AN EFFECT OF TURBINE BLADES SURFACES ROUGHNESS ON GAS POWER PLANTS AND PERFORMANCE DEGRADATION

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ABSTRACT

The fuel contaminations and impurities leads to an extensive effects on the axial flow turbine for gas turbine engine of Iraq power plants, such as water content, Sulphur, sodium cause corrosion, erosion, and fouling which is the adherence of particles and droplets to the surface of turbine, i.e. (blade surface roughness) then turbulent boundary layer and its energy will increase. The gas station 35 MW was selected to determine the impact of this phenomenon on the performance of the station. Boundary layer separation take place early, flow deflection angle and blade efficiency were reduced, while the pressure loss coefficient and drag are increased. Turbine blade does not only reduce the aerodynamic performance, but the reduction in cross-sectional area of the turbine blade could lead to serious turbine damage.

In this study, the relation between clean and rough turbine cascade will investigate to obtain aerodynamic behavior of both blades. A numerical solution (ANSYS Software) will use to simulate the test rig to predict the cascade blade performance and the upstream flow field, in order to achieve the main goals mentioned above. All the aerodynamic variables and parameters pressure and velocity distribution, energy dissipation, have calculated in the program energy dissipation were also calculated using numerical solution ANSYS software at wind tunnel Reynolds number of 1.783×10^5 and 3.566×10^5 .

KEYWORDS: Blade Roughness, Turbine, Corrosion, Velocity Profile, Pressure Distribution & Cascade Performance

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INTRODUCTION

The principle of the work of gas power plants is to compress air inside the station by compressor to generate high pressure and then burn it when mixed with fuel in the combustion chamber. The combustion gases then move to the important part of the plant, which is called a turbine that consists of several stages containing the blades that these gases pass through them and rotate the turbine to create desired power. Blade of turbine is one of the core aero components; it mostly influences the performance of the engine. There are many factors leading to the aero-engine performance declination, especially roughness increasing caused by lamina fouling is atypical reason. When the blade surface roughness increases, the main turbine characteristic parameters decrease in some degree and make the total turbine performance decline.

Stationary and moving blades of turbine are very important parts, which affected during the increasing of gas temperature. Therefore, accuracy of the geometrical shape and the blade surface are important factors for

providing turbine work. Thus the highest efficiency and best performance.

Corrosion or Erosion of Blades

Turbine blades are affected by high temperature of gases inside the turbine and combustion products. As a result, corrosion occurs which lead to the decay of the blade and thus decrease its efficiency. While the “erosion” is caused by, wearing a way of metal on, the leading edges of turbine blades by debris and impurities carried in the high velocity gas stream. The rate of erosion is determined by the quantity and type of debris carried in the gas stream and the operating temperature of the turbine.

kanshik Das and Puneet [1], Arora, carried out theoretical and practical studies to investigate the erosion that occurs in fixed and moving turbine blades due to collisions of solid objects. These studies were carried out in an aerodynamic tunnel to determine the erosion rate of fixed and moving blades for different collision when they are coated or unpainted to see the characteristics of those blades in both cases. The studies have shown that the amount of roughness and erosion increases when the collision angle and the size of solid parts increase. The theoretical study has proved that the collision occurs to the bottom surface of the blade and the end the upper surface of the blade and this collision works on the decay of the momentum of the solid objects when they collide in the fixed blade and increase in the moving blade.

Harkiran Singh et al [2], they studied a theoretical and numerical study to determine the effect of the roughness of the surface greater than 100 micron of the turbine blades that placed linearly at 100 microns. It was observed that the effect of roughness on the efficiency of the blade is evident at its upper surface compared to its lower surface. In addition, the amount of loss increases at the end of the upper surface and is larger while being less at the beginning of the blade

Lorenz et al [3], discover experimentally, the effect of surface roughness on the aerodynamic specifications of the blade after placing the roughness in several rows on the upper blade surface. The change in height and differing concentration of the roughness may have a significant effect on the loss of the boundary layers that prevail the surface of the upper blades. The experiments were carried out in various Reynolds number, and it was observed that the thickness of the boundary layers increased by 190% on the upper part of the fin.

R.P Taylor [4], showed that erosion rate is varied with respect to collision of particle quantity, angle of impact and particle velocity. He discovered that erosion is increases when the collision angle of the particles is between 20 and 30 degree

Theory of Calculations

Blade surface of turbo machines could experience significant degradation in shape or roughness due to harts operating environment. In most cases, it is known that blade surface becomes rough caused by deposition, erosion or pitting.

Sometimes blade roughness suppresses flow separation and shows positive effect on the performance. However, roughness usually increases blockage because of boundary layer thickness on the passage surface, which results in the performance and efficiency decreases.

