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Review on Common Failure of Steam Turbine blade

Tukesh Kumar Patel[1]; Prakash Kumar Sen[2]& Ritesh sharma[3]
[1]Student, [2,3]Faculty
[1,2,3]Department of Mechanical Engineering
[1,2,3]Kirodimal Institute of Technology Raigarh(C.G.) INDIA 496001

ABSTRACT:-

This paper is meant to help with failure investigation, presenting a review of the causes and effects involved when blades fail. Included are descriptions of failure mechanisms (stress; resonance; environment) and of the conditions causing the failures (design; manufacturing; operation). the first with a crack initiating at the strain raiser point and propagating at low rate, a second where and the third one consisting of unstable fracture. Stress intensity factor approach is used to identify the three crack zones and establish the mechanism of the machine failure. Blade failure is a common problem of a steam turbine and it's failure in-service results in safety risky, repair cost and operational revenue losses. Thus, the reliability of these blade is very the important for successful operation of a steam turbine. Dynamic analysis of a steam turbine blade in computational environment is carried out in the present work. Turbines are device for power generation. These are the source for converting the energy into electrical energy. Turbine blades are main component which rotates under fluid flow, which causes the conversion of potential/kinetic energy to convert into electrical energy. The sound stability of the turbine blades is essential to achieve the target. During exposure to adverse condition it may lead to formation of cracks either by corrosion or by erosion. In the present work attempt has been made to locate the cause of failure of the blade of steam turbine.

Keyword:- steam turbine; blade failure; stress; dynamic analysis; mechanism

1.INTRODUCTION

Blade failure is a common experience in power plants using steam or gas turbines. A steam turbine is a mechanical device that extracts thermal energy from pressurized steam, and converts it into rotary motion. Its modern manifestation was invented by sir Charles parsons in 1884 [1].

It has almost completely replaced the reciprocating piston steam engine (invented by Thomas Newcomen and greatly improved by james Watt) primarily because of its greater thermal efficiency and higher power to weight ratio.

Blades are important component of steam turbine and its failure is a common problem. A frequent cause of turbo machinery blade failure id excessive resonant response, The most common excitation source is the non-uniform flow field generated by inlet distortion wakes and/or pressure disturbances from adjacent blade rows. The standard method for dealing with this problem is to avoid resonant conditions using a Campbell diagram. An in-depth study of blades vibration problems that seriously impact development of advanced gas turbine configuration are presented in [2]. methods to predict the amplitudes of vibration of compressor blades are explained in [3].

Since blade failures are predominatly vibration related, blade vibration studies have acquired considerable importance and a good deal of work on the determination of natural frequencies and mode shapes has been contributed by several research workers, see Rao [4]. The dynamic loads on the blading can arise from many sources, the most predominant one being the excitation from the nozzles. When a rotor blade passes across the nozzles of a stator, it experiences fluctuating lift and moment forces repeatedly at a frequency given by the number of nozzles multiplied by the speed of the machine. This gives rise to excitation at a higher multiple of the machine

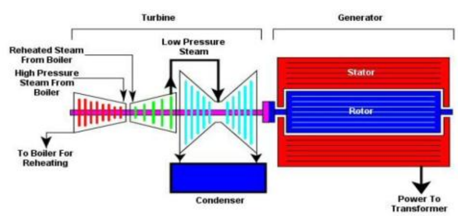

Figure.1. steam turbine

speed and is commonly the source of problem of HP blades. The nozzle excitation is more an aerodynamic phenomenon and the forces can be estimated by unsteady aerodynamic theories, see Rao [5]. It is the dynamic stress under resonance combined with the centrifugal steady stress that determines the fatigue life of a blade in a steam turbine. Determination of these stresses in the blade vane portion is illustrated by Rao and Vyas [6].

