THE CAUSES OF DAMAGES TO GAS TURBINES OF AVIATION TURBO-JET ENGINES

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The article provides and analysis of thermal deformations and damages to selected parts of aviation turbo-jet engines. The emphasis is laid upon damages to blades through corrosion, gas erosion, material cutting as well as cracks and fractures resulting from the operation of given types of aviation engines.

Keywords: gas turbine, thermal deformation, thermal damage, thermal erosion, thermal corrosion, material cutting, fracture of blades.

1 INTRODUCTION

The recent period has witnessed a number of gas turbine damages that occurred during the operation of MiG-29 fighters resulting in premature disassembly of their engines and a large scale repairs. The aim of the article is to analyze the damages to those gas turbines.

The gas turbine of a turbojet engine belongs to the thermally and mechanically heavily strained parts of engines. High temperatures and mechanical stresses applied to the selected parts of the turbine result in frequent damages leading to premature disassembly of such engines from the airframes earlier than required by the prescribed hours of operations justifying the overhaul.

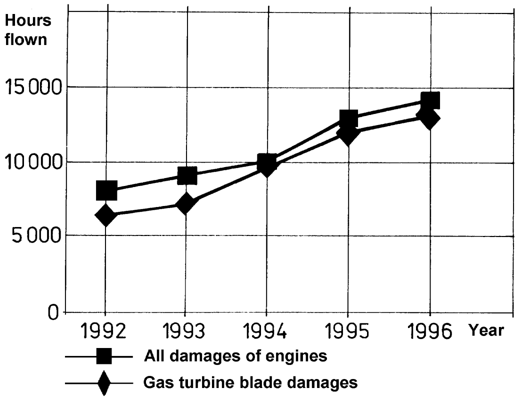

Fig.1. Comparison of average hours flown at CF6-80C2 engines disassembled owing to blade damages of gas turbine and further flaws as well

In order to asses the frequency of damages that occurred on the gas turbine, one can make use of statistical data informing on the share of damages of gas turbine on the overall number of engine failures. For example: at bypass engines, with a high bypass ration of PW 4000 (of all series) at an average number of hours flown at 11 000 hrs, two-thrids of the engines are sent to repairs ownig to gas turbine blade damages (cracks and flame cuts). At CFM 56-3 engines, 34% of them were disassembled as a result of gas turbine failure at an averge of hours flown of 10 000 hrs.

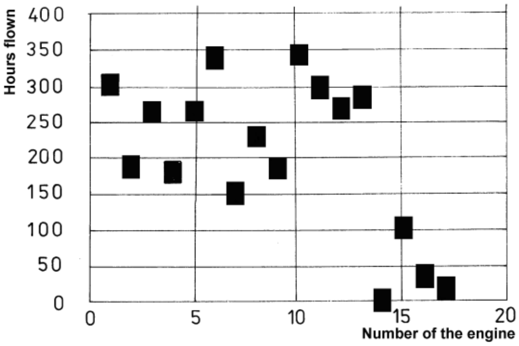

Fig. 2 Comparison of hours flown of RD-33 engines utill GT blade failures occured hours flown order of the engine

With the Slovak Air Force, on the MiG-29 fighters powered by RD-33 bypass engines, 33% as much as 42% of total engine failures have occurred due to damages of gas turbine components. The statistical data are unambiguously pointing out the importance of the finding in terms of the causes of the destructive damages to the parts of gas turbines. Identification of the causes to these failures could improve the reliability of those engines still within operational cycles.

When analyzing the processes taking place within the turbine, the following assumptions to serve as starting points of causes to gas turbine damages:

- Fuel is meeting the set requirements (its chemical composition is in compliance with the applicable norm);
- Fuel system operation is trouble free (fuel pressure, purity etc.);
- Engine operation and maintenance is performed to servicing and maintenance requirements applicable to the given type;
- Engine has not been subjected to loads over permissible limit.

Stator vanes and rotor blades of the gas turbine are to withstand high mechanical strain at high gas temperatures. Under such operational conditions, the majority of blade damages take the form of cuts on the guiding vanes and rotor blades, cracks caused by internal stresses of material, high-temperature oxidizing, corrosion and erosion of material of the turbine blades. The ability of gas turbine blades to withstand those adverse conditions is a factor limiting service-life of gast turbine and that of the turbo-jet engine as a whole, as well. Fundamental ways of extending the service life of gas turbine blades that can be taken into consideration are:

- Cooling of the stator vanes and rotor blades;
- Using high-quality (heat-resisting and heat-proof) material for manufacturing of vanes and blades;
- Surface protection of the blades by applying coating of high-temperature-resistant materials;
- Reducing losses within the system of cooling supplying cooled air to the blades and improving efficiency of their use for cooling (posing high demands on the technology of manufacturing blades or vanes);
- Providing for a constant thermal field at of the stator vanes stage;
- Providing for a high-quality engine regulation system.

