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Structural and Thermal Research of Steam Turbine Blades by Finite Element Method

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***Abstract:** In most modern years, the dimensions and materials of the blades of steam turbines have increased by raising the power of steam turbines. In preference to the wide-ranging application of turbo machinery and constant improvement of steam turbine blade materials and design techniques, steam turbine blade design and material behavior study technology have turned out to be a significant following in the line of investigation field. The optimized design and material behavior are the most significant factors limiting the efficiency of steam turbines, which is associated with the operating effectiveness of the steam turbines. On the other hand, because of the complicated form and the maximal effects of material behavior, it is not easy to predict and examine the behavior of the turbine blades for different geometrical shapes and materials by both the systematic method and an engineering generalization scheme. The forecasted finite element analysis method offers an efficient means to resolve those complicated project analysis and material behavior challenges. It can be utilized to establish the distribution of stress and heat flux in the entire blade geometry caused by the coupling effect of thermal stress distribution and axial loads on the blade structure. Attempts have been made to match the optimized blade thickness of the steam turbine by utilizing Finite Element Analysis.*

***Keywords:** Finite Element Method, structural and thermal analysis, Steam turbine blade.*

I. INTRODUCTION

Steam turbine blades are important as well as critical factors in thermal power plants to transform the steam's linear motion into rotary motion at turbine shaft [1]. The power plant will shut down if the turbine fails. It leads to the current failure and different losses. To enhance the trustworthiness of the turbine, various kinds of malfunction analysis are much needed [2]. A thermal power plant is typically producing electricity from fossil fuels' heat energy [3]. The electricity production devices undergo a variety of malfunctions because of its working conditions and such malfunctions have been produced by crack, fatigue, corrosion, erosion, and so on [4–10].

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The resultant efficiency of the steam turbines is enhanced with the help of adequate and well-scheduled maintenance work and the various malfunctions can be resolved through relevant malfunction analysis prior to the production of turbines [11]. Turbine blades design is the set of activities that includes the thermal, aerodynamical and structural effects. The consideration of thermal effects on the design of the turbine blade is to maximize the efficiency of the turbine, at the same time the various aerodynamical effects are the constraint factor of the turbine's performance. An optimization process is required to establish the objective function for the combined effects of thermal/aerodynamic activities on the steam turbine blades, whereas the structural design as constraints [12]. The malfunction of turbines is produced by several operating effects and external factors like the non-uniform distribution of thermal, stress and load. Corresponding material factors, operational and geometric parameters are proposed through a standard FEM. FEM i.e. Finite Element Method is comprehensively used to execute the structural and thermal analysis in steam turbine blades for the diverse working environment, dissimilar behavior of loads, material behavior and boundary conditions. At the current time, the power turbine components at thermal-energy technology applications have shattered their life spans or move towards their restraining values in a more rapid manner. In a reaction turbine, blades are undergoing repeated loading and it leads to failures because of non-uniform distribution of load, stress and temperature. Steam turbine blades are key elements in electricity generation, which transform the direct movement of high-pressure and high-temperature steam flows down a differential pressure into a rotating movement of the turbine shaft [13]. In order to anticipate the various failures which are happened in steam turbine blades because of the geometry of the blades and material behavior, it is essential to carry out the numerical investigation on the corresponding blades before it goes to manufacturing. FEM is extensively utilized in the steam turbine impeller blade subsystem strength analysis phase, but due to the problematical operating environment, the steam turbine has adopted various manipulations of loads and boundary conditions when utilizing a technique called finite element analysis [14]. Any type of deficiency is a widespread drawback of a steam turbine and its inability in-service leads to non-operating lost income, repair bills and security hazards. Thus, the consistency of those blades is significant for the effective function of a steam turbine [15]. Blades are considerable elements of steam turbines that are unsuccessful because of the stresses resulting from the flexural and centrifugal forces. A series of geometrical variables were included in the turbine blade that needs to be taken into account in the design phase [16].

The flow of steam is generated by axial loads and flexural forces on the steam turbine blades that are the reasons for malfunction because the stresses occur from axial loads and flexural forces [17].

A steam turbine blade has multiple numbers of design variables to design an exceedingly competent steam turbine. It is necessary to learn the numerous design intention functions and their performance of the steam flow. At the same time as the design stage, the steam turbine blades have multiple numbers of geometrical variables such as blade thickness; blade width, blades count, blade shape, etc. [18]. Based on the above literature, it shows that the numerical analyses of steam turbine blades are very essential to optimize its performance based on the design and other operating parameters. Therefore, this article investigates a comprehensive three-dimensional model of a typical steam turbine blade with dissimilar thicknesses by utilizing the finite element method. Based on the above literature we have found that the prediction of different failures in steam turbine impeller blades is highly essential to ensure its life under the specified operating conditions. So, this research focuses on the estimation of the distribution of von-mises stresses and total heat flux in typical steam turbine blades for various impeller blade thicknesses. A standard finite element method has been implemented in this work under the prescribed boundary conditions.

