Improve the integrity testing process based on QFD, FMEA and TRIZ

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Abstract. In today's aircraft industry — competitiveness in the domestic and foreign markets, is the main criterion for the development of quality, a high level of which is achieved through methods and approaches: QFD, FMEA, TRIZ. There is a possibility of application of these methods at tests of production, for the purpose to meet expectations of consumers with the most optimum combination of characteristics of production. The design process is often associated with a compromise of conflicting parameters, which means increased costs and loss of quality. Innovation in the production process can create great value. The rapid development of modern technologies and the commercial environment suggests that the design of production processes requires the application of a systematic method of improvement. The proposed method combines a number of quality tools to support the process of modern development of aviation. In order to implement the acceptance improvement, it is necessary, first, to analyze the product testing process in accordance with the influencing parameters and use QFD (quality function deployment) to obtain the basic requirements for the testing process. Secondly, to find the contradictions of the testing process and analyze them comprehensively. To creatively solve the revealed contradictions, apply the Russian theory of inventive problem solving (TRIZ). When using this technique increases both the efficiency and maneuverability of the use of quality tools to solve technological problems. The effectiveness of the proposed method of improvement is illustrated and confirmed by the example of the process of testing the tightness of the hose of the life support system of the product "Bion – M".

1. Introduction
Aircraft belong to complex technical systems, failures of which often lead to serious consequences.

Production of any production is based on stability of technological processes which confirmation serve static and dynamic tests of production with the maximum approach to real operating conditions. Static tests to a greater extent characterize the properties of the material, and dynamic — the validity of the selected parameters of structures and technologies.

Operational testing plays an important role in the production life cycle, as it provides an opportunity to confirm compliance with the requirements that should be assessed in conditions as close as possible to the actual operation.

The main methods of conformity assessment are measurement, testing and control, which must be carried out in accredited laboratories with certified testing equipment.

It is advisable to improve the quality of products to use modern tools and methods of quality management, such as: QFD, FMEA, TRIZ.
FMEA — “Analysis of the types and consequences of potential nonconformities” assesses the risks and possible damage caused by design and process nonconformities at an early stage in the design and construction of the finished product or components. It is divided into: PFMEA to identify potential inconsistencies of the process and DFMEA to identify potential inconsistencies of the design [4].

QFD — “Quality function deployment Method”, provides high quality of the created products at each stage of the life cycle with a guarantee of obtaining the final result that meets the requirements and expectations of the consumer [5].

TRIZ — “Theory of inventive problem solving”, used to identify and use the laws, laws and trends in the development of technical systems. TRIZ is designed to organize the creative potential of the individual so as to promote self-development and the search for solutions to creative problems in various fields. The main task of TRIZ is to propose an algorithm that allows to find the most suitable variant without searching for infinite variants of solutions to the problem, discarding the less qualitative ones. Or, to put it more simply, TRIZ allows you to solve the inventive problem so that the output to get the highest efficiency. [1]

According to modern research in the aerospace industry, the test process plays an important role between design development and production. However, the testing process has limitations or contradictions and requires a compromise between many factors. The rapidly changing modern market makes us strive for high competitiveness and develop production processes with the use of systematic improvement techniques to ensure stable product quality. A number of quality tools, methods and approaches are used to improve test design processes. Innovation processes usually mean a change in test technology that includes new designs, processes, the use of modern equipment and test models. This article describes the design strategy of production processes on the example of combining modern quality management tools: QFD, FMEA and TRIZ [2].

QFD and FMEA can help to identify the requirements to test the system and determine actions to address the shortcomings of the system. The TRIZ method is used to improve the testing process and to solve the conflict parameters of the process system. Since the design process at an early stage plays a crucial role, which determines the degree of compliance of the product with the declared requirements of the consumer, it is extremely important to build a systematic approach to the design of the test process. The implementation of a compromise strategy in the design of test processes helps to recognize and manage conflicting process parameters and find creative solutions to the problem [6].

