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DAMAGES TO TURBINE ENGINE COMPONENTS

Summary. This article defines the typical damage to components of turbine engines, highlighting the differences between them and indicating possible causes. The distinction between various types of defects helps to explain the occurrence and supports personnel in defining the most suitable maintenance action to be performed. The defects described below are common in high-airflow turbine aviation engines on commercial and cargo aircrafts.

Keywords: turbine engine damage, condition deterioration dent, nick

1. INTRODUCTION

Non-destructive inspection methods are nowadays widely implemented in gas turbine engine diagnostics. They contribute to safe engine operation throughout the service life to guarantee a constant level or predictable trend of parameters, including thrust or power and fuel consumption. In the early days, aviation equipment used to be in service for a specified period of time. Since then, certain related components have been withdrawn from use. The lifetime and overhaul programme was scheduled by the manufacturer, which mean that components were withdrawn, regardless of their condition or serviceability; indeed, above 50% of such components were withdrawn over time. Such policy is hardly acceptable in the context of modern economics. Since the 1960s, the way in which aviation equipment is used and handled has changed, such that the priority is on maintaining its serviceable condition. Diagnostics have developed simultaneously. “Live processing” on-wing data remains the main area of interest in diagnostics; however this will not replace scheduled maintenance

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inspections. Manufacturers are spending significant amounts on aviation materials, which means that those in involved in aviation maintenance require knowledge and experience of materials' characteristics, processes, deterioration symptoms etc. Such knowledge will allow them to diagnose adverse processes once they begin, in order to remove the affected equipment from service and carry out the appropriate actions.

One of interesting non-invasive diagnostic method is presented in [2, 3, 5, 6, 9].

The most common inspection methods are:

- X-ray
- ultrasonic
- eddy current
- magnetic particle
- liquid penetrant
- borescope inspection

X-rays enable the detection of discontinuities within a material, which cannot be seen by the human eye, such as cracks, inclusions or foreign objects. Cracks, loss of integrity and other discontinuity symptoms may be discovered by the ultrasonic method, which is used to examine welds. Eddy current inspection of different frequencies is employed to find surface and subsurface imperfections, material thickness, porosity etc. Surface and subsurface inclusions of ferromagnetic materials may also be discovered with magnetic particles. Surface cracks of all materials may be found by a liquid penetrant.

A major disadvantage of the methods listed above is that they require disassembly to be applied to a hidden component. This increases workload and costs, while it is practically impossible to inspect hundreds or thousands of engine components on a frequent basis. Therefore, apart from sophisticated diagnostics, visual inspection remains the foundation of condition confirmation. To improve human abilities in inspecting internal engine parts, various borescope inspection methods are used. These enable inspection without engine disassembly or removal. To view the inside of an engine, it is necessary to remove no more than the access port plug, which can be reached when the access panel is removed or the door opened. Due to the vulnerable design of fibrescopes, particularly their tip, the temperature of the inspected elements must be below approximately 90°C. The diameter of a borescope used for gas turbine engine diagnostics is typically between 4 and 7mm.

Borescope inspection equipment is expensive. High-quality equipment costs in the region of 25,000-60,000 euros, depending on the equipment's capability and additional functions, such as taking pictures, recording, adjustable focus, or measurement methods. The cost of a flexible light cable can represent 90% of the total cost of the fibrescope; therefore, it is important to pay attention to the avoidance of overheating, overvoltage, bending, excessive friction or force. This will result in breaking fibres, which will affect visibility due to the presence of black dots or poor angulation.

2. FACTORS INFLUENCING ENGINE COMPONENTS' CONDITION DETERIORATION

General and detailed inspections of turbine engine components are performed at all maintenance levels: line, base and depot. Inspections refer to both tracked and non-tracked engine elements. Engine elements are inspected with different frequencies and scopes. Some inspections are performed every day, while others are carried out every few years. However, some checks are determined according to specific calendar days and usually refer to aircraft systems other than propulsion. Lubrication of landing gear may be an example. There are very few scheduled engine inspections on an ongoing because the condition of most engine components is related to engine flight times or cycles. A scheduled inspection may be, for example, related to the engine parts.