II. DESIGN AND ESTIMATION

A standard modeling software (Solid Works) was used to model the typical steam turbine blades. A wide-ranging three-dimensional model of steam turbine impeller with blades has been prepared by engrossing the different dimensions from the present.

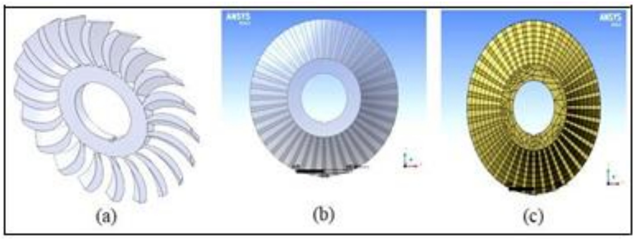

Figure 1 Steam turbine impeller with blades (a) Comprehensive three-dimensional model (b) Inclusive ANSYS imported model (c) Complete ANSYS meshed model.

In order to get the accurate and exact numerical results, analysis software (ANSYS 14.5) was used for FEA using the mess size of 1mm with triangular mesh type. The materials which were taken for the finite element analysis were assumed to be isotropic, elastic homogenous and linear. Modulus of elasticity, stress at yield point, Density and Poisson's ratio for turbine blade (Nickel Alloy) were taken as 205 GPa, 535 MPa, 0.25 and 7600 kg/m^3 respectively. Normally the steam turbine blades were subjected to carry the different range of forces due to the varying steam rate from the turbine, therefore in this numerical analysis, an axial force of 25 N has been applied to the blade. In all the three directions, the base part of the steam turbine impeller blade was preset. After the successful application of the different material characteristics and meshing parameters, the very next stage was moved towards the numerical analysis solution utilizing Finite Element Analysis (FEA). The thickness (t) of the steam turbine blades were selected as the variable parameter to carry out the numerical analysis. In this numerical finite element analysis, 6 unusual cases were prepared to estimate the distribution of Von Mises stresses and the amount of total heat flux in the root and tip portions of the steam turbine blades.

III. RESULTS AND DISCUSSIONS

The structural and thermal - finite element analysis was carried out on the steam turbine impeller blades numerically for dissimilar blade thickness i.e., 20.0 mm, 15.0 mm and 10.0 mm by describing the structural and thermal loads by means of an intention of discovering the most advantageous blade thickness for the greatest performance.

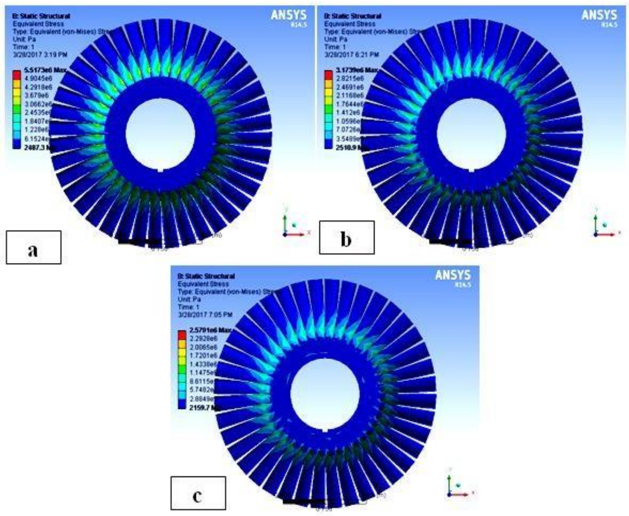

Figure 2 Equivalent Von-Mises stress distribution in steam turbine impeller blades for the blade of 10.0 mm, 15.0 mm and 20.0 mm thickness.

Initially, the steam turbine impeller blade with 10.0 mm thickness was selected and analyzed by mentioning 10.0 mm as blade thickness. Then by mentioning 300°C as inlet temperature of steam, the structural and thermal analysis was conducted on the other two-blade thickness, the appropriate von-misses stress distributions and overall heat flux have been observed.

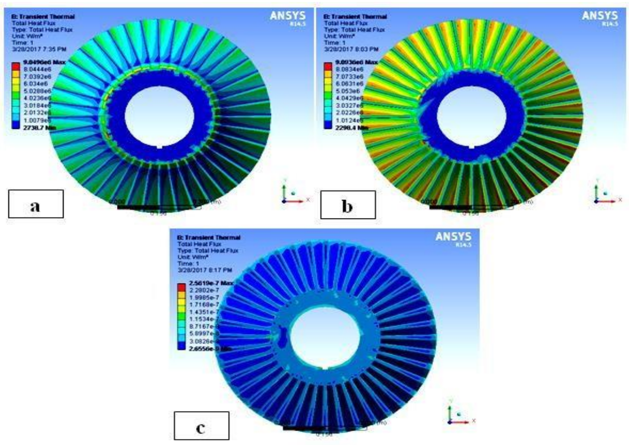

Figure 3 Total heat flux in steam turbine impeller blades of 10.0 mm, 15.0 mm and 20.0 mm thickness.

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The distribution of von-misses stress and total heat flux on steam turbine impeller blade thickness (with 10.0 mm) was much higher, when analyzed for blade thickness 15.0 mm and 20.0 mm.