TRIZ is a theory that can effectively resolve technological conflicts or contradictions with the help of original ideas. In the design of the test process and the use of TRIZ analysis of the contradictions of the process, which are the source of conflict moments of the test environment, is inevitable. However, if you solve the problem comprehensively, especially in a complex system of production processes, it is necessary to learn about all the requirements, not only about the demands of consumers, but also the requirements for the test system. And QFD (Quality function deployment) can be an effective tool for requirements analysis.

In accordance with the above, this article proposes a strategy for the improvement process. QFD, FMEA and TRIZ are used as an integrated methodology to select the appropriate solution for emerging problems in the testing process. First, QFD is used to transform process requirements into technical specifications. Meanwhile, many technical contradictions can be found, given the complexity of the system of production processes. In this case, TRIZ is used, for example, standard methods of eliminating technical contradictions, which are one of the effective tools to break down the complex system of the design process into principles and achieve several alternative modern solutions. Common design parameters for selecting a suitable process system include productivity, safety, environment, quality, flexibility and cost. If you cannot achieve a solution to the problems, you must apply TRIZ again. An example of the improvement process strategy is shown in figure 1 [3].

A methodology for the systematic and structured transformation of customer requirements into product requirements and the further deployment of requirements down to the workplace with the least risk is a modern instrumental way of developing innovations.
2. Object of research
The strategy of the improvement process is applied on the example of testing the tightness of the hose of the life support system of the product 12XM. Tests are carried out on the pneumatic panel VK 70209-398A. The block diagram of the test bench is shown in the figure 2.

The object of the test is the hose of the life support system of the product 12 KSM presented in figure 3. Hose construction consists of seal (pin & sleeve) and the sleeves 2K7-30, supplied by THAT 38.0051515-92. The elements of the sealing hose is exposed to the greatest stress, as it affects them the most free weight of the sleeve 2K7-30. The hose is installed on the outer surface of the spacecraft on the cable mast and serves to supply oxygen into the spacecraft from oxygen cylinders.

Based on the test procedure program, there are test requirements.
1. Before each test:
   - inspect hoses for mechanical damage and contamination;
   - in the case of the presence of moisture on the hoses to keep them dry.
2. After each test, the hoses must be completely drained and kept plugged. Drying is carried out by blowing air until complete removal of moisture.
3. When installing the hoses in a device for testing the tightness of coupling nuts of the joints to produce 1.0 to 1.5 facets of focus, are not allowed twisting of the hoses around the axis. Seal the joints with gaskets.
4. Test the hose for tightness with compressed air pressure $(3.45 \pm 0.15)\text{ MPa} \ ([35 \pm 1.5] \text{ kgf/cm}^2)$ for 5 minutes under water with a preliminary exposure of 10 min. No tightness is not allowed (no air bubbles from the hose in the water and pressure drop on the pressure gauge).
5. The necessary measuring instruments used in the tests must be verified and the test equipment must be certified.
3. Application of the QFD method to identify the basic requirements and process parameters «leak test»

The term QFD is a method that allows to deploy the customer requirements into performance characteristics, performance characteristics — into part characteristics, part characteristics into manufacturing process and manufacturing process — into control tools [6, 7]. QFD should be used since the conceptual design stage, because the decisions made at this stage provides about 70% of the project’s success with minimal costs [8].

Figure 4 shows the structure of the main QFD tool — the House of Quality, which received such a name for its shape.

Requirements for the process of testing for tightness and contradictions of parameters exist simultaneously, which usually affects the appearance of many technological conflicts between the accuracy of observations and the speed of testing, the presence of air bubbles and the lack of pressure, etc. it is Necessary to assess the requirements and contradictions of the test process, this requires to find out the controversial points of the process without missing anything. The first thing to do is to find out the exact parameters of the requirements, not a General description. QFD (quality function deployment) can be an effective tool for this. Secondly, the limitations of the process system, which are related to costs, technologies and resources, etc., must be fully taken into account.

The purpose of the deployment of quality functions (QualityFunctionDeployment — QFD) is to ensure the quality of the created products at each stage of the life cycle, which would guarantee the final result that meets the requirements and expectations of the consumer [7].

Technology QFD includes a 4-phase (level): quality plan product (phase 1), the quality of the product components (phase 2), quality plan process (phase 3), the quality plan of operations (phase 4), each of which used a matrix diagram is a special kind of quality. Quality house is an element of quality functions deployment technology (QualityFunctionDeployment — QFD) [8].

