

Scientific literature reviews; investigating analysis of turbine blade operational failure

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Abstract

As a source of energy in industry and power plants, turbines must have reliability in operation. One that affects the performance of the turmin is the condition of the blades. The multi-cycle fatigue experienced by the blades of compressors and turbines caused by dynamic stresses caused by the vibration and resonance of the blades in the engine operating time is a common type of failure. Over the past five decades, researchers have studied and investigated turbine blade failure. The main purpose of this article is to provide a brief overview of recent studies on turbine blade failure. The author only focuses on describing some of the failure methodologies used in various studies to investigate turbine blades. This article discusses each of these factors in more detail.

Keywords:

Corrosion failure, corrosion fatigue, fracture, fatigue fretting failure, turbine blade.

1 Introduction

The importance of studying the reliability and efficiency of large steam turbines has grown significantly as the generating capacity and pressure of individual power units has increased. The increased size of the turbine, as well as design changes (such as larger rotors, longer discs, and blades), resulted in increased stress and vibration, forcing designers to use more durable materials [1]. The turbine blades inside a gas/steam turbine are subjected to harsh conditions. They work in high-temperature, high-pressure, and potentially high-vibration environments. This factor can cause the blades to fail, causing the engine to suffer damage [2]. As a result, turbine blades are meticulously designed to withstand such extreme conditions. Compressor and turbine blades, as well as turbine blades, are the most frequently rejected components. Various factors, in general, contribute to the failure of turbine blades. Corrosion failure, fatigue abrasion, and fatigue creep, on the other hand, have a significant impact on the blade's service life. Furthermore, this article combines different points of view on various causes of turbine failure [3].

According to [4], the blades on the surface of the turbine blades are completely degraded due to overheating. Corrosion pits are formed on the surface of the blade, these holes act as notches to generate stress concentration and restart due to fatigue which further spreads due to hot corrosion. For Al-Pt coating it is completely degraded, highly oxidized. From these investigations, it was concluded that gas turbine blade failures occur due to the combined effects of surface degradation. Thorough failure investigation is essential for effective engine management

maintaining air [5, 6]. In this paper will present some reviews regarding the failure of the turbine blades as well as the investigative methods used by previous researchers.

2 Method

In this paper, we will describe a literature review and elaborate on the results of research from 45 papers from indexed journals that analyze the failure of various turbine blades. This paper will examine the failure of turbine blades caused by corrosion failure, component failure, fretting-fatigue and fatigue failure. This paper provides an overview for further researchers and industry to determine technical steps in improving the performance and reliability of turbine blades and as the basis for our next paper. This paper will also present a comparison of the methods used by previous researchers and with the aim of obtaining a method that is more accurate, detailed and makes it easy for researchers to investigate turbine blade failures.

3 Result and Discussion

This section discusses various factors contributing to turbine failures. Many researchers who participated in this survey have contributed to various studies of turbine blades.

3.1 Corrosion Failure

Metals corrode when they wear out, dissolve, or oxidize as a result of chemical reactions, particularly oxidation. This occurs when a gas or liquid chemically interacts with an open surface, most often metal. Corrosion speeds up when exposed to high temperatures, acids, and salts. Because of the unacceptable failure rate of most blades and discs, several projects have been launched to investigate the root cause of the problem [7]. Metals corrode when they wear out, dissolve, or oxidize as a result of chemical reactions, particularly oxidation. This occurs when a gas or liquid chemically interacts with an open surface, typically metal. High temperatures, acids, and salts hasten corrosion. Because of the unacceptable failure rate of most blades and disks, several projects were launched to investigate the root cause of the problem [8].

Low-pressure steam turbine blades, as shown in Fig. 1, are more prone to failure than medium and high-pressure steam turbine blades. Corrosion Fatigue (CF), Stress Corrosion Cracking (SCC), pitting corrosion, and erosive corrosion are the most common mechanisms of failure of low-pressure blades in steam turbines [9]. Hata et al [10] came to the conclusion that corrosion fatigue is the primary mechanism of low-pressure steam turbine damage and that any fatigue cracking should be regarded as corrosion fatigue. Corrosion-chemical enrichment is thought to be closely related to corrosion-fatigue damage to the blade in wet/dry transition zones and aggressive environments. Many researchers have confirmed that corrosion-fatigue cracks frequently form from holes in intercrystalline cracks and progress as flat fatigue cracks with coastal markings and strokes, as revealed by fractography [11].

