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Investigation on Influence of Cooling Design in Structural Stability of CMSX-4 made Gas Turbine Guide Vanes

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Abstract: ***Recent decades researchers' attention focuses on minimizing thermal damages of materials in high temperature applications. Even though new materials invented for those applications, the problem still exists. The cooling is imperative for such components regardless of fixed or moving. This research deals with the structural analysis of impingement cooling design as well as a showerhead cooling design on gas turbine vanes made up of CMSX-4 material. CMSX-4 is a single crystal super alloy and developed for high temperature applications. The cooling design influences the structural stability of the guide vane. The investigation includes displacement, stress and strain analyses on both designs. The Pro-E employed for computer aided modeling and ANSYS R14.5 employed for finite element analysis. The results revealed that proposed showerhead cooling design is structurally more stable than conventional impingement cooling design.***

Keywords: *CMSX-4, Guide vane, Cooling Design, FEM, ANSYS*

1. Introduction

Application of gas turbine is vital and their design must ensure the safety in operation, less operating cost, reliable in operation with greater efficiency [1,2] Recent trend is to increase the temperature of inlet gas to boost up powder density and thermal efficiency [3,4]. Gas turbine blades and guide vanes are exposed to high temperature (1500°C) in the gas turbines. Even a small variation in blade or vane temperature will lead to reduce its life span by half [5]. For avoiding thermal damages, a jet of compressed air (at 650°C) is employed for upkeep the temperature of blades and vanes nearly 1000°C. A variety of cooling designs are available for that selection of appropriate design is very complicated task [4]. Because it involves the tasks on curved surfaces like developing turbulent layer, forming streamlines, numerical analysis, complex interaction etc. [5]. Many studies conducted cooling performances over curved surfaces some of them discussed here. [6] Studied the cooling impingement performance on the channel. [7] Investigated the turbulent slot jet cooling performance on concave plates with respect to the curvatures of impinging surfaces. The authors optimized cooling performance at R/L = 1.3. The R/L is a dimensionless value of the curvature. After conducting so many experiments the authors developed k-ε turbulence model. The model is still used for solving many cooling related issues on curved surfaces [8]. [9,10] investigation was on slot impingement cooling of the semi circular surface. k-Ɛ models is very useful and produces accurate results on cooling related problems on the impingement surface [11]. In couple of decades before [12] conducted experimental investigation as well as numerically investigation in showerhead cooling performance on turbine guide vanes. The authors reported that 18% and 44% heat reduction achieved at the leading edge [13] Studied the contribution of the hole size, location and quantity of them in cooling passage on gas turbine guide vanes. [14] Conducted numerical simulation to predict swirl cooling on the circular passage in two rectangular sections of internal leading edge of the blade. [15] Studied by Numerical investigation on the effect of rim seal and end wall flows of the turbine and its airfoil design parameters.

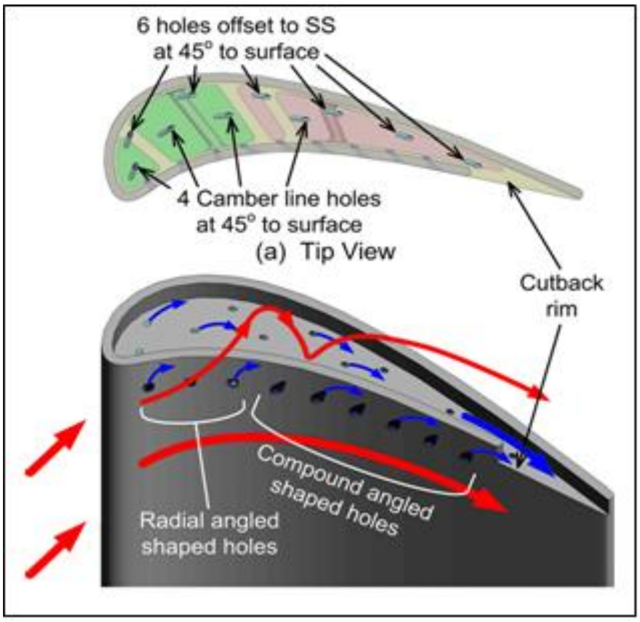

Figure 1: Guide vane with Impingement Cooling

ANSYS is generally employed for design Mechanical Machines, investigates alternate materials and their compatibility for the applications. For example Saravanan et al [16] designed Two-Wheeled Inverted Pendulum for the Material Handling. The authors used CATIA for 3D modelling of structural components like the handle, motor bracket,wheel Boss, support stem of handlebar, loading