All these measures have one goal in common on, i.e. protection of blades against unfavourable operating conditions and thereby extending the trouble-free operation to a maximum period of time.

The cause to the gramentation of the blade is the formation of crack, which when propagation, results in surpassing a critical value of blade strength, when it no longer can withstand the mechanical strain. The crack in itself can develop as a result of mechanical damage, overheating of the material, fatigue, ageing and design or manufacturing defect [5].

The individual forms of damages to the gas turbine blades can be demonstrated on the exampmle of defects experienced on the gas turbine of the RD-33 engine. The rotor blades of the first stage of the operate under rather adverse conditions characterized by high overall temperature of gases, high speed of airflow, large centrifugal forces (maximum rpm of the HP turbine rotor are $n_{K,max.} = 15\ 500\ min.^{-1}$) and bending stresses.

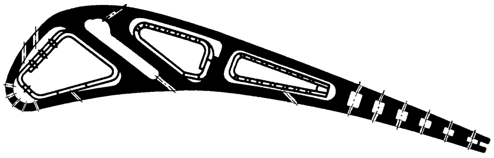

Fig. 3 – Design of the cooled guide-vane of the high pressure gas turbine (first stage) on the engine RD-33 [4]

The guide-vanes of the first stage on the gas turbine operate in the field of the maximum temperature fiel (total temperature of gases on the gas turbine input $t_{3c,max}$ achieves the value of 1263°C) [1] . The fact that affects the level and way of cooling of the guide vanes. They are intensively cooled by secondary bleed air from the combustion chamber.

The guide-vanes of the second stage of the gas turbine input are cooled by air bled from the high pressure compressor (HPC) [2].

2 GAS CORROSION

Gas corrosion, as the corrosion of metals in high temperature gases, is a kind of chemical corrosion. At this process, metal is disintegrated as a result of its chemical interaction with the ambient environment. The characteristics of the material to withstand gas corrosion is termed as heat-resisting capability. As a result, oxides of metals are generated, that is why gas corrosion is often called as oxidation at high temperatures. The first stage of oxidation is absorption of oxides on the surface of the metal. The immediate cause to the absorption are known as the van Der Waals´ forces (the source of the power is in the rotation of electrons and are present independent molecules or atoms) and powers of chemical bindings. Based on it, one distinguishes physical and chemical absorption. At this type of corrosion, the profile of the gas turbine blade leading edge is changing greatly, affecting the flow of hot gases (distribution of the heat and pressure field) within the gas turbine area. This fact can be considered as an active factor also causing reduction in the parameters of the operational cycle of the individual parts o f the gas turbine.

Fig. 4 Gas corrosion on the guiding mechanism of the high-pressure gas turbine (photo Martin Schmidt)

Fig. 4 shows the visible areas of advanced stage of corrosion, when fall out (scale off) of the corroded layer occured. The illustration also shows the proximity of the damaged area becoming apparent through visible changes in the colour, proving local loss of resistance wihtin the surface area.

3 MATERIAL CUTTING (BURN-OUT)

Appart from heat resistance, alloys, forming the basis of manufacturing gas turbine blades also dispose high level of fire-proof characteristics. When operating in an oxidizing environment, high burn-out is experience at alloying additives. The surface layer is being deprived of alloying elements thereby making it leaner for alloying element and thus more apt to develop cracks. In order to increase heat resistance, alloys based on iron, nickle, cobalt are added chromium, aluminium and silicium in amounts necessary to generate oxides of these elements. Cutting (burnout) of material as it, is weakening the body of the blade and creates favourable conditions for develeping cracks on the gas turbine blades.