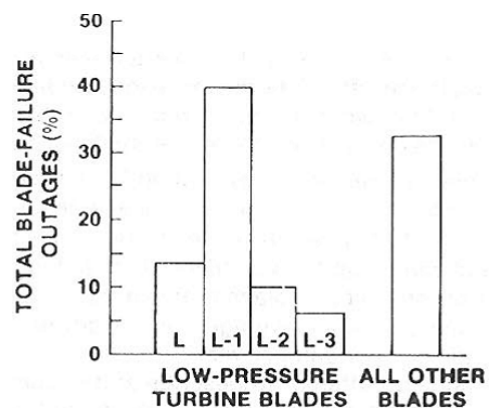


Fig. 1. Distribution of blade failures in fossil turbines in the USA [11].

Zhang et al. [6] investigated the causes of low-pressure stage blade base destruction in steam turbines. The crack is propagated by a combined corrosion-fatigue process, according to metallurgical studies. The analysis revealed that the metallurgical cause of the blade shank's destruction is corrosion fatigue in the zone of highest stress concentration caused by a mismatch and installation error between the blade shank platform and the rotor mounting shaft. Vibrations in the vicinity of the first mode of vibration also propagate the crack. Chipchin presented an analysis of the failures of blades made of 12 percent martensitic chromium stainless steel in the thermoelectric turbofan center's medium pressure stage. According to the data, at least one of the medium pressure stage's blades failed due to a corrosion-fatigue mechanism, the cause of which is associated with the presence of corrosion holes on its suction side. High-pressure blades have a lower hardness than standard blades, as well as holes and corrosion cracks [12].

According to [13] structural analysis (XRD) corrosion products on the blade shows that the most significant amount of deposit is formed from NiO and Cr₂O₃ as shown in Fig. 2.

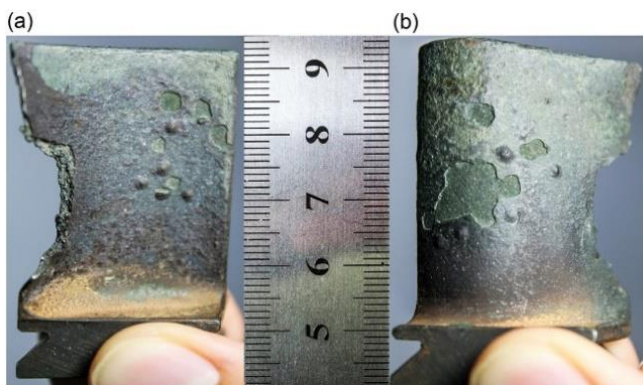


Fig. 2. First-stage-nozzle blade of gas turbine a) pressure surface, b) suction surface [13].

Determine the root cause of the low-pressure turbine blade (low pressure) failure, i.e. whether it is due to material issues or changes in operating parameters caused by network frequency, boiler water chemical composition, and so on [14]. Several holes/grooves were discovered on the blade's edge, and chloride was detected in these holes. Crevice corrosion is caused by this. Cl carriers that can be found on blades the destruction is intercrystalline, and it is caused by corrosion fatigue. Gould et al [15] investigated the causes and processes of cracking in the working blades of the fourth stage of low-pressure turbines in 500 MW steam turbines. The presence of corrosion holes on the blade's leading edge was revealed by the microstructure, and the EMF analysis revealed oxide scale as a corrosive medium inside the corrosion holes. The crack spreads as a result of the combined corrosion-fatigue process. Corrosion can reduce the blade's reliability by causing fatigue cracking and increasing the acceleration rate [16].