The condition of the engine parts is dependent on the following factors:

- area of operation
- influence of foreign objects
- temperature conditions
- correct fixture of parts
- load distribution
- lubrication
- proper maintenance and storage
- contamination avoidance
- maintenance performed

The phenomena described in this article may all be revealed by visual inspection - general or detailed - but it is more important and more difficult to discover a root cause of the symptom being observed. The terms explained below help to precisely define and describe any finding during an inspection. This will make it easy to distinguish one deterioration symptom from another, which in turn will allow for planning the appropriate repair approach, as well as reveal the root cause of phenomenon.

Fig. 1. Evidence of a bird strike

3. TYPES OF DAMAGE

The types of damage are defined below in alphabetical order.

Arcing is caused by the inaccurate electrical discharge between an electrode and the part in question due to inadequate contact. A igniter input terminal well would be a typical example here. Such a condition is unacceptable, since it may result in an uncontained discharge.

An *arc burn* resembles several small circles located on the surface, which are caused by heat influence. Such a phenomenon may appear on blades, even at their leading edges, rendering them unserviceable.

Battering is evidenced by minor surface indentations and the result of constant hitting by minor objects.

An object is *bent* when the angular distortion from the original contour occurs. This damage is typical on leading and trailing edges of engine blades and caused by a lateral force. Such damage poses more danger to airfoil strength values than aerodynamics and, as such, bents are sometimes considered as dents by some manuals. In this scenario, it is to be measured in a lateral not an axial direction. A typical bend often appears on trailing edges as a result of foreign object impact. A large-scale bent in various dimensions is called *buckling*, which is caused by a foreign object or mechanical or thermal overload. An example of a trailing edge bend, which is to be investigated as a dent, is illustrated below.

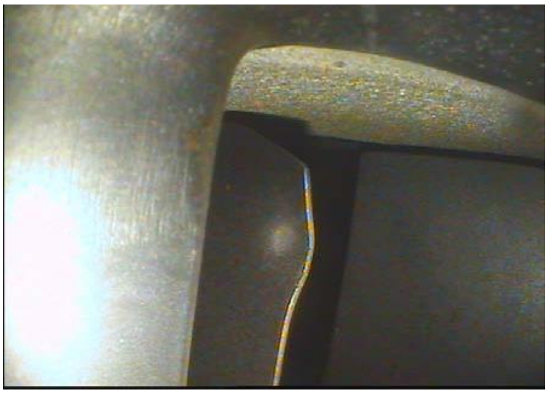

Fig. 2. Low-pressure compressor’s trailing edge blade bend

Binding refers to two adjoining components that rub against each other, which may result in tightening or a seizure. The reason for this condition may be a decrease in separation due to temperature changes and/or the different thermal capacity of materials or a foreign object between affected areas. The rotor seizure is an example here. Such a condition may occur if the engine is shut down and requires a cooling period, which has not been observed.

Blistering occurs as a result of improper bonding between a base material and painted or plated surfaces, which appears when the surface coating is raised from the base material. This condition is aggravated by heat, moisture and a contaminated environment.

Bowed refers to the impairment of the original shape, either by impact or by influence extended over time. Contrary to bent damage, bowing involves a larger curved radius and is caused, for example, by heat rather than a lateral impact.

Brinelling refers to damage that is typical for bearing races and is the result of a shock load carried by the bearing, which exceeds material hardness. Brinelling most often appears during an extended non-operation period of an engine. The load will cause unacceptable roller or ball distortion. Bearings that are not loaded evenly will show a brinelling tendency. This condition may also be caused by inadequate manufacturing and/or assembly. Brinelling results in a groove of the same size as the balls or rollers of the bearing, while indentation is still metallic on the bottom.