To identify the quality requirements of the process and operations, we need the third and fourth level of QFD methodology. For QFD the third level, we need requirements to test the system and steps of the process of "testing for leaks".

Requirements for the test system according to the degree of failure are divided into three main types:

1. **Anticipatory:**
   - ergonomics of testing.

2. **To health:**
   - the presence of the user in the workplace;
   - high performance (maximum number of tests per day);
   - the safety of good products.

3. **Obligatory:**
   - quality assurance seal of rubber hoses to end fittings;
   - impact of loads provided by operational factors;
   - reproducible taking into account the capabilities of the test equipment;
   - evaluation of the reliability of the test object according to the test results;
   - security testing.

**The stages of the process "test for leaks":**

1. Install the hoses in the equipment and connect to the pneumatic console;
   - To drown out the hoses;

2. Give pressure to hoses with compressed air \( P = 0.5 \text{ kgf/cm}^2 \);
   - Place the hoses in an armored bath water;

3. To increase the pressure in the hoses to 36 kgf/cm\(^2\);
   - Withstand pressure for at least 10 minutes;
4. Check for the tightness of the sealing space and the wall of the hose within 5 minutes. Leakage is not allowed (Signs of leakage are air bubbles in the chromatic solution or pressure drop on the pressure gauge);

5. To relieve the pressure to 0.5 kgf/cm²;
6. Remove hoses from armored bath;
   Bleed the pressure to 0 kgf/cm².
7. Disconnect the hoses from the pneumatic console;
   Remove plugs from hoses and tape;
8. Blow the hose with compressed air P = 10 kgf/cm² until the moisture is completely removed;
9. To reflect the result of the test;
10. To establish technological plugs in the hose.

Figure 4 shows the third level QFD.

As a result of the QFD of the third level, the key operations and parameters of the "leakproofness test" process are determined:

1) Withstand pressure for at least 10 minutes (14.5%);
2) Reflect the result of the test in the sheet of test marks (11.5%);
3) Install the hoses in the equipment and connect to the air gun (10.6%).

For QFD the fourth level, we need the operation to the process "test hose for leaks".

Auxiliary requirements for the "leak test" for the hose object of the life support system of the product 12 KSM are presented in the second section "Object of study". Figure 5 shows the QFD of the fourth level.

Based on the matrix diagram, QFD allows you to understand the key operations that affect product performance, product quality and process parameters of the "leak test".

Figure 3. Hose, life support system.

Figure 4. Third level QFD for «leak test».
4. The application of TRIZ

There are many controversial points in the testing process, so it is advisable to use TRIZ at an early stage of design. One of the prerequisites of TRIZ is that there are objective laws of development and functioning of systems, based on which it is possible to build inventive solutions. In other words, many technical, production, economic and social systems are developing according to the same rules and principles. Soviet scientist and inventor Heinrich Saulovich Altshuller discovered them by studying the patent Fund and analyzing the ways of development and improvement of technology for a long time. A list of 40 standard methods of eliminating technical contradictions has been created — a kind of desktop guide for the inventor, but a special kind of guide: the inventor should consider it as the basis for which it is necessary to replenish the new technical and patent publications. TRIZ is a human-oriented systematic methodology for solving inventive tasks based on knowledge. It can solve technical problems and offer innovative solutions using a knowledge base.

To study the similar features of other inventions for the use of TRIZ and determine the patent purity of the studied object of technology: a stand for checking products for leaks, a patent search was conducted and materials were selected for further analysis:

1) Stand tightness control of filter elements and filter packages — utility model №74617.
2) Stand for testing the tightness of the transformer housing — utility model №106368.
3) Stand for checking the tightness of radiators before and after repair — utility model №172904.
4) Stand for checking the tightness of gas valves of the boiler — utility model №99849.
5) Walls for leak test — the invention № 2583880.

Stand for testing air hoses — utility model № 38 463 is selected as an analogue for the use of TRIZ, the stand refers to devices for monitoring and testing of brake systems and is designed for testing brake hoses with air. Currently, the company is known to stand the test of hoses, which hoses the consolidation is done manually, the lifting and lowering of the frames with handheld hoses.

