Technological aspects of reliability control of aviation tribomechanical systems

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Abstract. The results of the analysis of the quantitative distribution of aircraft parts by type of operational defects are presented. The analysis was performed based on the data of the parts defects of friction units of three types of aircraft, three types of helicopters and two types of aircraft gas turbine engines. It is shown that defects caused by wear have a significant influence on the structure of aircraft and aircraft engines. It is established that wear due to fretting corrosion is the leading type of wear of tribomechanical systems of aircraft and aircraft engines. The actual fatigue strength of the part is much lower than the calculated one, which can cause unforeseen premature destruction. Choosing the right combination of materials in a fretting pair can also significantly reduce the negative influence of fretting corrosion on fatigue strength. The perspective trends of development of the technologies directed on increase of fretting resistance of elements of aviation tribomechanical systems are analyzed and defined. Development and application of multi-operative, complex methods of creation of the specified coverings allow increasing sharply operational properties of friction surfaces.

1. Introduction

The issue of reliability of aircraft is of particular importance in the general problem of continuing the reliability of machines. Many years of experience and analysis of the results of the assessment of the technical condition of the aircraft in recent years shows that among the wide variety of defects of parts in the structure of aircraft and aircraft engines a significant place is obtained by defects of tribological origin [1-4]. Such defects are natural for most aircraft parts that are subject to replacement or renovation during repair, and fretting is one of the main types of defects that cause malfunctions and failures of the aircraft during operation.

2. Analysis of the results of determining the technical condition of parts during repair

According to the results of the analysis of data on the occurrence of malfunctions and failures of aircraft parts, Figures 1 and 2 show the generalized data of the percentage distribution of aircraft parts by type of operational defects [3]. The analysis is based on the results of determining the technical condition of parts during the repair of medium-range turboprop and turbojet aircraft of Antonov family and one of the modern gas turbine engines. Defects of tribological origin included such defects as working and wear of contact surfaces, reduction of tension or increase of gap in couplings, damage of working surfaces from gripping, contact-fatigue and abrasive destruction and other similar defects characteristic of different types of wear. Quantitative assessment of the percentage distribution was performed by the coefficient of damage to the design of the product:

$$K = \frac{\sum_{i=1}^{k} n_i}{N} \tag{1}$$

were, $\sum_{i=1}^{k} n_i$ is the amount of damaged parts of the product by the i-th defect,

N is the total quantity of damaged parts of the product structure.

The diagram on Figure 1 represents the percentage distribution of parts by type of operational defects for a group of aircraft, the percentage of parts which damage is associated with friction and wear is about 25% and in the total amount of defective parts. These damages are in third place after parts with such defects such as “destruction” and “corrosion”. The largest percentage, about 27%, are total quantity of defective parts of the gas turbine engine, parts with defects by friction and wear compose (Figure 2).

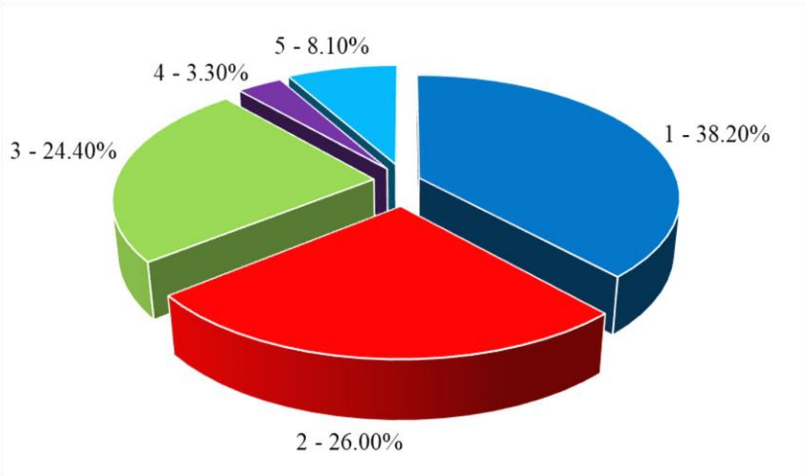

Figure 1. Diagram of the quantitative distribution of parts by type of operational defects on aircraft: 1 – cracks, destruction; 2 – corrosion; 3 – wear defects; 4 – deformation; 5 – others.