False brinelling is a sort of fretting corrosion rather than a brinelling indentation, which looks like straight traces across the roller or ball, which are caused by a smaller but frequent load. Contrary to true brinelling, this is acceptable, since it neither causes distortion nor deteriorates roller or ball values.

Brinelling and false brinelling may be discovered by careful visual inspection. False brinelling occurs when an engine is not operated, but transported over long distances.

An element is defined as *broken* when it has been split into several pieces, which is most likely caused by an acting force and fatigue.

A *bulge* is a mild distortion or displacement of the material without separation due to excessive pressure and/or thermal influence. Wheel tyre swelling is an example of a bulge.

A *burn* refers to structural damage due to heat influence with no or improper protection, lubrication, clearance and shielding, or uneven temperature spread. It is accompanied by discoloration and, if not corrected, breaks the flow of material, which means the total loss of characteristics.

Fig. 3. Chromel-alumel thermocouple junction burnt

Burnishing is a smooth flattening of a surface, with no wear to the material in depth. Therefore, it appears between surfaces of restrained contact. This condition is acceptable, provided it does not result in pile-up.

A *burr* is observed when the material is displaced, but not removed, which breaks the material flow, causing a sharp edge. This condition may result from peening, improper machining or foreign object impact.

Carboning refers to layers of carbon stocked on a material. Fuel nozzles are the parts of the engine where such a phenomenon most often occurs. This is the by-product of a combustion process, which is not often perfect. The area of accumulation is the result of fuel atomization, mixture swirling and low axial flow. Carboning of fuel nozzles is not a cause for rejection, provided it is not excessive. Excessive carboning will affect fuel spaying, which will further result in an uneven fuel/air mixture and stream temperature.

Fig. 4. Minor carboning on the fuel nozzle

Chafing is typical description for the abrasion of two adjacent components, if at least one of them moves in a limited area against the other. This effect is often discovered between two tubes or pipes if they are not sufficiently separated from each other.

Fig. 5. Chafing between two adjacent cables due to insufficient separation

Chipping refers to the breaking away of small pieces under mechanical force, which is quite often an acceptable condition. This will result in local stress concentration due to material discontinuity. Contrary to flaking, chipping has a significant depth.

Fig. 6. Chunks of surface coating at the trailing edge of a high-pressure turbine blade

Crazing is a net-shaped surface effect, which usually does not pose a danger, provided that it is not accompanied by a base material crack.

Corrosion is the result of a chemical reaction on the base material, which is inhibited by a salty, humid and contaminated environment. Corrosion sharply affects mechanical strength and causes surface porosity, although corrosion is not always visible on the external surface. If subsurface corrosion exists, blistering of the surface coating and/or minor roughness may occur. Corrosion can also be caused by constant tensile stress when applied to aluminium alloys, high-strength alloys and some stainless steels. Corrosion appears also when stress is applied and affects the base material through minor cracks. This is usually caused by inadequate surface finishing. Galvanic corrosion appears when there are current flows between two materials of different potential. If corrosion remains unrepaired, it will develop into exfoliation.

Crack is a minor fracture, which appears due to excessive abrupt load initiated at the weakest point of the structure, i.e., nick or gauge. If the crack occurs on the surface, it may be prevented from expanding by drilling. It is important to have a smooth surface in order to avoid stresses. The blending of a damaged blade is an example of such a rectifying method. It restores smoothness to the affected area and prevents further failure.

A *curled* object is evidenced by the folding of a rotating part against its case. This is quite often observed when an axial compressor or turbine blades rub against the outer case. This effect is unacceptable. During visual inspection, it is important to check whether the upper half of the rotor stage is in contact in the case of static conditions.

A *dent* is a round-bottomed, smooth and shallow cavity, which results from impact or prolonged constant overload. Material is displaced, but not removed.

