, certain components of the product “A” are simply introduced into the design of the product “B”, and, as can be seen from the above, such an approach of reusing the results of previous development projects will be much more effective.

In accordance with CI, it is necessary to separate the concepts of “creation of an innovative product” from “development of basic elements or technologies”. In the process of creating an innovative product, it should be created by taking advantage of borrowing of the existing technologies or elements that will provide it with competitive advantages in the commercial market.

Development of the basic technologies must be performed independently and before the creation of consumer products, clearly focusing on the needs of consumers or the market as a whole.

Description of the RK-SM-MKA complex

The RK-SM-MKA complex (Fig. 2) is a set of devices for various purposes: a receiving device, a transmitting device, a command-distributing device (CDD), an anti-T-R device, as well as a framing and recording device (FRD), which prepares the information for transmission to the transmitting device of the complex.

The main problem in the adaptation of the RK-SM-MKA complex that occurs when it is placed onboard a Meteor-type spacecraft is the need to transform the interfaces for the exchange of telemetric and command information by modifying or re-designing the FRD of the complex for new requirements, taking into account the changed spacecraft bus. In any case, since the documentation for the complex was previously completely verified and the designation “O” was received, such changes in the equipment of the complex would lead to the need to repeat the cycle of ground testing of the product.

Description of the proposed methodology

When installing spacecraft products on spacecraft that were not originally designed to accommodate the aforementioned complexes, as a rule, it becomes necessary to make significant changes to the design of the finished product, because of the uniqueness of each individual space bus. Unification issues are an extremely important aspect of modern space device engineering, which has finally been given the necessary attention [9], but they are not to be considered in detail in this article.

Changes in design documentation for the adaptation of complexes are caused, among other things, by potential changes in the requirements to layout, interfaces of equipment, as well as resistance to external influences from outer space.

Therefore, when planning and implementing the necessary improvements, as a rule, they begin with the modification of the existing documentation and modernization of the components of the complex to meet the changed requirements, which, as a consequence, leads to the repetition of the entire procedure for ground-based experimental testing of not only the upgraded components, but also the complex in whole. Unfortunately, the optimization process takes a very long time and requires considerable financial resources.

Due to the established practice in the design of the spacecraft, the antenna-feeder complex is functionally a part of the radio complex; therefore, it is developed and manufactured by the space bus manufacturer. For this reason, within the framework of this work, the issues of creating an antenna-feeder complex are not considered, and only the considerations of the development of on-board equipment are given.

During the adaptation of the RK-SM-MKA on board a spacecraft of the Meteor-M type, it became necessary to change the design documentation for the length and structure of the cable network of the complex (due to the re-arrangement of the product for installation on the new bus), the introduction of additional protective casings for some devices to meet more stringent requirements for external influencing factors (IAF) taking into account the changed altitude of the orbit. In addition, the most serious challenge in solving this problem was the need for substantial reworking of the RK-SM-MKA interface to make it compatible with the service subsystems of the spacecraft.

The most obvious solution in this situation was the revision of the FRD device, which carries out information exchange when receiving commands from the spacecraft and transmitting the target information to the radio link. It is necessary to take into account that the RK-SM-MKA complex was manufactured according to the documentation approved for the batch production. Provided that the decision was made to finalize the FRD instrument, taking into account the seriousness of the modifications not only of the on-board equipment, but also of the control equipment, it would be more likely to repeat the cycles of ground-based experimental testing to confirm the corrections to the approved documentation.

In accordance with the contractual documents for the RK-SM-MKA complex, a full cycle of tests and other necessary work is about 24 months, which does not satisfy the delivery time of the equipment required by the bus manufacturer, taking into account the limited time before the scheduled launch of the spacecraft.

Therefore, in accordance with the CI approach, it was decided not to modify the RK-SM-MKA complex in terms of changing the functionality of its devices and to deliver the RK-SM-MKA unchanged.

To ensure the adaptation of the complex, it was decided to develop a special and relatively simple device to perform an extremely specialized interface transformation function which would ensure the transfer of commands to the RK-SM-MKA complex, as well as the information output from the complex to the service systems of the space bus.

Description of the interface conversion unit

The interface conversion unit (ICU-K) is a separate unit, which consists of two independent packages, main and backup, according to the scheme of cold redundancy, which provides the required level of reliability.

The ICU-K accepts the relay commands, a serial 17-bit code of the on-board time scale (OBTS), in the format of the on-board control system of the Meteor-M spacecraft and converts it into a format that provides the RK-SM-MKA equipment control (Figure 3).

ICU-K performs the following functions:

– reception of the second timestamp from the OBCC of the “Meteor-M” SC and its transfer with other pulse parameters to the RK-SM-MKA;

– reception of the serial 17-bit code of the OBTS from the OBCC of the “Meteor-M” SC once per second and saving it in the buffer of the ICU-K (when saving, the previous code is overwritten);

– reception of relay commands from the OBCC of the “Meteor-M” SC and output of an information frame (digital command) with the code of the accepted relay command and the code of the on-board time stored in the buffer of the ICU-K to the RK-SM-MKA via the RS232 interface;

– reception from the RK-SM-MKA of the acknowledgment of the command transmission;

– output of the telemetry about the command transmission to the “Meteor-M” spacecraft.