2. THE ICCIDENT AND THE FAILED BLADE

Blade failure is a common experience in power plants using steam or gas turbines. Once in a while, these failures form a part of major incidents. On 19 November 1968, RMS "Queen Elizabeth 2" suffered HP turbine blade failures during its maiden voyage from Tail O' the bank, resulting in complete damage to the 9th stage starboard HP turbine rotor and fleeting and Coats [7]. Another major accident occurred on 22 August, 1997, after a major overhaul of a 600 MW turbo-set in porcheville, france, where the last stage blade failed, see frank [8]. The machine under question is a 236 MW nuclear turbine with one single flow HP and one double flow LP cylinder.There are five stages in the HP cylinder and five stages in each flow path of the LP cylinder. A schematic lay out of the machine is given in fig. 1. Bearings 4 and5 are mounted in the same housing, the machine has put in 16,264 h of operation at the time of failure which took place in the early hours of 31 March 1993.

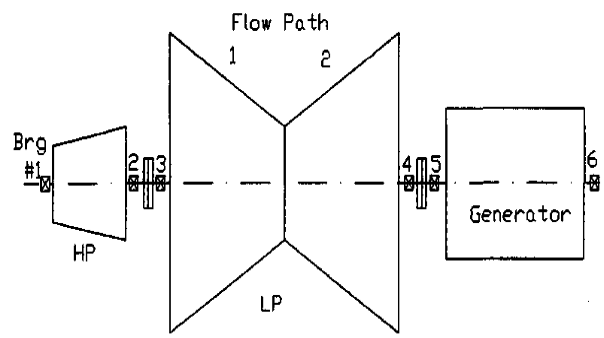

Fig.2. Arrangement of 236MW turbo-generator set.

3. Major Steam turbine components

- Major internal components
  - Rotating Blading (Buckets) and discs/wheels
  - Shafts, Rotor, Bearing, and Seals
  - Stationary Blading (Nozzles) and Diaphragms
  - Shells, blade rings, or casings
- Major external Components/Supporting Systems
  - Main Stop, Trip & Throttle, Intercept Valves
  - Governor/Control Valves
  - Admissions, Extraction, Non-Return Valves
  - Steam and Drain Connections
  - Over speed Protection System
  - Lubrication System
  - Electro-hydraulic Control System
  - Water/Steam Chemistry Controls
  - Turbine Control System

4. Turbine Failure Mechanisms

- Major Turbine Internal Components (Blading, Discs, Rotors, Diaphragms, Shells)

- Corrosion: Pitting form Corrosive Elements in Steam
- Creep: Permanent Thermal Distortion Caused By Higher Steam Temperatures and Life Consumption
- Erosion: Particulate and Water Droplet Damage

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- Foreign/Domestic Object Damage: Debris Damage
- Stress Corrosion Cracking: High Stress and Corrosive Conditions
- Thermal Fatigue: Cracks form Thermal Cycling of Thick Parts

  - Major Turbine External Components/Steams

- Valves: Contaminants in Steam, Wear of Mating Parts, Damaged Seats Causing Valve Sticking and Leakage
- Lube Oil System: Loss of Oil Protection Not Working
- Water Induction: Water from Steam Lines, Drains, Feed water Heaters Causing Thermally Distorted Rotors (Bowed) and Shells
- Contaminated Steam/Water and Particulate from Boilers
- Turbine Over speed Protection Not Working

Composite Industry Steam Turbine Failures-Mechanisms and Causes (HSB Files)
(Ranking: 1=Highest, 4=Lowest)