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platform, base plate, Flange, support bracket, etc., and assembled them and analyzed by means of Finite Element Analysis in ANSYS work bench. Saravanan et al [17] investigated alternate material for the drive shaft. The authors considered composite materials like E-glass/epoxy proposed and Kevlar29/epoxy composites along with conventional steel of grade SM45. The ANSYS R14.5 is employed for FEA and found Kevlar29/epoxy composites reduced weight by 81.05%, 0.22% reduction of traditional stress and 57.1% increased buckling capacity than conventional steel.

This research focuses on the investigation influence of impingement cooling design and showerhead cooling design on CMSX-4 made gas turbine guide vanes' structural stability. The guide vanes fixed and arranged between two parallel covers and normal to the turbine shaft. The flow rate of the gases could be varied by adjusting them appropriately. The impingement type cooling is evident in many turbine blades and vanes. At the leading edge of the airfoils and at the mid-chord of the vane the heat loads are enormous. The jet impingement cooling and its sectional views are shown in figure 1. According to [12] findings film cooling performance can be improved by adding showerhead with fan-shaped holes. An optimal cooling design depends on many factors such as state of approaching flow, blowing ratio, hole shape, the number of cooling rows and cooling type. This investigation is focused with showerhead cooling in the place of impingement cooling type.

2. Materials and Methods

CMSX-4

The modern turbine blades are preferred to made up of single crystal super alloy for enhancing the life cycle. This material offers additional rupture, shock load strength, fracture toughness, and excellent coating properties. Hence such turbine exhibits outstanding performance and extended life span [18-21]. Due to its significant property, it reduces the required wall thickness (improves strength to weight ratio) i.e. reduces the weight [19]. CMSX-4 is such single crystal super alloy. Its chemical composition is described in Table 1.

Table 1: Chemical Composition of CMSX-4

Composition	*Weight%*
Ta	6.5
Hf	0.1
Al	5.6
Co	9.6
Ti	1
Mo	0.6
Cr	6.5
Ni	Bal
Re	3
W	6.4

Structural Analysis

Modeling

The cross section of the guide vanes were modeled in Pro-E. Their dimensions and profile particulars can be referred in Figure 2 for impingement cooling design and Figure 3 for showerhead cooling design. The conventional cooling design type is impingement and the showerhead cooling design is improved design. The 3D meshed model is shown in Figure 4 for impingement cooling design and Figure 5 for shower head cooling design. The messing contains 186 nodes.