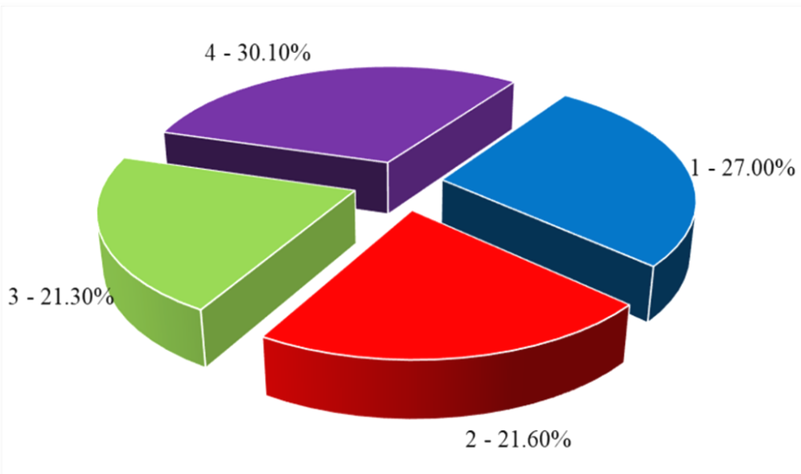

Figure 2. Diagram of quantitative distribution of parts by types of operational defects on the gas turbine engine: 1 – wear defects; 2 – mechanical hardening, dents, chips; 3 – cracks, destruction; 4 – others.

The great variety of materials combined in aviation tribosystems. Different nature and level of operating contact and volume loads, temperatures, physicochemical properties of working environments and other working conditions of units of tribomechanical systems of airplanes and aircraft engines lead to various tribological processes which are responsible for their mechanism of surface destruction, nature and intensity of wear. An analysis of the percentage distribution of defective parts based on the kinematic characteristic of their relative displacement in the mechanical couple. This analysis helps us to determine the leading type of wear, which causes the loss of efficiency of the parts of the aircraft. The analysis was performed based on the data of defects of parts of friction units of three types of planes, three types of helicopters and two types of aviation gas turbine engines. Parts were selected for analysis, on which wear or other operational damage characteristic of friction units was constantly recorded during the repair process. The results of the analysis are presented in the Table 1.

Sliding friction at relative cyclic micro displacement prevails in details for all types of aircrafts, differing in the nature of the relative motion of the types of friction. This type of friction corresponds to wear caused by fretting corrosion. In the most general case, fretting corrosion is understood as a type of wear of contact surfaces of metals under load as a result of oscillating relative displacements with small amplitude in conditions of corrosion.

Table 1. Distribution of parts of aircraft friction units by the nature of relative motion that causes wear

The nature of the relative motion of surfaces	**The proportion of damaged parts, %**			**Leading types of wear**
	Planes	**Helicopters**	**Gas turbine engines**	
Relative cyclic micro displacement	64.1	51.2	87.8	Fretting corrosion
Sliding in rotational motion	11.4	14.2	8.5	Mechanical-oxidative wear, abrasive wear, wear during gripping
Sliding in reverse rotation	10.3	21.4	2.5	
Rolling	10.3	21.4	2.5	Fatigue wear with chipping and peeling
Others	10.3	1.6	1.2	

The large number of aircraft parts damaged by fretting corrosion can be explained by the fact that this type of wear develops mainly in nominally stationary and immobile units and joints. The objective preconditions for the occurrence of micro-displacements in the tribocontact and the development of fretting corrosion create cyclic and vibration loads, which for most structural elements, systems and units of aircraft, helicopters and gas turbine engines are constant factors. In addition, fretting corrosion has a latent period of development and can be detected only after a certain, sometimes long, period of operation. The peculiarity of fretting corrosion is that the type of surface fracture not only initiates intense metals wear, but also significantly reduces their fatigue strength. As a result, the actual fatigue strength of the part is much lower than the design one, which can cause unforeseen premature failure.

3. Discussion and systematization of research results

Systematization of the results of research on the problem of struggle fretting corrosion, [5] shows that the search for effective measures to increase fretting wear resistance can be carried out in the following areas:

- design methods to prevent the relative vibrational movement of the contact surfaces, or reduce its amplitude to a safe value;
- selection of the most favorable combination of contact materials couple;
- the use of effective lubricants and lubrication methods;

- technological methods by surface hardening, modification, application of protective coatings.

The most common design methods to struggle fretting corrosion are to create a reliable stress fit for tension joints, increase the tightening force of threaded joints, it creates tight pin, key and riveted joints, the choice of rational structural schemes of parts and assemblies. The first group of methods allows increasing the friction forces in the couplings and, as a result, to reduce the relative displacements of the contact surfaces. By choosing a rational design scheme, it is possible to achieve a significant reduction in damage from fretting corrosion by optimizing the power and kinematic modes of operation of parts, continuing a reduction of contact micro-displacements and local stress concentrators.

