GASEOUS EROSION AND CORROSION OF TURBINES

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Abstract

The paper presents main service problems of turbomachinery users. These are gaseous erosion and corrosion of turbine elements specifically in jet aero engines.

The factors that have an influence on this phenomena initiation and development have been described. The illustrated examples show the development of turbine elements degradation caused by them. The influence of this phenomena on jet engine reliability and flying safety has been analyzed.

One of the basic jet engine health diagnostics method (during service) has been presented.

Keywords: *turbine, diagnostics, erosion and gaseous corrosion*

1. Introduction

Fatigue cracks, mechanical and thermal deflections, overheating, burning, chemical corrosion and mechanical and gaseous erosion are main causes of decreasing turbomachinery lifetime and if undetected can be a real threat for users safety.

Considering this endoscope testing has a great number of advantages. It doesn’t need tested machinery disassembling into parts. Used tools don’t interact with tested object. Moreover, obtained data gives an ability for fast damage source detection and periodic observation of developing parts degradation. This all made it one of the main Non-Destructive Testing (NDT) methods used in air transport. It is necessary both from economical and technical point of view because together with decreasing present technical state identification time the costs decreases and maintenance safety increases. [1].

Continuous visual testing (endoscope) and connected with it engine parts health analysis give an ability to make some simplifies about damages and its initiation. That’s why the main source of compressor blades damage is Foreign Object Debris (FOD). In armed aviation it can be caused by random accidents, the need of operating from temporary airfields or lack of needed cleanness around jet inlet or airfield surface. It can also be caused by badly done blade coating and following erosion damage.

A great influence on observed damages hale also working environment e.g. air dustiness, salinity or chemical contamination.

By analysis of weighted average of damages number we can observe that the number of compressor parts damage (in Polish Air Force) is not the highest part. Developing degradation of engine hot parts is 22% of all damages number and is another part (with the compressor) that should be periodically tested by endoscopic technique.

This also makes possible to early detect and correct other damage premises including badly organized combustion processes because of injectors damage. That problem can cause in existence of non-uniform and unsteady temperature field upwind to turbine. The source of this can be:

- fuel metering unit control system failure,
- wrong combustion chamber geometry design,

- fuel chemical composition change,
- fuel storage problems.

These are only a few problems that occur in hot section of jet engine. They can be also a source of others (more dangerous) which are many cases of gaseous corrosion and erosion.

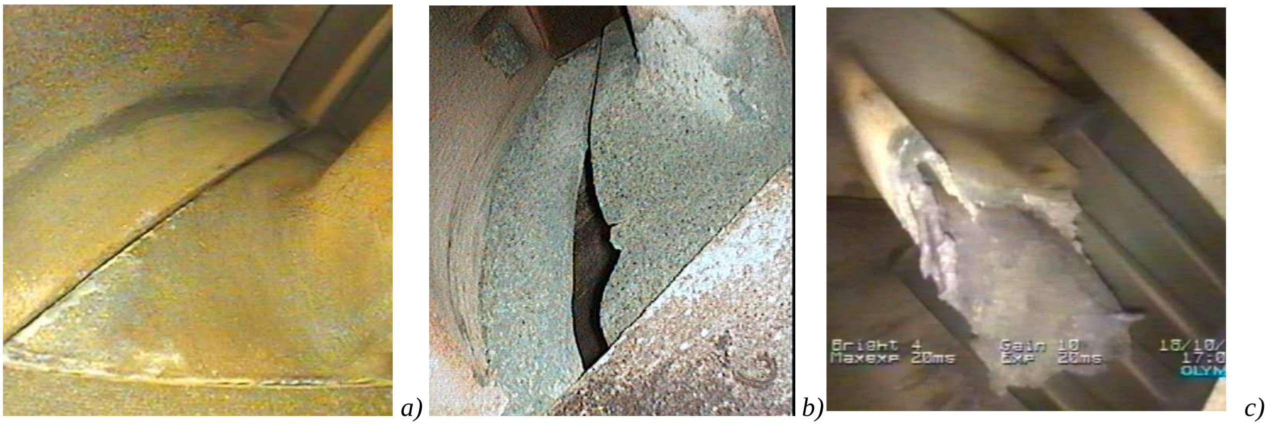
That’s why the diagnostics engineer must have a wide knowledge not only about engine structure and design but also about processes that take place in hot parts of an engine (combustion, flow, structural and manufacturing technology).