The destruction of the blade of the gas turbine's second stage was investigated, and it was discovered that there was significant pitting on the front and rear edges of the blade surface, as well as signs of fatigue on the fracture surface. Cracking was discovered to be initiated by hot corrosion of the front part and spreads under the influence of fatigue. To create and simulate CE models of broken blades, the ANSYS code is used [17]. The desire to increase productivity while decreasing efficiency paved the way for advanced alloys and surface coatings for turbine blades to be developed. Turbine blades are typically protected by advanced coatings, which are typically based on chromium and aluminum but frequently include exotic elements such as yttrium and platinum group metals to ensure corrosion and oxidation resistance during operation [18].

Several surface treatment methods appropriate for operating conditions have been used to prevent erosion damage caused by solid particles and water droplets, flow path contamination, and corrosion fatigue. Recently, boration, ion coating, plasma arc welding, radical notarization, and multilayer hybrid nickel phosphate coating methods have been developed and improved [19]. Hata et al. [10] investigated corrosion fatigue and various surface treatment methods used on real blades to improve corrosion and fouling protection. They've created coating methods and blade designs that keep dirt and corrosion at bay. The hybrid PTFE ni-P coating, rapid flushing, and large-pitch nozzles prevent the steam turbine from losing efficiency. The nickel-aluminide coating RT22 has better destructive properties in a saline solution atmosphere than materials for blades made of a heat-resistant nickel-based alloy [20]. Corrosion holes and intercrystalline cracks contribute significantly to the corrosion-fatigue destruction of steam turbine blades [21]. According to EPRI in a 22 percent NaCl solution, the corrosion and fatigue resistance of annealed 12 percent chromium steel increases. Gii et al. [22] investigated the role of shot blasting on residual surface stress and its effect on SCC and corrosion fatigue in a 3.5 percent NaCl solution. They concluded that deeper forging is advantageous for increasing corrosion resistance. Other corrosion-protection surface treatment methods, such as electroplating and electroplating, have been investigated [23].

Katinic's [21] research indicates that this is a fracture of two nearby blades. It was discovered that these were the two end blades of a package next to it. The blade root, which is under the most stress, is where the fracture develops as shown in Fig. 3.



Fig. 3. Fracture surface of the rotor blade roots-5th rotor wheel [21].

3.2 Component Failure

Damage to a component is typically classified into two types: system failure and component failure [24]. A component is considered damaged if one or more tools are damaged to the point where they cannot function properly, causing interference with the tool's operation. Damage to components or equipment will inevitably occur sooner or later, usually several stages preceding the damage, such as a violation (accident) then begins to feel the damage, if the damage is allowed, the damage becomes greater and may threaten that the equipment will be completely damaged in the end [25, 26].

According to [27] the damage model and the cause of the damage are two distinct concepts, with the damage model being the result and the cause of the damage being what can cause the damage. Damage models can also be derived from causes and effects that occur over time, beginning with symptoms, progressing to problems with an engine component, and finally to damage to the engine as a whole. The mechanism of damage typically describes the metallurgical, chemical, and tribological

aspects of the process that cause this type of damage to occur. The primary causes of damage are force, time, temperature, and the reactive environment [28, 29].

3.3 Fretting-Fatigue

As shown in Fig. 4, one of the most common areas of fretting failure is the attachment of the blade to the disk at the spruce joint. In gas turbine engines, this is one of the critical components that can fail due to fretting fatigue [30]. Despite the fact that these connections are nominally fixed, there is relative movement in the microscale at the interface between the contacting bodies as a result of centrifugal tangential movements, vibrations, and vibrations, which causes damage and a significant decrease in fatigue life. This is known as fretting fatigue, and it frequently occurs at the attachment points of gas turbine and jet engine blades and disks [31].

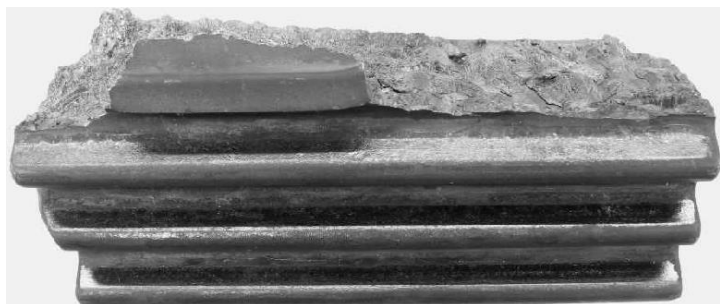


Fig. 4. The area of the spruce root left over from the cracked blades [31].

