On Unification of Used Materials and Processes at the Enterprise

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Abstract: The unification is one of possible ways to reduce costs and labor intensity. When unique technologies are used, the unification of technological processes can not be massive, but it can greatly simplify the manufacture of assemblies and units by reducing the amount of plating coating and finding the best coating to provide reliable material prevention. A liquid rocket engine is a subject to enormous loads during its operation, and the loss of tightness in the fuel and oxidizer channels can lead to irreversible consequences. The unification of the materials of the sealing elements is one of the necessary directions to ensure the safety of the engine. Thus, by unifying the engineering process of plating coating a stable tightness of detachable joints can be achieved, the production cycle may be optimized by reducing the number of toolings. By the end the unique technologies ensuring the tightness of components and assemblies will not be lost.

1. Introduction

The succession of technical solutions in the form of technological unification reduces the variety of processes and technical equipment, eliminates duplication of works during the technological preparation of production, reduces its labour intensity and duration, expands the application scope of progressive means and processes, implements the resource saving policy and provides production flexibility.

For the purposes of technological process unification, one should elaborate production processes for duplicate parts and tooling, as well as develop single processes, such as of plating coating application, and further module technology of coating application in multiproduct manufacture.

Sealing elements, which ensure tightness, are essential structural components of liquid-propellant rockets. Effective solutions for sealing element design significantly influence on profitability, reliability and energy conversion efficiency of a power unit.

Complete tightness often remains an unfeasible wish not only because of fundamental physical problems, but also due to the required solution cost effectiveness [1]. One of the key factors of a successful performance of works is to solve the problems of a design and technological unification and standardization of products and technological processes.

A variety of service conditions and tightness requirements led to the creation of a variety of sealing elements, mainly based on mechanical sealings [2]. Quite often repair costs exceed the price of destroyed assemblies or even the whole power unit in hundred or thousand times.

The problem is now becoming ever more relevant with lack of state funding and unwillingness of business to invest into long-term projects. Optimization of production processes by means of
unification will provide us with a certain positive economical effect and minimize labour intensity of process flows. Which, in its turn, will decrease production costs. Whereby the positive economic effect spreads on both technological processes (main indicators of unified process quality are productivity, service life, reliability and other indicators reducing operational costs) and personnel, for example, reducing training time.

2. Main Part
Being a scientific production association, “NPO Energomash” aims at unification mainly through the material selection, optimization of the number of items and used materials, which all together will reduce production and labour costs, e.g. for sealing element manufacture or plating coating application.

One of the major requirements considered during unification and standardization is design for manufacturability. It should be noted that a technologist and designer should closely cooperate during designing works in order to manage design for manufacturability.

Design for manufacturability means the combination of its properties that in desired conditions ensure optimal labour costs, finances, materials, and time for technical preparation of production, operation, repair and pursuant to established quality indicators are observed.

Production manufacturability should ensure reduction of time and money for design and technological preparation of production and for manufacturing of the product. Production manufacturability should provide reduction in labour intensity and production costs, including costs of technical preparation for production. The main problems, arising during creation of a new rocket and space technology, are primarily associated with the demands to improve efficiency and increase service life. Operational parameters depend on permissible levels of pressure, temperatures and speeds, the limits of which are often determined by the capabilities of used sealings [3].

JSC “NPO Energomash” is a principal designer of liquid-propellant rockets with large power and high energy characteristic.

Large powers lead to high voltages in the assemblies and units of the engine. Respectively, it is required a high tightness of numerous detachable joints and the use of elastic metal sealings, which provide the necessary contact with sealing surfaces, sufficient to ensure tightness. Reliability and tightness of detachable joint depend on the initial load on the sealing surfaces, the value of which should be sufficient to provide the required contact pressure.

Processes, for sealing purposes, are determined by liquid and gas properties, heat transfer and heat loss, phase changes, wear and corrosion, balance of forces and torques applied on moving parts, vibration state, etc. Rather frequently these determining parameters are so closely interconnected, that it is hard to calculate precisely the sealing system behaviour in service [4]. In view of this, it is necessary to find the solution or to prove that it is impossible to create a definite seal with the requirements stipulated by the existing state of technology.

Strict requirements for operation reliability of units and component supply lines with detachable joints are applied to the sealing elements of modern re-usable liquid-propellant rockets.

Sealing elements work at heavy deformations and frictions of the joint contacting surfaces caused by high power, dynamic and thermal loadings, which leads to rivets and fretting wear of these surfaces. To ensure a longer service life, the sealing elements must be elastic and made from high-strength alloys with good ductility and fatigue strength.

Elastic sealing elements should provide the specified tightness and maintain serviceability within larger temperature and pressure ranges.

Consequently, our goal is to improve sealing reliability and decrease labour intensity. For this, we elaborate a unified technology for sealing manufacture, including: 1. Selection of base material; 2. Maturation of surface preparation for coating technology; 3. Optimization of coating layer thickness.

In order to fulfill these goals, the first stage of works in “NPO Energomash” Labs included necessary researches of defects and reasons of their occurrence on sealing surfaces of parts. These works are required to achieve required parameters of used materials.
Years of experience and collected statistics show that when assembling an engine for qualification tests, and often after them, various connections are formed with leakages. In the course of our experimental works, we investigated a number of different sealing elements installed in especially critical assemblies and units.