Fig. 7. Dents on a compressor blade’s leading edge

Distortion is an unexpected change in the basic contour, which is generally the result of impact, thermal or mechanical influence or stresses applied to an object.

Erosion is a reaction on material, which causes it to slowly wear away when exposed to high temperature, fumes, acids, greases, oils and other active chemical compounds. The higher the temperature, the faster the reaction. A gas generator module is most affected by this erosion phenomenon, particularly combustion chambers and high-pressure turbines. Erosion is also aggravated by massive stream flows and turbulence.

Fatigue failure is caused by one of the following factors: material inclusions, sharp edges, nicks, gauges, minor crack or tear, local and/or repeated force. An excessive force crack is initiated in or near the place of the highest stress concentration, very often at or near the surface. Fatigue failure occurs due to repetitive or constant load, while failure will start at the weakest point, then propagate inside the material. The reason for fatigue cracking is, firstly, the rubbing of the grains of the material under stress, followed by mutual battering. Battered and splashed grains set a “flat” surface, which initiates the crack. Fatigue failure caused by excessive force will occur when nuts or bolts are over-torqued. This is quite common during aircraft maintenance; as such, torque application procedures, which are described in the general maintenance chapter, must be observed.

Flaking is the disintegration of paint or other external surface due to poor bonding or excessive load. An example of this deterioration is a when the coating flakes on high-pressure turbine vanes and blades. Due to high-temperature exposure, those airfoils are covered by bonding and ceramic coatings, which significantly increase the operational level of the blade by more than 100°. A bonding layer is an alloy of nickel, cobalt, chromium, aluminium and yttrium, while ceramic coating is a zirconia-stabilized yttrium oxide. The bonding layer produces oxide when exposed to high temperature and is porous enough to accommodate the outer zirconia layer, which decreases thermal shock on the airfoil. Given the design of high-pressure compressor vanes and blades, the flaking of protective layers affects engines’ long-term condition.

Fig. 8. Coating missing from the high-pressure turbine blade’s concave side due to flaking

Foreign object is a common phrase that refers to the situation when there is an element present, which is not an engine part. The object may loosen freely in the respective area or be fixed to or stuck in some way. “FOD” is an abbreviation for foreign object damage, while “DOD” means domestic object damage.

Flowing refers to the spreading of a plated or painted surface, which is usually accompanied by blistering and caused by excessive thermal influence and/or inadequate bonding.

A *fracture* occurs when material falls apart into two or more large-sized pieces. This is caused by an extreme force or coincidence of less significant stresses.

Fretting is a kind of corrosion, which results from the intensive rubbing of adjoining surfaces under a significant load, which results in high-frequency vibration. Due to the friction of the surfaces, minor particles separate from the materials, but remain between surfaces during operation mode because of tight clearance, causing additional friction and pitting. These particles will also cause the hardening of adjoining surfaces, which may result in stress cracks over the long term. Fretting, which is aggravated by a humid environment, is typical for blade platforms and mid-span shrouds. Fretting of aluminium or magnesium will be visible as a black colour, and as a brown colour on steel components.

Fretting corrosion is acceptable only on non-functional areas.

Galling is a type of damage that occurs when two adjoining materials protrude each other, resulting in degradation to both surfaces. This happens under high pressure and relative movement with chafing.

Glazing is a slight friction between two elements, caused by inadequate lubrication and under load, which is typical for ball bearings and resembles a circumferential groove with a well-rounded bottom. Glazing affects machined surfaces on bearing races and, as such, is unacceptable.

A *gouge* is a deep and sharp indentation usually caused by improper handling or sharp foreign object impact. Material is displaced from the surface, but not removed. The gouge breaks the material flow. With significant length, it is called a score.

A *groove* is round-bottom indentation, resulting from the periodic wear of two parts in mutual motion. The reason may be misalignment or a foreign object trapped in-between.

Guttering is an extensive erosion, which takes place over a long time, starting with a crack, tear or nick exposed to a high temperature stream.