2. Jet engine turbine parts destruction

In most cases damage dimensions that can be passed (for service) are included in technical user’s manual of an engine. But during long service some other damages that are not a key factor for safety decrease (and are not included in tech. manual) are observed. Then the knowledge about effects carried by phenomena that take place in engines, is a key to prognose the exact part lifetime and service conditions limitations. As an example we can see what happened with turbines on Fig.1.

The source of this was badly organized combustion which caused local, short duration combustion area (flame) downwind shift (up to turbine blades). It caused a situation in which during start-up procedure fuel-air mixture combustion could occur at turbine stator vane area and increase temperature there rapidly.

This process periodic disturbances are illustrated by noticed changes of surface state. It should be mentioned that combustion chamber section structure corresponds with these disturbances. That’s because the axes of injectors are directed to turbine inlet stator vane hub. It occurred by burning insulation coating and then by developing blade material loss (fig. 1c). The stator blades internal cooling didn’t slow this process down.



a) *b)* *c)*

Fig. 1. The part of jet engine HP turbine stator vane [7]
Gaseous corrosion. a) ÷ c) corrosion and erosion material „washing out” form two of stator blades hub

Moreover, the signs of gaseous corrosion show that the whole process is a long lasting one and started when the engine got into service (fig 1b). It was accelerated by existence of some parts of W, Mo, Co and some sulfur compounds in the fuel. Corresponding to military norm for JET A-1 (or F-35) fuel the sulfur compounds fraction is up to 0.3 % by volume. It can cause that carbon-dioxide fraction in combustion products (exhaust emission) can get about 0.014% by volume [3]. So, the higher sulfur fraction in the fuel the higher SO_2 and SO_3 fraction in the exhaust emission – the threat of turbine damage increases.

However, we can say that produced fuels correspond with norms in a range of tolerance. The same think we can say about engines. We can say that this situation is somehow a closed circle.

Engine manufacturers are supported on fuel norm and design engine corresponding to them. They have to make a choice between structure complexity and engine production, overhaul and service costs. This is based on their knowledge and experience. The fuel producers are not going to make the norms tougher because there is no need from the engine user. They all forget that all of this causes our environment.

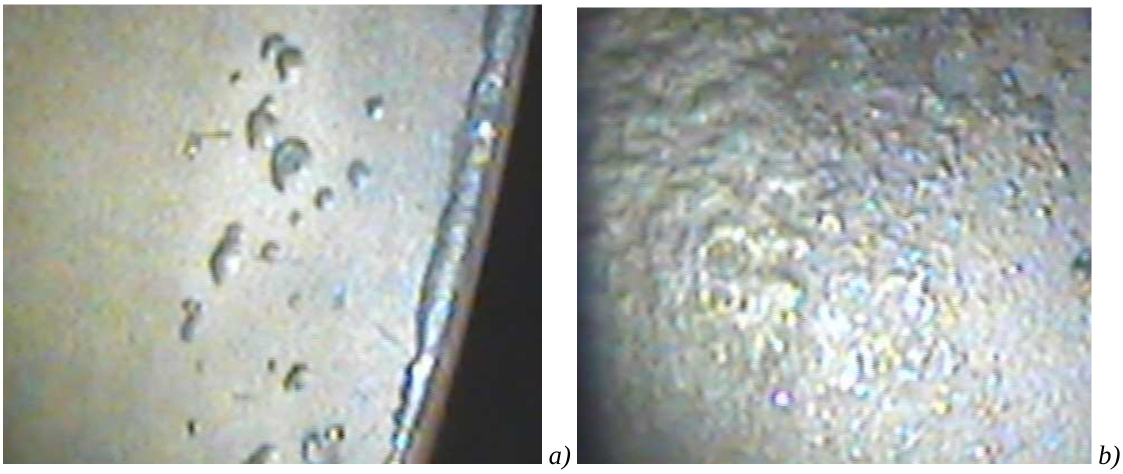


Fig. 2. The view of pressure side of turbine rotor blade of a jet engine used in high salinity environment [7] Two following stages of a) ÷ b)oxidation and sulph idation.