The main material for the sealing elements is alloy steel, which has high strength characteristics while maintaining high ductility when the temperature goes down to -253°C. The steel is not sensitive to stress raisers along the whole range of cryogenic temperatures [5]. Tests of detachable connectors simulators with sealings made from the selected steel in liquid hydrogen at 35 MPa under conditions close to real showed that the sealing maintains high tightness, and leakage does not exceed 7.5 × 10^-11 g/s, which is significantly lower than acceptable values. Thus, in order to ensure protective characteristics and, consequently, to increase tightness, we estimated unified Cu+Ag plating coating.

During the complex inspection of sealing elements after tests, we face the following difficulties:

1. Defects in the form of through deepenings, which are located across the contact track, were identified by macroanalysis of the working sealing surfaces (Figure 1)

2. There are numerous relatively deep stripes oriented in the circumferential direction on the sealing surface (Figure 1)

3. Electron microscopical study showed presence of silver in the form of “knobby” bulbs on the surface of through deepenings

4. Using Surftest SJ-400 profilograph, the profilogram of the sealing surface in the circumferential direction (Figure 1) was made and the surface roughness coefficient was determined (roughness coefficient of the sealing surface is \(Ra = 1.76\) (should be within 1.25 as per the design documentation))

5. A defective area of wear with significant plastic deformation in the radial direction (from inner to outer diameter) is present. The sealing surface has a circular deformation trace due to the contact with the sealing surface.

Figure 1. Deviation visualisation
(1—deformation trace; 2—through deepening; 3,4—demarcation of copper and silver layers; 5—“knobby” bulbs on silver coating; 6—roughness).
6. Electron probe microanalyzer studied the areas of cracking and particles pitting and showed that the X-ray spectrum contains both silver lines and copper lines, which indicate complete wear of the silver coating in these local areas.

7. Peeling of the silver coating along the outer surface of the first layer of silver coating is presented. The peeling cause was revealed to be the low adhesion of the silver outer layers to the first layer surface.

8. The microstructure of the coatings was studied on transverse microsections (Figure 2). At the transition corner between the sealing surface and inner diameter of the part, the copper coating was “polished” down to zero, and the first silver layer is absent (mechanically removed). Silver in this area has a two-layer structure and ~ 30 μm thickness (Figure 4).

Figure 2. Macroimages of sealing section, sealing surfaces and outer diameter surface.

Figure 3. Surface of undamaged silver coating (a); surface of deformation trace (b); radial grooves (c); cracking of silver coating and pitting of scales on fretting surface (d).
Figure 4. Copper and silver coating microstructure
Stripping of the silver coating goes along the boundary between the first and second layer

Figure 5. Coating microstructure.
Stripping of the silver coating goes along the boundary between the first and second layer is shown.

All these deviations lead to excess of maximum permissible tolerances for tightness and leakages.

Conducted researches show that the identified fractographic indicators of wear on sealing surfaces, such as multiple surface (fatigue) cracking, formation of fragmented particles, their pitting, subsequent movement and deformation between the contacting surfaces, present the traces of fretting wear, which intensity depends mostly on normal pressure and amplitudes of the reciprocal deflections of the contacting surfaces (Figure 3).

Circular deformation traces on the sealing surface, as well as on the surface of the sealing outer diameter, indicate that they are pressed under the pressure to the corresponding surfaces of the gas generator body; while the absence of a noticeable degree of fretting wear on these surfaces suggests that the reciprocal deflections between them and the surfaces of the gas generator body are practically absent, i.e. during movement of the gas generator body surfaces, the sealing moves with them as a whole.

It appears that the stripes detected on the sealing surface are resulted from grinding the surface of the copper sublayer by a sandpaper, while according to the design documentation, polishing of the copper coating is allowed.

Low level of adhesion of outer layers of the silver coating to the first layer demonstrates low-quality preparation of a surface of the first layer under the application of subsequent layers. It seems that application of a multilayer silver coating is a “mistake”, since a single-layer coating with the same thickness is more technological and functional (Figure 5). Silver of a given thickness should be applied on copper-coated sealing surfaces polished up to the cleanliness required by the design documentation (copper is an adhesive sublayer for silver and its mechanical treatment is technological
nonsense). In this case, the functionality of a silver coating will be provided and the probability of defects because of its low adhesion will significantly decrease [6].

3. Conclusions

To sum it up, unification of materials, implemented to eliminate revealed anomalies, improves plating coating adhesion and sealing element elasticity. We also optimize the process of copper-and-silver coating application.

Revealed circumstances compel us to reconsider the technology of copper-and-silver coating application, selection of surface preparation modes and of coating modes.

It is suggested to stipulate 5 μm as a minimum copper coating thickness to ensure adhesion between the base material and silver coating and, respectively, to comply with silver thickness requirements in the drawing. It is suggested to exclude copper coating polishing and, thus, prevent physical interference into the sealing surface. Absence of stripes during polishing and silver bulbs due to improved adhesion decrease a risk of leaking sealing production.

Satisfying all specified requirements, we decrease coating application time from 1 shift to 2 hours, which allows us to reduce labour costs by 4 times and further reduce production costs.

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