Fig. 5 Material cutting (burn-out) of material on the guide-vanes in the guiding duct of the low pressure turbine of the RD-33 engine (photo Martin Schmidt)

Fig. 6 Material cutting (burn-out) on the guide vanes in the guiding duct of the low pressure gas turbine of the RD-33 engine (photo Martin Schmidt)

4 DEVELOPMENT OF CRACKS

Applying the general characteristics of heet-resisting and fire-proof characteristics of the gas turbine rotor blades and guide vanes, one can state that the heat resiting feature of the material prevents gas corrosion from developing and propagation and heat-proofness ensures the required strength of parts when under dynamic loading. Overheating of the gas turbine blades is particularly damaging to the individual parts of the gas turbine. It occurs in the field of critical temperatures. Rotor blades and guide vanes are made of stable material capable of operating for a long period under critical temperatures, i.e. within a certain range of temperatures. Going beyond the boundary temperature (even though for a shorter period) results in severe degradation of the basic material characteristics (heat resisting and heat-proofness), e.g. Material is decomposed at a certain temperature and constant loading for a period of 200 hrs. On increasing temperature by 200ºC, with loading remaining the same, the material is decomposed already after an hour, provided that the temperature goes beyond the boundary temperature.

Fig.7 Material cutting (burn-out) in the area of contact with the sectors of guiding vanes (photo Martin Schmidt)

Fig. 7 is an evidence document on cutting (burn-out) along the line connecting guide vanes sectors in the rear part resulting from crack development.

5 MECHANICAL AND THERMAL DAMAGES

Such kind of damage can be caused by wipes, impressions, dents and agnails on the gas turbine blades. They develop as a result of material expansion or thermal deformations on parts of the gas turbine either caused by losing their fire-proof or heat-resisting characteristics. These mechanical and thermal damages develop in the weakening areas of the material and are sources of concentrated stress resulting in cracks causing fractures on parts of the blades. Fig. 8 apparently reveals the destroyed rotor blades of the gas turbine resulting form thermal and mechanical damage, caused by surging of the MPM-20 experimental engine that took place in the course of the experimental measurements in the laboratory of small-size jet-engines at the Department of Aviation Engineering, Faculty of Aeronautics, Technical University Košice. The detailed picture (Fig. 9) of the destroyed rotor blade of the MPM-20 experimental engine clearly shows the thermally affected area, differing in colour and gradually transitioning into the area of cracks with the definite cutting off the part of the blade [3].

Fig. 8 Destroyed rotor blades of the gas turbine on the MPM-20 experimental jet-engine as a result of thermal and mechanical damage (photo Marián Hocko)

Fig. l0 is a recording of the remarkable callus on the surface of the HP gas turbine blade, part of the RD-33 engine with changes in the profile shape (impression in depth). The callus is located on the end part where the leading edge is transitioning into the back of the rotor blade.

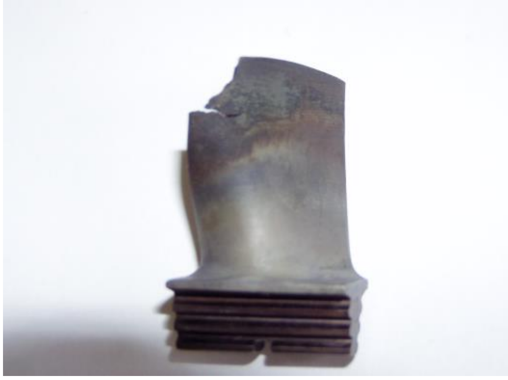

Fig. 9 Detail of the destroyed rotor blade, part of the MPM-20 experimental jet engine as a result of thermal and mechanical damage (photo Marián Hocko)

Fig. 10 Deformation on the surface of the rotor blade leading edge of the high pressure gas turbine (photo Martin Schmidt)

6 CRACKS

Changes in the composition of the surface layer are related to the fact that when alloys oxidize, alloyed by chromium and aluminium, the oxidation layer contains substantially higher amount of such elements than the alloy itself. Diffusion of the important alloying elements from the surface layer results in the reduction of mechanical strength, while increasing the concentration of vacancies thereby creating favourable conditions for the development of porousity. The most favourable areas for development of porosity are on the boundaries of grains which then, with time, develop into micro-cracks. Such micro-cracks form the basis for further development and propagation of cracks oover the individual parts of the gas turbine.

Fig. 11 Cracks on the guiding vane of the high pressure gas turbine (photo Martin Schmidt)

Fig. 11 is an evidence of cracks that have developed in the leading edge area and are propagated along the profile in the bed-side of the high pressure gas turbine guiding vane.

Fig. 12 Crack and collapse of the rotor blade on the high pressure gas turbine of the RD-33 engine (photo Martin Schmidt)

Fig.12 is an evidence of a crack at the end of a blade and also of the apparent traces of blade profile collapse in the weakened area.