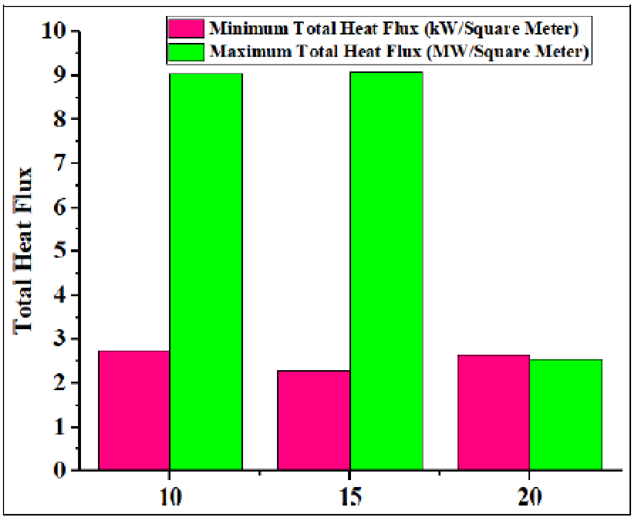

Figure 4 Maximal and minimal Von-Mises stress distribution in steam turbine impeller blades of 10.0 mm, 15.0 mm and 20.0 mm thickness.

When the blade thickness of 15.0 mm and 20 was proposed to be used, it is affected the performance of the steam turbine due to the lesser distribution of von-misses stresses and total heat flux from the blade root surface to the top surface. The distribution of von-misses stresses and heat flux, which are achieved from the numerical finite element analysis with blade thickness 20.0 mm, 15.0 mm and 10.0 mm are demonstrated in figure 2-3 respectively. The maximum von-misses stress distribution was observed from the root portion at the impeller base for all blades with a 10.0 mm, 15.0 mm and 20.0 mm of thickness respectively. Nevertheless, the minimum von-misses stress distribution was noted at the tip of the blades. In the same way, the

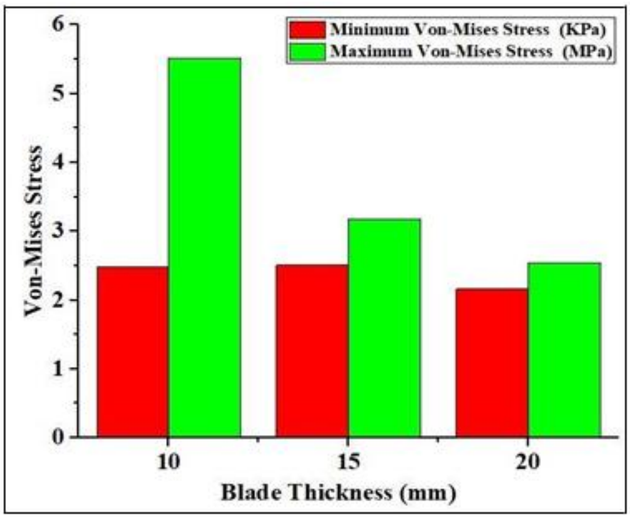

Figure 5 Maximal and minimal heat flux distribution in steam turbine impeller blades of 10.0 mm, 15.0 mm and 20.0 mm thickness.

Majority amount of heat flux was observed at the root portion in the impeller base. On the other hand, there is a very lesser amount of total heat flux at the tip of the blades. A lesser amount of Von-misses stress was observed in the steam turbine impeller base of the blade with 20.0 mm of thickness in comparison to blades with 10.0 mm and 15.0 mm of thickness. The minimal Von Mises stress distribution of 2.1597 kPa was noted for a steam turbine blade with 20.0 mm of thickness among the remaining two blades with 10.0 mm and 15.0 mm of thickness. Conversely, the highest Von Mises stress distribution of 5.5173 MPa was noted for a steam turbine blade with 10.0 mm of thickness among the remaining two-blade thickness (15.0 mm and 20.0 mm). The 9.0936 MW/m^2 of overall heat flux was acquired by a steam turbine blade with 15.0 mm of thickness. For the steam turbine blade with 20.0 mm of thickness, it was observed that the least total heat flux of 2.2298 W/m^2.

IV. CONCLUSION

A comprehensive three-dimensional model of a typical steam turbine impeller blade was modeled and analyzed using the standard modeling and analysis software package. In this numerical analysis, a typical finite element method was adopted to carry out the evaluation of von-misses stress distribution and total heat flux over the steam turbine impeller blades. The different blade thickness 10 mm, 15 mm and 20 mm were taken for this numerical analysis. According to the results of the structural and thermal analysis, it was found that the distribution of von-misses over the steam turbine impeller blade was higher at 10.0 mm blade thickness when compared with other blade thickness. The distribution of total heat flux on the steam turbine impeller blades for the blade thickness of 10.0 mm was higher when compared with other blade thickness. The distribution of von-misses stress and total heat flux which were obtained all the way through the finite element analysis indicated the lower values for the blade thickness of 20.0 mm. It was noted that the typical steam turbine impeller blades with 10.0 mm thickness consists of the most advantageous performance under the given operating environments.

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