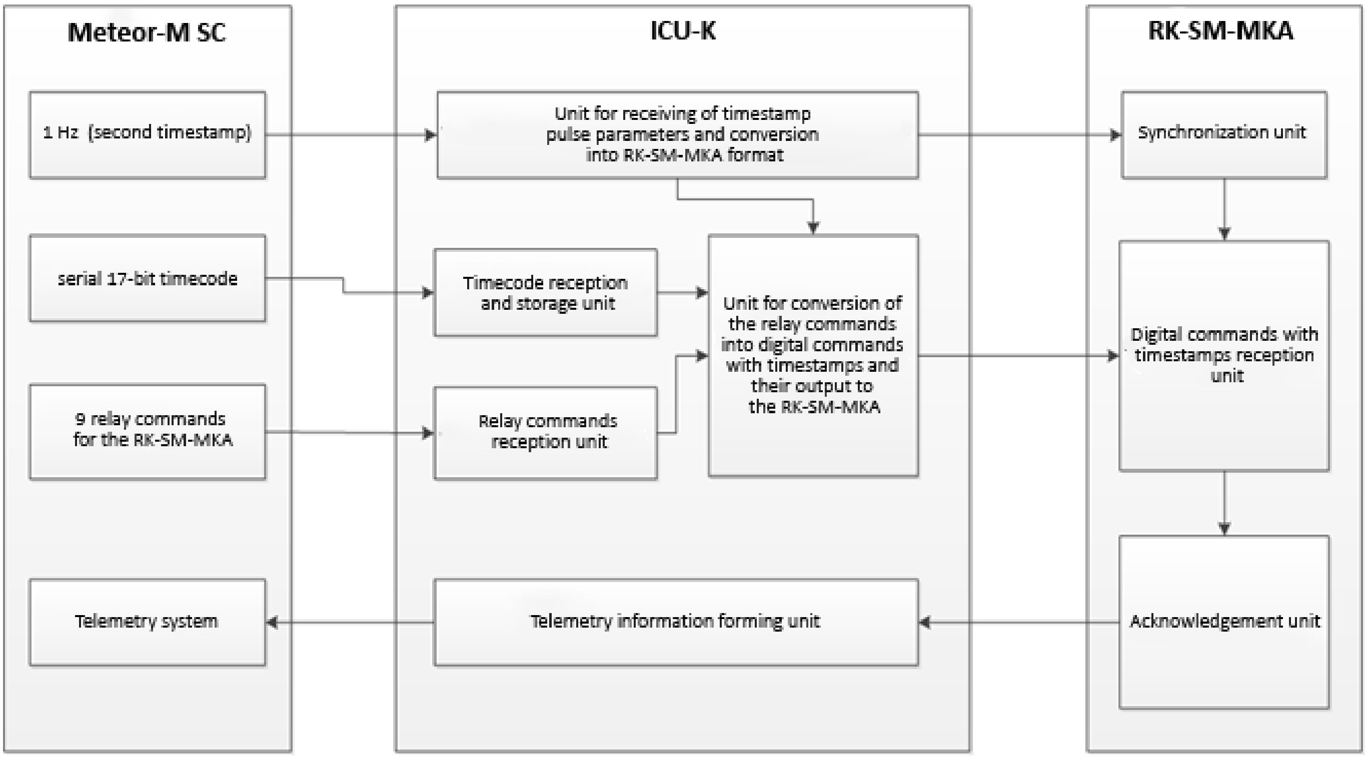

Fig. 3. Scheme of operation of ICU-K

Results of application of the CI approaches

The abandonment of the classical scheme of execution of activities within the framework of system engineering approaches, readiness for a flexible change in the requirements for the system or the final product, made it possible to shorten the delivery time of the equipment significantly. Thus, the term for manufacturing the interface transformation unit (excluding the time of the procurement of the components) was no more than 9 months, including the cycles of ground-based experimental testing.

Taking into account the minimum necessary modifications to the RK-SM-MKA complex, delivery of the equipment was ensured within the timeframe necessary for the scheduled launch of the spacecraft. The forthcoming launch of the "Meteor-M" No. 2-1 spacecraft is very important, because for the first time in many years, a spacecraft with a payload of search and rescue will appear in the low Earth orbit, which will allow Russia to renew its international obligations to the COSPAS-SARSAT Program.

In addition, as part of the import substitution program, when designing the equipment for the interface transformation unit, the basic technologies of programming and functional use of the Russian-made electrical, electronic and electromechanical parts were worked out, which in the future will be used in other development projects of JSC "Russian Space Systems".

Taking into account the gained experience, the developed software (both technological and target), circuit solutions, EEE parts and technological equipment for the use of the Russian-made EEE parts, it can be summarized that a set of engineering "artifacts" was obtained that will improve the efficiency of advanced space device development projects, which is especially important when using the domestic EEE parts.

Conclusion

In conclusion, it should be noted that in this situation, the space industry, both in the Russian Federation and in the world, increasingly loses its "driver" positions in the application of the cutting-edge technologies in device engineering.

Taking into account the rapid development of consumer electronics markets, as well as the change in the current techno-economic paradigm and the constant complication of the developed products, it becomes clear that it is necessary to change the management approaches to the organization of scientific research work and space technology development projects, orienting and adapting (indisputably) the experience of creating devices for the mass market.

It is shown that the application of the continuous engineering approaches based on the basic principles of the classical system engineering can shorten the time of the adaptation of RK-SM-MKA equipment for installation onboard a spacecraft of the "Meteor-M" type.

A method of project management using the approach of strategic re-use of the previously completed CI development projects is proposed. In accordance with the above methodology, it was decided not to modify the RK-SM-MKA complex and to implement the delivery in accordance with the approved documentation. To implement the necessary changes in the adaptation of the product, it was suggested to develop a relatively simple device that performs a substantially limited function: the transformation of interfaces.

As a result, it was ensured that the search and rescue complex was adapted for installation on the new spacecraft within a period not exceeding 9 months, taking into account the need to fundamentally rework the interfaces of interaction with the service subsystems and the complete layout rearrangement onboard the spacecraft.

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