A significant reduction in fretting corrosion damage can be achieved by choosing a rational combination of friction materials couple [6]. By choosing the right combination of materials in the fretting couple, it is also possible to significantly reduce the negative impact of fretting corrosion on fatigue strength. However, it can be stated that for metallic materials there is no such combination of materials in the contact pair, which would allow to completely avoiding fretting corrosion. In addition, at present, no universal principles have been established for the construction of fretting corrosion resistant couplings.

Analysis of works on the use of lubricants as a method of preventing wear during fretting corrosion shows that any lubricant and method of introducing it into the contact zone in the presence of relative micro-displacements does not preclude the development of wear, but can only slow its intensity. Therefore, lubrication, including the use of solid lubricants, is considered as a method of deferral, rather than as a cardinal method of combating fretting corrosion [7-8].

4. Practical realization

Technological methods provide the greatest opportunities for preventing fretting corrosion. According to the classification given in [7], this group includes various methods of treatment of contact surfaces of parts that increase hardness, corrosion resistance, prevent metal contact, reduce friction, that are methods that inhibit the development of conductive processes of frictional fracture during fretting corrosion – setting, fatigue-oxidation, corrosion-fatigue and abrasive processes. For this purpose, methods of surface plastic deformation, modification of surfaces by thermos diffusion saturation with various elements, electro spark alloying, surface treatment with concentrated energy sources, application of galvanic, gas thermal and other protective coatings were used.

Among the technologies of obtaining wear resistant protective coatings, the most universal are the methods of gas-thermal spraying. An important feature of the methods of gas thermal spraying is the ability to control the composition, structure and properties of coatings by selecting the components of the source material, technological modes of spraying, structural schemes of coating. A large number of works, including works on research of wear resistance of gas thermal coatings in the conditions of fretting corrosion [9, 10] are devoted to development of materials for gas thermal coatings, establishment of communication between their structural phase structure, technological parameters of spraying and properties.

A significant disadvantage of almost all protective coatings for tribotechnical purposes, in particular gas-thermal coatings and coatings formed by various methods involving carbide, oxide, nitride and other solid phases, is insufficient strength and wear resistance at high contact loads and unsatisfactory ability to run.

In the case of gas thermal spraying, low strength and wear resistance of coatings are caused by such factors as porosity, high hardness, fragility, low strength of adhesive-cohesive bonds in the "coating base" system. Today, additional methods of additional processing, such as melting, thermodiffusion saturation of the surface with alloying elements, thermal and thermomechanical treatment, infiltration with special suspensions and melts, etc are used to increase both surface and volume strength of gas-thermal-coated coatings.

A promising direction given the provision of high tribotechnical properties and load-bearing capacity is the creation of coatings with gradient properties and coatings of discrete structure. In the first case, the increase of tribotechnical characteristics can be achieved by reducing the resistance of the surface layers to shear stress and, accordingly, reducing the level of their frictional load, second - by creating a favorable stress-strain state of the friction-loaded surface. The latter minimizes the stress from the action on the tribosystem of external forces and friction forces. At the same time, the discreteness of the structure, due to the limitation within a single discrete area of normal stresses and stresses in the plane of the adhesive contact, provides a higher adhesive-cohesive strength of the discrete coating [11].

Recently, in the development of technologies for surface hardening of parts, the most progressive direction, which allows to increase sharply the performance properties of friction surfaces, is the development and application of multi-operational, integrated methods [12]. These methods are based on the sequential or simultaneous application to create wear-resistant surface layers of two or more technological methods. Methods of electrocontact thermomechanical hardening are the most intensively developed among the complex technologies of tribological direction. They combine laser treatment and next thermodiffusion saturation of the surface of the part with various elements. Electrospark alloying and next laser melting and thermodiffusion saturation of energy coatings. The use of combined methods makes it possible to create surface layers with different physical and mechanical properties and to increase the wear resistance of parts [11, 13-16].

Methods of increasing the wear resistance of titanium alloys and tribocouples of hot section of the engine [17-21] have special development and application for aviation tribotechnological areas.

Conclusions

Thus, the results of the analysis indicate the relevance and importance of the task of increasing the durability of parts of tribomechanical systems in solving the general problem of continuing reliability and increase of overhaul and general technical resources of aircraft. This task is especially applicable for vibration and cyclically-loaded parts of nominally fixed assemblies and joints, the durability of which is limited by insufficient wear resistance of functional surfaces in conditions of fretting corrosion processes. The complex and unpredictable nature of this type of friction contact destruction of materials and the objectively existing trend to design machines on the principle of high survivability and uniformity with a minimum safe margin of safety, puts the problem of fretting stability of structural elements in a number of priority and most important tribology tasks of aviation and general mechanical engineering.

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