Component	Failure Mechanism	Cause(s)	Frequency Rank	Severity Rank
Turbine Rotor and Bearing	Loss of lube oil	1. Pressure switches did not work. 2. Backup lube oil pump did not work. 3. Duplex filter switching problem 4. Oil supply valve leaked 5. Ruptured bearing oil line	1	3
Bucket or Bucket cover failure	Fatigue, corrosion, erosion, rubbing, and SCC	1. Blade and/or cover cracked, pitted, thinned or eroded and finally broke. 2. Corrosive chemicals in the steam 3. High backpressure for last turbine stage. 4. Water induction 5. Resonance sensitive bucket design 6. Bowed rotor and/or humped shell	2	2
Turbine Rotor	Over speed (OS) with or without water induction	1. NRV stuck open during shutdown 2. Mechanical OS device did not work. 3. Main Steam stop/T&T valve stuck partly open. 4. Lost control of test 5. Control-OS did not work	3	1
Turbine Rotor	Major rubbing, high vibration	1. Quick closing valve did not close properly (broken disk) 2. Direct contact of rotor with buckets, nozzles, seals, and shells 3. Misalignment 4. Protective system did not work	2	2
Nozzle and Bucket, HP and IP stages	Solid particle erosion	1. Exfoliation – boiler inlet piping 2. Main steam stop/T&T valve inlet strainer broke.	3	4
Nozzle and Bucket, LP stages	Droplet erosion	1. Saturated steam in the LP turbine 2. Poor turbine design.	3	4
Nozzle and Bucket, all stages	Foreign or Domestic object damage (FOD/DOD)	1. Debris in inlet line to turbine 2. Main steam stop/T&T valve inlet strainer broke. 3. Parts adrift inside turbine, or broken nozzle partitions or bucket shrouds.	4	3

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5.Fracture of steam turbine blade

Fracture is a form of failure and is defined as separation or fragmentation of solid body into two or more parts under the action of stress, at temperature below the melting point. The process of fracture can be considered to be made up of two component crack ignition and crack propagation. Fracture can occur under all service conditions. Material subjected to alternating or cyclic loading fail due to fatigue. The fracture under such circumstances is called fatigue fracture.

Depending on the ability of material to undergo plastic deformation before the fracture two fracture modes can be define these are ductile and ductile and brittle fracture.

Figure.3.1. illustrasting fracture

5.1.1 Ductile:

It is characterized by appreciable amount of plastic deformation prior to propagation of the crack. It is characterized by extensive plastic deformation ahead of crack tip. Crack growth is stable and resists further extension unless applied stress is increased. Ductile material can absorb shock or energy (during the deformation) before failure. It occurs in most metals which are not too cold. FCC metals are usually ductile because of the presence of large number of active slip system. The surface topography of ductile failure is cup and cone type.

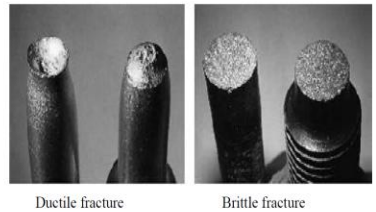
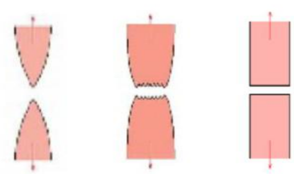


Figure.3.2. Illustrating types of fracture

5.1.2. Brittle:

It is characterized by rapid rate of crack propagation with negligible plastic deformation. Crack propagates by cleavage nearly perpendicular to direction of applied stress with breaking of atomic bonds along specific crystallographic plane (cleavage plane). It is caused by decreasing temperature, increasing strain rate, tri axial stress condition. Less amount of energy absorption occurs before. It occurs mostly in cold metals and ceramics. BCC and HCP metal are susceptible to brittle fracture because there are very less number of active slip planes or slip systems for plastic deformation.



Highly ductile fracture Moderately ductile fracture, Brittle fracture
eg. Pure gold eg. Most metals

Figure.3.3. Illustrating crack propagation

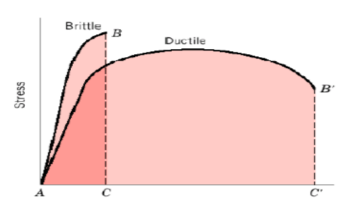


Figure.3.4. represents the degree of plastic deformation exhibited by both brittle and ductile materials before fracture.