Cracks may appear small at first, but they can eventually cause serious damage to the component. The only way to prevent fretting fatigue is to eliminate or reduce slippage at the interface, which should be done during the design process [32]. Fretting fatigue accelerates germinal cracking, growth, and, ultimately, destruction compared to non-fretting fatigue (normal fatigue). The complex interaction of multi-cycle and low-cycle fatigue results in fatigue failure of the turbine disk [33].

Under conditions of high cyclic fatigue, the formation of a characteristic furrow characteristic of progressive crack growth [34]. As a result of the complex interaction between multi-cycle and low-cycle fatigue, turbine disk failures due to fatigue occur. The fractures of the turbine blade of the third stage of the 150 MW TPP block, located at the root of the spruce top, were investigated. They discovered that the mechanism of destruction is high cyclic fatigue caused by fretting on the spruce's side surface (i.e. fretting fatigue), and they concluded that the lack of shot blasting during repair was the cause of the corresponding failure. The causes of low-pressure air turbine blade failure (LPT). Damage to the medium pressure turbine (IPT) and the LPT airfoil was discovered during a boroscopic inspection [35]. The fretting fatigue stage is the first stage of the LPT blade malfunction mechanism (LPT1), which causes a flight stop.

A friction fatigue test was used to validate the numerical results. Mutoh and Satoh, as well as Jina et al., investigated material fatigue life. The Palmgren-Miner linear breakdown hypothesis is widely used to predict life in varying or varying voltage amplitude conditions [36]. They also investigated the fretting fatigue of Ti-6AL-4V titanium alloys, which are commonly used in the manufacture of gas turbine engine blades and disks, under Variable Amplitude (VA) fatigue loads and compared the rule of linear cumulative damage with the rule of non-loading. -The linear method of damage accumulation, as well as the Marco-Starkey cumulative damage theory, were used to predict the fatigue life of Ti-6AL-4V alloy under VA loading. Namjoshi and Mall concluded that the nonlinear method of damage accumulation is better suited for assessing fatigue life under variable amplitude load than the linear method.

3.4 Fatigue Failure

The blades of steam/gas turbines are subjected to extremely high voltage and temperature levels during each cycle of engine operation, and due to the vibrations that occur in the turbine during transient loads, fatigue is the most common cause of blade failure. According to a study conducted by Hoshyarmanesh et al. [37] multi-cycle fatigue is the cause of at least 40% of failures in the high-pressure stage of steam turbines. In 1992, the United States Air Force Scientific Advisory Board UU conducted another study, concluding that multicycle fatigue (HCF) is the sole leading cause of failure of gas turbine engines in military aircraft. When the rotor accelerates or brakes during start-up or stop operations, the turbo engine's blades resonate in transient modes, and the instantaneous or harmonic nozzle pitch frequency coincides with one of the blade's natural frequencies.

According to Mazur et al. [38], when pressure fluctuations, flow recirculation, and counterflow are combined with the flow of a negatively falling vane and hitting the vane, excessive vibration stress can develop, resulting in fatigue failure. Limiting dynamic stress under such operating conditions is necessary to avoid fatigue failures and extend the turbine's service life. Most researchers conclude that during fatigue failure, observed fractographically with SEM, the observed fractures are usually of the transcrystalline type at low temperatures [39], with coastal marks found on the fracture surfaces. Fig. 5 shows that the blade fatigue failure does not originate from continuous operation under vibration stress, but during a transition event.