Operation of the best performance and efficiency becomes an important issue now considering total cost of operation and maintenance during a life cycle of machinery. Therefore understanding the effects of blade roughness on the flow and performance is important aspects not only in design but also in operation and maintenance.

If blades or walls become rough for any reason, even small roughness will break up the thin viscous inner layer and greatly increase the wall friction and heat transfer coefficient.

A software computer program has been used to presage the flow field around the turbine blade and simulate the blade with real dimensions as shown in figure (1), using software when fixed at the low speed wind tunnel test section. ANSYS is the governing equations solver. The governing equations are the continuity, momentum and energy equation for steady, unsteady, incompressible, compressible, two-or three dimensional viscous flow. The computational solution of Navier-stokes equation is applied to a finite control surface fixed in space and flow field of interest is covered with a mesh of grid point (node and element).

Governing Equations

In analysis of flow in turbo machines, the governing equations will usually be used in particular coordinate system suitable to the problem. In general, the flow of gases is subject to the general fluid laws of flow, continuity, momentum and energy conservation. While Solving Euler equations, for two dimensional flow, and steady flow which is the main reference to the full three dimensional Navier-stokes equation.

Continuity Equations

The law of conservation of mass gives the continuity equations

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_x)}{\partial x} + \frac{\partial(\rho v_y)}{\partial y} + \frac{\partial(\rho v_z)}{\partial z} = 0 \quad (1)$$

Where

V_x gas velocity in x direction (m/sec).

V_y gas velocity in y direction (m/sec).

V_z gas velocity in z direction (m/sec).

ρ = gas density (kg/m³)

x, y and z = global Cartesian coordinates.

t = time.

Density change can be expressed in terms of pressure change so that

$$\frac{\partial \rho}{\partial t} = \frac{\partial \rho}{\partial p} \cdot \frac{\partial p}{\partial t} \quad (2)$$

Therefore, gas density can be derived with respect to gas to produce the equation of state. [5]

$$P = \rho RT \text{ So that } \rho = P/RT \quad (3)$$

R= gas constant (kj/kg.k), T= gas temperature (k)

Momentum Equations

In a Newtonian fluid, the stress and rate of deformation of the fluid can be write in equation below [6]

$$\tau_{ij} = -p\delta_{ij} + \mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) + \delta_v \lambda \frac{\partial u_i}{\partial x_i} \quad (4)$$

Where:-

τ_{ij} = Stress tensor (n/m²)

u_i = Orthogonal velocity in x, y, and z direction (m/sec).

μ = viscosity (kg/m.sec).

λ = Second coefficient of viscosity.

Relative Pressure

Relative pressure can be expressed in terms

$$P_{abs} = P_{rel} + P_{ref} + 1/2[(w) \cdot (w) \cdot (r)] \cdot (r) - \rho_0(g) \cdot (r) \quad (5)$$

where:-

- ρ_0 = Reference density.
- P_{ref} = Reference pressure.
- (g) = Acceleration vector due to gravity.
- P_{abs} = Absolute pressure.
- P_{rel} = Relative pressure.
- (r) = Position vector of the fluid particle with respect to the rotating coordinate system.
- (w) = Constant angular velocity vector of the coordinate system.

While density can be, find using equation of state.

Pressure Coefficient

In case of incompressible and compressible fluid the equation below pressure coefficient:

$$P_{coeff} = \frac{2(P - P_f)}{\rho_f v_f^2} \quad (6)$$

P_{coeff} = pressure coefficient

P_f = free stream pressure (N/m²)

ρ_f = free stream density (kg/m³)

V_f = free stream velocity(m/sec)

Wall Shear Stress

Wall shear stress at the blade surface is related to the the amount of the turbulence modeling

$$\frac{V_{tan}}{\sqrt{\frac{\tau_w}{\rho}}} = \frac{1}{K} \ln \left[\frac{E_s \delta \rho}{\mu} \sqrt{\frac{\tau_w}{\rho}} \right] \quad (7)$$

Where

μ = viscosity (kg/m.sec)

δ = Distance of the rear wall node from the wall (m)

V_{tan} =velocity at the rear wall node parallel to the wall (m/sec)

E_s = constantin the turbulence mode

τ_w = wall shear stress (N/m²)

RESULTS AND DISCUSSIONS

Figure (2), (3), (10) and (11) represent the energy dissipation upstream and downstream the trailing edge of the cascade. All these figures are for Reynolds numbers (2.147661×10^6 and (2.624919×10^6) . For two cases, the energy dissipation increases slightly along the suction side of the blades because of the generation of small vortex at the outer region of the turbulent boundary layer. Therefore, generation of the energy dissipation at the wake trailing edge has become high.