5.2 Basics of Ductile Fracture:

The ductile fracture can be divided into three categories:

5.2.1 Shear failure:

It occurs as a result of extensive slip on active slip planes. It is characterized by slip on successive basal planes until the crystal separate by shear. It is observed mainly in H CP metals like magnesium.

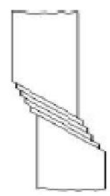


Figure.3.5. Ductile fracture by shear failure

5.2.2 Complete ductile failure:

Slip occurs in failure by slipping is common phenomenon. Slip planes in case of polycrystalline materials unit it is drawn to a point before rupture. It happens in case of very ductile and pure materials like gold and lead.

Figure.3.6. Complete Ductile failure

5.2.3 Cup & cone type failure:

Fracture begins at the centre of the specimen by the mechanism of void nucleation. Growth and coalescence followed failure by shearing along the shear planes to form the cup and cone type failure.

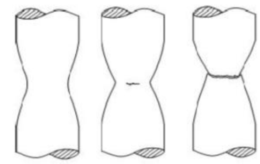


Figure.3.7. Cup & cone failure

5.3 Dimple Rupture:

When overload is the cause of fracture, most common structural alloys fail by a process known as micro void coalescence. The micro void nucleate at regions of localized strain discontinuity, such as that associated with second phase particles, inclusion, grain boundaries, and dislocation pile-ups. As the strain in the material increase, the micro voids grow, coalesce, and eventually form a continuous fracture surface. This type of fracture exhibits numerous cuplike depressions that are the direct result of the micro void coalescence. The cuplike depressions are referred to as dimples, and the fracture mode is known as dimple rupture [9].

Dimple shape is governed by the state of stress within the material as the micro voids from and coalesce, fracture under conditions of uni-axial tensile load result in the formation of essentially equiaxed dimples bounded by a lip or rim. Depending on the microstructure and plasticity of the material, the dimples can exhibit a very deep, conical shape or can be quite shallow. The formation of shallow dimples may involve the joining of micro voids by shear along slip bands [10]. The fracture on the blade in an aircraft gas turbine has been studied to see the cause of crack initiation [11].

An analysis of the cause of fracture in a steam turbine blade root was investigated by kubiak etal [12]. The analysis concludes that the metallurgical mode of the blade root failure was the corrosion fatigue at the zone of the highest stress concentration caused by mismatch and errors in the installation between the between the blade root platform and the rotor fastening tree. Also the crack was propagated by vibration around of the first mode of vibration [12].

The failure analysis of twelve percent chromium martensitic steel blades of the medium –pressure stage of a thermoelectric centre turbo-blower was presented which brakes during use [13]. The result indicated that

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at least one of the blades of medium pressure stage failed by a corrosion-fatigue mechanism, whose nucleation was associated with the pressure of corrosion pits on its suction side. The high pressures blades presented hardness bellow the specification and presence of corrosion pits and cracks [13].

An another study of failure of turbine blade indicate environmental effect [14]. The fracture initiated from a cavity caused by erosion. The erosion of the trailing edge is not normal, but can occur during prolonged operation on the partial load. Additionally, NaCl corrosion may have contributed to the failure located at the trailing edge of the blade. The time required for the blade to fracture by high-cycle fatigue after it was freed from the blade group was estimated to be about 10 min [14].

The fracture of LPT1 blade which caused the in-flight shutdown event initiated from a V-shape notch defect. The failure mechanism of this blade was fretting fatigue for there were conditions of fretting wear and some fretting pits and cracks were visible [15].

5.3.1 Failure mechanism of Environmental effect

Stress corrosion:

Rare with blades, but fairly common with rotors, where it has caused some catastrophic failure. Fracture would be inter granular and branched. Usually the part disintegrates into many pieces. It is caused in stressed parts by corrosive steam or by standby in corrosive environment (chorine in moist atmosphere, for example; or leaving a turbine open with inadequate weather protection). At standstill, the necessary static stress component is residual stress, mainly at or near areas where local yield or creep has occurred during operation.