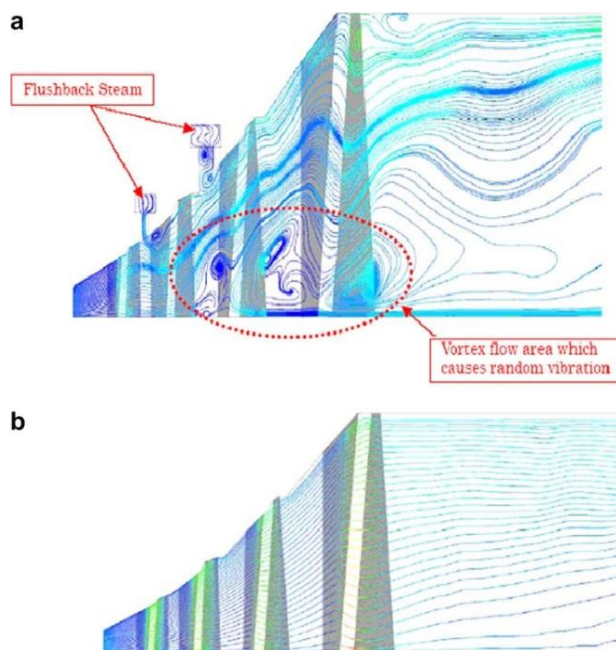


Fig. 5. Steam flow stream lines distribution at the L-0 stage (a) during low load operation, (b) during nominal load operation [38].

The difference between multi-cycle fatigue and low-cycle fatigue is determined by determining whether the predominant component of the deformation occurring during cyclic loading is elastic (high cyclic) or plastic (low cyclic), which is dependent on the material properties. as well as the magnitude of the stress aerodynamic blade fatigue fractures can happen during transients (low load and low vacuum), but not during continuous (stable) operation under vibration stress [40].

The operating parameters of the unit, the natural frequency of the blade/rotor, the blade tension, and the fracture mechanics are based on a metallographic study [38]. They concluded that the multicycle fatigue mechanism is responsible for the onset and spread of L-0 blade failure. This conclusion also suggests that blade fatigue failure occurs during transients rather than continuous operation under vibration load conditions. They also investigated the failure of the last turbine stage (L-0) in a 28 MW

geothermal installation. Cracks in the airfoil of the blade begin near the trailing edge, near the blade platform. Based on the results of the final stage of the metallographic investigation of the blade, the operational parameters of the unit, the natural frequency of the blade, and the blade stress, a conclusion is reached regarding the occurrence and spread of multi-cycle fatigue failure of the blade via the erosion-corrosion process.

Kholid et al. [41] discovered variable voltages in turbine blades due to the excitation of resonant states due to variations in the gas pulse load, and these variations are due to the creation of uneven temperature and pressure distribution along the turbine end due to anomalies in the combustion process and the creation of a difference in gas velocities due to deformations of individual turbine nozzles in his study of the fatigue failure of an aircraft engine. The authors conclude that turbine blade destruction is primarily caused by multi-cycle fatigue cracking at the bending point, and it is recommended that during maintenance aimed at maintaining the uniformity of the combustion process and the uniformity of the turbine shape. Blade, the failure of the VTS can be avoided. Yang et al. [42] conducted low-cycle fatigue tests on GTD-111 superalloys to predict low-cycle fatigue durability at various temperatures. The fatigue life computed using the Coffin-Manson method and the deformation energy method was compared to the fatigue life measured at various temperatures. The authors conclude that as temperature increases, the stress range narrows and the plastic deformation area expands, demonstrating cyclic hardening. In the blades of aviation gas turbines to determine the source of the crack. Turbine blades made of a heat-resistant nickel-based alloy are cast in accordance with Directional Curing (DS) melting models. Cracks start at the trailing edge of the blade and spread due to fatigue from the cyclic loads that the blade is subjected to during operation. Roy et al. [43] investigated the catastrophic failure of a 150 MW gas turbine caused by extremely high vibrations. Prior to the failure, the turbine ran for about 1800 hours in a short-term mode, with a record number of starts - 65. They discovered that the majority of the destroyed blades belonged to the first row of mobile blades, with four missing blades. Subsequent research revealed that the initial cause of the blade's destruction was low-cycle fatigue, which occurs due to cracks in the holes of the safety pins (voltage amplifiers) located at the base of the blade and extending.

Misra et al. [44] investigated the destruction of turbojet engine turbine blades and discovered that the turbine blades first crack in the fatigue mechanism for a certain period of time, and then fail due to overload at the last moment. The hot gas flow severely damages the broken turbine blades, causing them to change color. This thermal destruction roughens the gamma Prime phase in the matrix (Ni Super-based alloy) and reduces the fatigue strength of the base material, resulting in premature fatigue failure. Hardness measurements show that the material's strength has decreased due to gamma raw phase degradation. The significance of other parts connected to the malfunctioning engine shaft was also considered.