Figures (4),(5),(12),(13),(18),(19),(20)and (21) represent the variation in the velocity profile in pitch-wise direction between the blade suction side and upper wall of wind tunnel test section at Reynolds number (2.62×10^5). For rough surface results, the velocity profile is distorted slightly due to the presence of surface roughness in all cases. This phenomenon increases and develops as the number of Reynolds increases.

Figure (6),(7),(14) and (15)represented the pressure distribution along the pressure and suction side for both cleanand rough surfaces at Reynolds number(2.147661×10^6 and (2.624919×10^6)

Although the boundary layers on both pressure and suction surfaces of blade are initially laminar, as they are pass the leading edge, both under and above and go to transition is natural.

The comparison of two cases shows that the pressure distribution along the surfaces have strong adverse pressure gradient. This leads to separation bubble occurs due to sudden curvature surface roughness change.

Because of frictional effects on the blade surface and test section walls, they add losses and therefore the stagnation pressure loss coefficient is increased. The rough surface also affects the flow field so that the action will progress and augment; therefore, boundary layer separation and stall moved upstream, for the reason the rough surface give pressure loss greater than the clean surface.

Table(1) represent the variation in pressure coefficient with respect to pressure distribution for upper and lower side of blade. This table include the pressure coefficient at Reynolds number (2.23×10^6). It showed that the pressure coefficient gradually decreasing with increase in the surface roughness because the flow is smoothly leaving suction and pressure sides of the blade surface. The Reynolds number does not influence strongly the C_p while the rough surfaces have a remarkable influence on the C_p for all Reynolds numbers.

**Table 1: Velocity=55 m/sec Stream Pressure=537.3 Pascal for
Clean Stream Pressure=7681 Pascal for Rough**

Pressure Distribution(pa) (Clean)	Pressure Coefficient	Pressure Distribution (Rough) (pa)	Pressure Coefficient
2.3×10^{-3}	0.955	2.3×10^{-3}	-2.916
5.37×10^{-2}	-0.00016	5×10^{-2}	-3.8916
-4.98×10^{-3}	-2.99	-3.98×10^{-3}	-6.3194
-2×10^{-3}	-1.375	-5.28×10^{-2}	-4.4487
-1.7×10^{-3}	-1.2124	-8.17×10^{-2}	-4.605
-10^{-3}	-0.8331	-2.4×10^{-3}	-5.4632
1.457×10^{-3}	0.4984	8.2×10^{-2}	-3.71822
1.457×10^{-3}	0.4984	7×10^{-2}	-3.7832
1.2×10^{-3}	0.3591	6×10^{-2}	-3.8374
6×10^{-2}	0.0339	-8×10^{-2}	3.7290

Figure 1: Blade Dimension

Energy Dissipation at Velocity 45 m/sec

Figure 2: Clean

Figure 3: Rough

Velocity Distribution at 45m/sec

Figure 4: Clean

Figure 5: Rough

Velocity Distribution at 45m/sec

Figure 6: Clean

Figure 7: Rough

Pressure Distribution at 45m/sec

Figure 8: Clean

Figure 9: Rough

Kinetic Energy 45m/sec **Figure 10: Clean** **Figure 11: Rough****Energy Dissipation at 55 m/sec** **Figure 12: Clean** **Figure 13: Rough****Velocity 55m/sec** **Figure 14: Clean** **Figure 15: Rough**

Pressure Distribution at 55 m/sec

Figure 16: Clean

Figure 17: Rough

Velocity Profile (Clean Surface) at 45 m/sec

Figure 18

Velocity Profile (Rough Surface) at 45 m/sec

Figure 19

Velocity Profile (Clean Surface) at 55 m/sec **Figure 20****Velocity Profile (Rough Surface) at 55 m/sec** **Figure 21****CONCLUSIONS**

The analysis of the present results may give some useful information about the effect of surface roughness's on the turbine blading. These results may be of great interest to the maintenance team from the operation point of view. Therefore the following conclusions may be made:

- It was found that the Pressure distribution along the surfaces have strong adverse pressure gradient. This leads to separation bubble occurs due to sudden curvature surface roughness change. The rough surface also affects the flow field so that the action will progress and augment; therefore, boundary layer separation and stall moved upstream, for the reason the rough surface give pressure loss greater than the clean surface
- Boundary layer separation take place early so that flow deflection angle and blade efficiency were reduced, while the pressure lose coefficient and drag are increased
- Turbine blade does not only reduce the aerodynamic performance, but the reduction in cross-sectional area of the turbine blade could lead to serious turbine damage.
- The energy dissipation increases slightly along the suction side of the blades because of the generation of small vortex at the outer region of the turbulent boundary layer. Therefore, generation of the energy dissipation at the wake trailing edge has become high.

Therefore, accuracy of the geometrical shape and the blade surface are important factors for providing turbine work. Thus the highest efficiency and best performance.

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