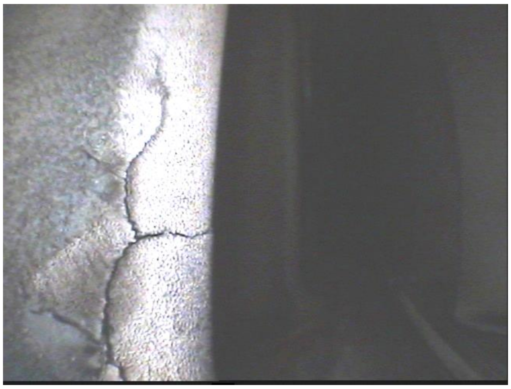

Fig. 13 Branched crack on the guide vane of the low pressure gas turbine on the RD-33 engine (photo Martin Schmidt)

Fig. 13 is a branched crack in the leading edge area of the guide vane on the low pressure gas turbine of the RD–33 engine. Probably, it is a crack in the surface layer.

7 FRAGMENTATION OF BLADES

The damages to the heat-resisting or heat-proof characteristics of materials related to the development of cracks, followed by fractures of blades or opening of the guide vanes of the gas turbine guiding duct along its height.

Fig. 14 Fractured guide vane of the low pressure gas turbine on the RD-33 engine (photo Martin Schmidt)

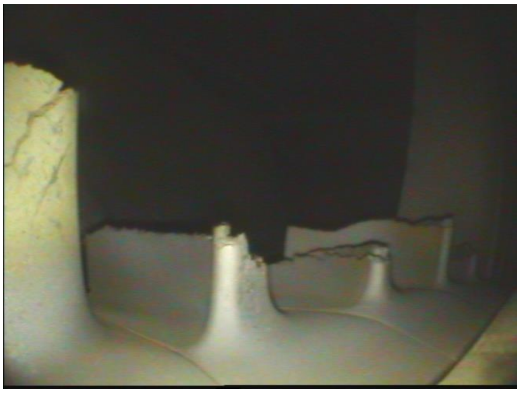

Fig. 15 Broken rotor blades of the low pressure gas turbine on the RD-33 engine (foto Martin Schmidt)

Fig. 15 is documenting five broken rotor blades located side-by-side in a row on the low pressure gas turbine of the RD-33 engine. Fractured blades were located also on other parts of the blade grid of the low pressure turbine. Viewing the picture, one cannot unambiguously determine whether it is the result of mechanical damage of running blades, as the fracture on these rotor blades could also have resulted from the loss of fire-resisting characteristics followed by the destruction. Only the next photo in Fig. 16 can unambiguously prove mechanical damages on the rotor blades of the gas turbine. Fig. 16 is an evidence of mechanical damages on the leading edge at the ends of the rotor blades on the LP gas turbine of the RD-33 engine.

Fig. 16 Mechanically damaged rotor blades on the low pressure gas turbine of the RD-33 engine (photo Martin Schmidt)

8 OPENING OF BLADES

Fig. 17 is illustrating a further case of destructive damages hollow guide vanes on the LP gas turbine of the aviation engine. It is the case when the development of cracks results damages to the material and subsequently opening up the guide vanes of the gas turbine. Quite frequently, a whole set of guide vanes of the gas turbine stage is torn open.

Fig. 17 An open guide vane of the low pressure gas turbine on the RD-33 engine (photo Martin Schmidt)

9 CONCLUSION

Based on the review of the damages suffered by the gas turbine parts, one can assume that the primary cause to the deformation of rotor blade and guide vanes of the gas turbine consists in the change of chemical- and phase -composition of the alloy resulting in the reduction of heat-resistance and fire-proof characteristics of the materials used. The primary symptom of such changes is corrosion and the change in the geometrical shape of the gas turbine blades. Secondary symptoms are attributed to the deformation of rotor and guide vanes changiong their geometry result in changes in the flow of gases in profile grids of the engine at the individual stages of the gas turbine (slowing down the flow of gases, generating whirls in the flow, locally increasing thte temperature and the like). Changes in the flow affect the pressure and temperature gradient sat the particular stages of the gas turbine. As a result, the speed of airflow at of the stages turns higher as originally assumed (calculated) and with large cyclical changes of pressure. The deterioration in the airflow also results in reduced performance, and higher consumption and higher operating temperatures as well. When performing chcecks at the individual parts of the gas turbine, it is of paramount importance to diagnoze the damages and in case of geometrical changes of the stator vanes and rotor blades of the gas turbine, from safety points of view, and increase the frequency of checks on the hot parts of the air-gas duct of aviation engines.

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