The lack of coating surfaces making precision during production and especially overhaul can cause a case illustrated in Fig. 2. It is certified by their placement (blade pressure side and leading edge LE). Also working environment that is a high salinity one (low level flights over sea) had an influence on this. On the upper example [4] we can observe early stage of oxidation (fig. 2a) characterized by small area of changes and increasing oxidants bubbles (low roughness change). In fig. 2b we see developing phenomena of oxidants bubble rise and their area development (high roughness changes). The chromium depletiation from lower alloy surfaces had started.

One of delay methods of his process is engine clearing but its frequency should be determiated during endoscopic testing.

Describing turbine alloys corrosion development we should divide this process into parts They would be: metal-oxidants, oxidants-atmosphere chemical reactions and reagents diffusion through products layer. At first we should find out if we deal with strong (as in Fig. 2) or with porous (like in Fig. 3) oxidants layer. In the first case the oxidants layer is a protection and the corrosion speed is dependent from reagents diffusion in oxidants layer (speed is inversely proportional to its thickness).

Together with corrosion development on chromium-nickel-steel alloy surface the characteristic products layer is growing. On its border appears an eutectic mixture layer Ni_3S_2 – Ni, over this appear additions like Cr, Al, Ti, W, Mo and below this we can observe sulfurs [5]. The composition of sulfurs in nickel alloys with increased strength for corrosion is different than in alloys which corrode with high speed. In the second one we observe such corrosion products like $(Cr, Ti)_3S_4$, CrS, $(Cr, Ni, Ti)_3S_4$, $(Cr, Ni)_3S_4$, $(Cr, Al, Mo)_3S_4$ and Ni_3S_2. The first three are more stable than another. So, in order to obtain high intensity growing of corrosion products (including sulfurs Ni_2S, Ni_3S_2,$(Cr, Al, Mo)_3S_4$) the sulfur activity in working environment should be increased [5].

When we start-up and cut-down turbomachinery for many times we can get products of incomplete combustion that form soot in some engine parts (combustion chambes sections, turbine blades, injectors). Because of this we observe exact part material “washing out” as a cause of high temperature corrosion.

Despite morfologic signs of corrosion we can observe in such layer oxidants (in external layer) and sulfurs (by the pure alloy). When the time is passing by we observe mixing of them in both of these layers. This is how we explain an eutectic mixture Ni_3S_2 – Ni appearance on corrosion layer and pure alloy border. When it develops fast the upper explanation is also good enough for oxidants NiO and $NiMo_4$ existence. They are also “washed out” by sulfur exhaust Ni_3S_2.

Fig. 3. A part of HP turbine blade of turboprop [7].
a) Sulfur-oxidant corrosion source at LE;
b) Corrosion cracks and lack of material made by LE „washing out”

The other form of tested damage is intercrystalline corrosion which changes alloys chemical composition at crystal borders. It appears in salted working environment with temperature higher than 1050 K on Ni, Co, Fe matrix alloys. More Cr in alloy decreases this trend. When machinery service in different temperatures and periodic exceeds its temperature limit (chromium composition decrease in overheated area) increases the ability of this phenomenon appearance. It can lead to coating products spalling by hot exhaust flow (Fig. 2 and 3).

These changes should be followed by new blades production technology and material development (multiple layer coating, ceramic coating). But it only can slow the whole process down. As an example we can see the turbine destruction process (Fig. 4).

In figure 4 (a ÷ b) coating damage on blades LE – its area increases (by the blades hight) together with turbomachinery service time (fig. 4b). The lack of not only coating but also insulating layer can be observed after another 25 service hours (fig. 4c). We know that summarized service time for this engine is not higher than 80 hours. Described damage was observed for 80% of blades in this turbine rotor vane. It could be caused by turbine cooling system malfunction.