The disadvantage of the known stand is the use of manual labor, that is, manual hose clamping and lowering of the framework.

Figure 5. QFD fourth level for the process of verification of impermeability of the hose.
The purpose of the proposed utility model is to increase the performance of testing hoses by automating the testing process by using a pneumatic actuator and a sealing unit.

In this article TRIZ is applied in relation to the process of testing the hose of the life support system of the product 12KSM, the purpose of which is to check the quality of sealing of rubber hoses in the end fittings by the loads provided by the operational factors reproduced taking into account the capabilities of the test equipment, as well as to assess the reliability of the test object according to the test results.

Risk analysis by FMEA [4] allowed to determine a number of contradictions of the test process, for example, such as: the dependence of the pressure in the test bench, affecting the test result, i.e. if the pressure in the system is up to 36 kgf/cm², it is possible defective hose is allowed to work, at a pressure above 36 kgf/cm² there is the appearance of microcracks in the hose.

On the basis of the table of application methods of solving technical contradictions the selected factors: No. 11 Pressure and No. 27 Reliability. To solve these contradictions, standard methods of their elimination are proposed, such as: № 19 "Principle of periodic action", which consists in the transition from continuous to periodic (impulse) and № 35 "Change of physical and chemical parameters of the object", which allows to change the concentration or consistency.

On the basis of the above methods, measures have been developed to improve the stand for tightness control:

- Air supply will be carried out according to a certain law (pulse mode) short-term supply to the system is not constant, but variable, with a certain frequency and amplitude of oscillations.
- Adding a chemical reagent to the test environment of the bath to change the physical and chemical properties of the water, in order to improve the visualization of the detection of non-tightness of the hoses.

5. Conclusions and discussion

1. Operational testing plays an important role in the production life cycle, as it provides an opportunity to confirm compliance with the requirements that should be assessed in conditions as close as possible to the actual operation.

2. Modern methods and approaches are applied and investigated: QFD, FMEA, TRIZ, for improvement of process of tests on tightness.

3. QFD fourth level for the process of verification of impermeability of the hose allowed us to identify key activities that could affect efficiency of production.

4. Risk analysis by FMEA revealed a number of contradictions in the testing process, for which TRIZ was used.

5. A review of patents for existing analogues of the test bench to test products for leaks, as well as the application of the theory of inventive problem solving allowed to come to solutions of technical contradictions.

6. Measures to improve the test stand are defined.

References

[1] Duflou J R and D’hondt J 2011 Applying TRIZ for systematic manufacturing process innovation: the single point incremental forming case Procedia Engineering 9 528–37
[2] Li T S and Huang H H 2009 Applying TRIZ and Fuzzy AHP to develop innovative design for automated manufacturing systems Expert systems with applications 36 (4) 8302–12
[3] Wang C, Zhao W, Wang J, Li X, Zhang K, Guo X and Zeng J 2015 The Optimizing Strategy of Systematic Process Innovation based on QFD TRIZ and AHP Applied Mathematics & Information Sciences 3 1593–604
[4] Vysotskaya M V, Khyrashcheva D V, Orlova S I, Tsyman V N, Russkikh I V and Shurshev M A 2018 Improving the process of leak testing with modern quality management methods Quality and life 3 (19) 16–24
[5] Dmitriev A Ya and Mitroshkina T A 2019 Improving the efficiency of aviation products design
based on international standards and robust approaches *IOP Conference Series: Materials Science and Engineering* **476** 012009

[6] Dmitriev A Ya, Vashukov Yu A and Mitroshkina T A 2016 *Robust design and technological preparation of the manufacturing of aviation equipment* (Samara: Samara University) p 76 [In Rus]

[7] Dmitriev A Ya and Mitroshkina T A 2016 The ontological model and the hybrid expert system for products and processes quality identification involving the approach based on system analysis and quality function deployment *ITM Web of Conferences* **6** 02005

[8] Dmitriev A, Mitroshkina T and Rogachev G 2017 Structural and parametric analysis of robust design quality of complex technical systems *ITM Web of Conferences* **10** 01001