Inclusions are defined as foreign particles or impurities inside the material. These are usually flaws, which occur during the manufacturing process. Inclusion may be localized by magnetic inspection.

A *nick* is a groove-like bottom indentation on the surface or edge. Contrary to a dent, it breaks the material flow and concentrates stress. A nick bottom may be followed by the crack. While nicks are inflicted by a sharp tool or other subject impact, they are most often caused by a small, but sharp, foreign object. FOD or sand nicks are typical types of damage to leading edges of compressor blades.

Peeling occurs when the surface finish has broken away.

Pick-up is an overlaying of material with no depression of the material at the point of removal. Material from one surface adheres to another surface. This is caused by the tight rubbing of adjacent surfaces or an excessive axial load on threads. It will occur when the thread connection is arranged inadequately or is not lubricated.

Pile-up is an overlaying of material, which, contrary to pick-up, occurs when material displaced from the point of removal leaves a depression.

Pitting is caused by irregular chipping or foreign object influence or may result from corrosion. This occurs in response to a chemical environment, i.e., exhaust gases, causing oxidation to the material and forming irregular cavities. A lack of or poor protective coating will be an inhibiting factor. Mechanical chipping is caused by overloading and/or inclusion removal in operation mode. The other reason for pitting may be electrical discharge.

Rupture refers to damage to a surface, which occurs due to pressure breaking through or force from inside.

Scoring is the effect of abrasion, resulting in multiple scratches, when a minor foreign particle is trapped between two moving surfaces of significant size, causing dragged indentations and base material removal. Sharp edges in relative motion may also cause such a phenomenon.

A *scratch* is a very shallow elongated indentation with a sharp bottom on the surface caused by a sharp minor object (e.g., sand) or improper handling. Contrary to a crack or groove, it has no significant depth.

A *shear* is discovered when two adjacent surfaces move in opposite directions.

Skidding is caused by excessive slipping between two adjacent elements, causing wear or a frosted surface. The reason for this is poor lubrication and intermittent load. This kind of damage is typical to silver-coloured ball and roller bearings.

Spalling is the excessive chipping of covered surface, which results from the regular chipping of a covering layer over a long period of time. Area and depth are more affected by the chipping, which is most often caused by fatigue crack or another progressive surface irregularity. Spalling may originate from base material inclusion or any similar defect. Ball bearing spalling is caused by uneven load on the contact surface, surface flaw or crack.

A *tear* occurs when forces act on a part in perpendicular dimension. Contrary to a crack or nick, a tear is not enclosed in one plane and observed when material is pulled apart. Most often, it is caused by the impact of a significant, tough and sharp foreign object.

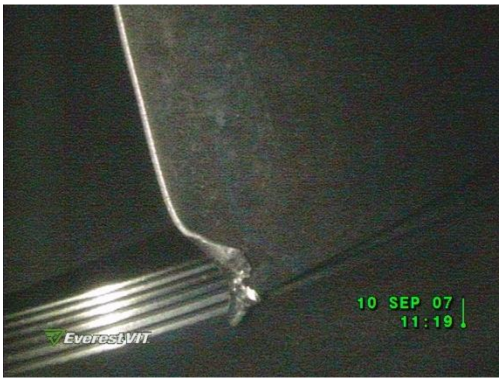

Fig. 9. High-pressure compressor with a leading edge tear

4. CONCLUSIONS

Most of the above descriptions refer to engine blades and vanes, given that these are the most vulnerable components of a turbine engine. The reasons behind these types of damage are specific working conditions: temperatures up to 1,600°C, up to 18,000 RPM and huge aerodynamic influence, as fully ducted turbine engines use up to 1,500 kg/s of air to produce thrust. Furthermore, their condition is influenced by gas stream contamination and different atmospheric conditions. This means that all the elements of the duct should be frequently and carefully inspected, since failure of those elements may result in engine failure or increased overhaul costs due to unscheduled engine removal.

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