Oiao et al. [45] used a nonlinear EMF to determine the turbine blade's stationary voltage and dynamic characteristics. To determine the cause of the blade failure, the stationary stress and dynamic characteristics of the blade are evaluated and synthesized, and a prestressed modal analysis is performed to study the dynamic behavior of the blade nodes and discs under working conditions. Hou et al. concluded from their analysis that the first bending vibration mode has no significant contribution to the failure. The maximum stress associated with the second vibration mode coincides with the point of origin of the crack, making it a possible cause of fatigue.

Bhaumik et al. [46] investigates blisk failures during the development of aircraft engines for specific applications. Due to the flashing of the GTD turbine rotor during the inspection, cracks were observed on the trailing edges of the blades. The unfavorable orientation of the columnar grain in the airfoil, as well as the high

operating temperature, are the causes of such cracking. Following the formation of the initial crack as a result of a stress rupture, it is natural for the crack to spread due to the cyclic loads experienced by the blade during operation. The presence of coastal marks and striations confirms the depletion mechanism's growth of the second stage of the crack. In the airfoil section, the author recommends using coarse columnar granules with a high coefficient of elongation to improve high temperature resistance and tear resistance. The onset of layer cracking may be related to thermal fatigue mechanisms caused by transient high thermal loads (i.e., movement, starting, and braking), as well as the onset of cracking along grain boundaries and propagation on substrates caused by creep mechanisms (high stationary loads) [47].

The blades are exposed to internal cracks of the cooling holes in various parts of the airfoil, which is aided by the destruction of the base layer and alloy due to high-temperature operation [38, 48]. A thorough examination of all the factors influencing the occurrence of failure is performed. A mixed fatigue/propagation mechanism has been discovered to control the initiation and propagation of layer/substrate cracking. Dewangan et al. [49] investigated the failure analysis of a gas turbine with first and second stage blades made of nickel-based alloys. On fracture surfaces, micropores are found, which serve as a source of creep mechanisms, reduced ductility and toughness of alloys due to carbide deposition at grain boundaries, and phase degradation of the alloy (uneven particle growth). As a result, it is concluded that the cause of the rotor blade failure may be an increase in blade length and contact between the end of the blade and the housing as a result of creep after a long period of operation.

A major breakthrough, in addition to alloy improvement, was the development of Directed Crystallization (DS) methods and the production of Single Crystals (SC). By aligning grain boundaries in one direction (DS) or completely eliminating grain boundaries (SC), this method significantly improves fatigue and creep resistance [50]. The development of thermal barrier layers was another significant advancement in the technology of manufacturing materials for turbine blades (TBC). While DS and SC improved creep and fatigue resistance, TBCs improved corrosion and oxidation resistance, which were both major concerns as temperatures rose.

4 Conclusion

Conclusions can be drawn based on the literature and research presented that low-pressure turbine blades are an important component of steam/gas turbines, and that corrosion fatigue is the cause of the majority of turbine part damage caused by wet/dry transition zones. Furthermore, the presence of corrosion holes and intercrystalline cracks initiates corrosion-fatigue cracking, resulting in the failure of low-pressure (ND) turbine blades. The efficiency of low-pressure turbine blades, on the other hand, can be increased by implementing appropriate corrosion protection measures, such as surface treatment methods, blade design improvements, and real-time washing. The destruction that usually occurs in the upper part of the root leaf is caused by friction fatigue. To avoid this, advanced coating techniques, laser impact treatment, low ductility firing process, shot blasting, and ultrasonic impact treatment can be used to improve abrasion fatigue resistance.

High thermal transient phenomena/loads are the primary cause of high-pressure steam/gas (TP) turbine blade fatigue failure. To avoid this type of failure, designers frequently employ a probabilistic approach to blade design. It is possible to increase the fatigue strength and creep fracture of turbine blades by using directional curing (DS) and single crystal production (SC) methods. Furthermore, a thermal barrier layer (TBC) has been proposed for high-temperature gas turbine blades to increase resistance to corrosion and hot oxidation.

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