5.3.2 Corrosion-fatigue:

Perhaps the most common single factor in blade failures in the wet region of turbines, affecting especially the dry/wet area near the saturation line, it is well described by Barer & Peters, [16].

Corrosion fatigue is usually transgranular , displaying thereby little concern for the microstructure. The trasgranular behavior demonstrates the primacy of the mechanical of stress cycling component. It is also likely that some intergranular action might accompany corrosion fatigue where the fatigue component is small or absents for various periods. Along similar lines is the corrosive action proceeding at right angles to the corrosion fatigue crack.

6.Symptoms

6.1 Failure location (fatigue failures), on blade assembly

This can provide good clues concerning the destructive mechanism.

-Failure in shroud or lashing is proof that the shroud or lashing assembly was too weak to perform its function to dissipate oscillating loads (by averaging the pulsations on each blade in such a way as to cancel the total for the entire packet as for as possible). This could be a result of design weakness, unexpected resonance, corrosives, or manufacturing deficiencies (shroud not pulled down). Usually several of these factors are involved.

-At foil base or root: with long blades this indicates a probability of resonance. With shorter blades, it is a sign of insufficient shroud stiffness, or of a poor shroud dissipation factor , or of a weak blade design (too narrow, poor root).

-Foil, other than base: Higher mode resonance.

6.2 Fracture Analysis

See “Failure Mechanisms” for correlations. One can get an idea of fatigue damage accumulated in apparently healthy blades by holding the root of a blade firmly, in a vise, with top of jaws at failure location. Then bend blade with a long pipe and/or hit hard with a sledgehammer. This sometimes tells a lot about remaining ductility. Some of these blades may break like a poor grade of cast-iron (especially the ones having cracks), showing very little ductility and a very coarse fracture surface. This gives a clue about magnitude of stress-levels involved and their distribution around the wheel and within the packets.

7.Crack Initiation

Referring to fig. the crack initiation is clearly observed at the sharp corner of the trailing edge of the blade root. For such a fatigue crack to initiate, we can use local stress-strain approach, see [17]. Though the procedures to determine the crack ignition are somewhat established, it becomes difficult in practice to apply them to a complicated geometry such as the present case. It is more appropriate therefore to adopt stress Intensity factor approach to estimate the required loading, see Barsom and Rolfe [18] for crack initiation.

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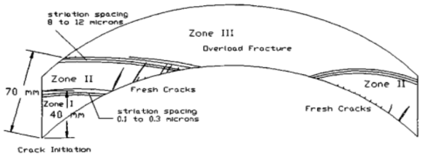

Figure.4. Three zones of fracture in blade

8.Conclusion

This paper present the blade failure in steam turbine is described. Blades fatigue strength decreases under resonance condition, since displacement amplitudes are higher than normal load conditions, which starts cracking and spreads until failure in less time.

In order to guarantee designed useful life of blades, it must be monitored turbine functioning to avoid working on resonance speed zones for long periods of time, considering that if crack appears, vibrating modes would change and it raises the chance to get into resonance zones.

Result show that natural frequencies decrease and displacement amplitudes raise with cracking, also cracking propagation requires less number of cycles and it reduces blade useful life under resonance conditions, compared to normal operation status.

From this work it can be concluded that the procedures of determining the natural frequencies, mode shapes, excitation forces, modal damping, fracture initiation, propagation and failure can be used with a fair amount of confidence in the design and diagnosis of turbine blades.

From the previous discussions, several conclusion about the maintenance and overhaul of steam turbines can be made:

- The blade material was as per specified grade of steel and there was no in homogeneity regarding microstructure of blade material.
- Throughout the blade surface surface deposit containing Si was detected. It is expected that the impingement of silica particles led to formation.
- The failure mode was intergranular type. In all probability, failure was due to corrosion-fatigue.

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