The mentioned engine is still in service because our experience shows that before destruction we will first see cracks in pure alloy of a blade (fig. 4e) – this is dangerous for fighter jet service.

It is still not known at which phase the engine should be taken out of service.

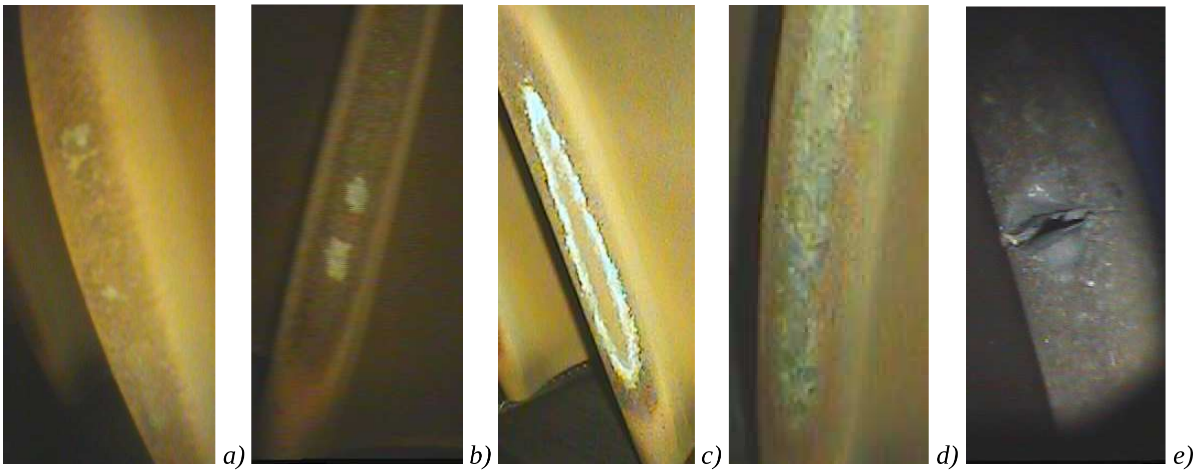


Fig. 4. A view from LE of HP turbine rotor blade of jet engine [7]. Following stages a) ÷ e) of damage

3. Diagnosing

There are many algorithms that determinate NDT frequency [3] but most of them were designed for stationary turbomachinery or air transport jet engines – the machinery with known fatigue cycle number. It’s more difficult for military jets where the load on engine parts is dependent from mission type, its duration and pilots habituations.

It’s very important to equip engine in start-up number and flight duration acquisition unit. All limitations passes (including g-force) should also be registered. Basing on them it is possible to find an endoscope testing frequency. All previous flights parameters (that are available) are also considered.

In a computer engine health monitoring systems (used in Polish Air Force) the subjective way of diagnosing is used. Data analysis and the knowledge of persons who make it determinates an effect. This is because the mentioned systems don’t have automated symptoms identification and analysis applications. They only illustrate needed parameters. The analysis is made by technicians and its effects are based on their knowledge and experience. It is very important in case of a few over-limits existence. So, basing only on flight recorders data it is very hard to identify the time period to the next testing.

The knowledge of engine structure is also a key for a good visual testing. Not only the ability of measurement system usage but also the analysis of noticed pictures is needed.

That’s why the safe horizon of turbomachinery health monitoring (basing on endoscopic visual inspection) is based on: mentioned knowledge and experience, statistic each type of machinery damage data and acceptable level of critical damage existence level [6].

4. Conclusions

So, every not defined by manufacturer turbomachinery damage case should by analyzed separately, including known and common cases experience and basic knowledge about effects of such damage on other parts of an object.

There is of course the ability of some analysis data obiectivity but it needs some procedures of automated or half-automated large sort of damage data processing. It also needs development of knowledge about material fatigue properties, and correlation between damage propagation with data obtained during structural experiments.

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