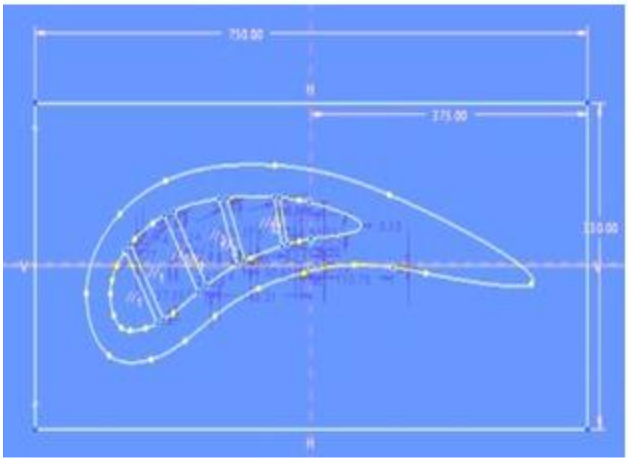

Figure 2: Profile and Dimensions of Guide Vane with Impingement Cooling Design

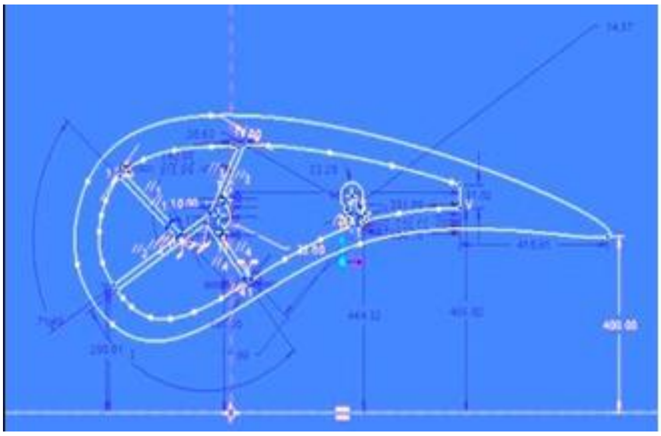

Figure 3: Profile and Dimensions of Guide Vane with Showerhead Cooling Design

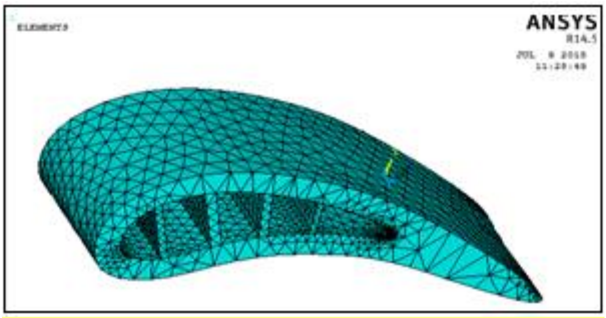

Figure 4: 3D Meshed model of Guide Vane with Impingement Cooling Design

Finite Elemental Analysis

The structural stability investigation includes displacement analysis, stress analysis and strain analysis. Such analysis was conducted by finite element methods by using ANSYS release14.5 software. The details of displacement analysis for impingement cooling design is shown in Figure 6 and for shower head cooling is in Figure 7. Similarly the stress analysis details for conventional and new cooling design in

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Figure 8 and Figure 9 respectively. The strain analysis particulars are shown for conventional cooling design in Figure 10 and for improved cooling design in Figure 11.

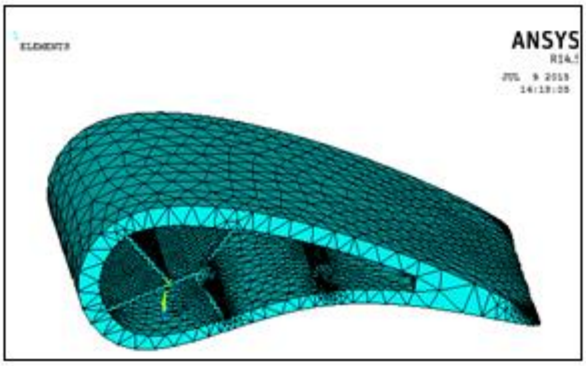

Figure 5: 3D Meshed model of Guide Vane with Showerhead Cooling Design

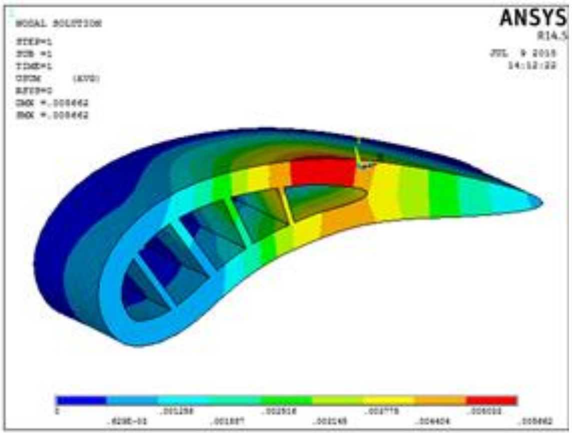

Figure 6: Displacement Analysis on Guide Vane with Impingement Cooling Design

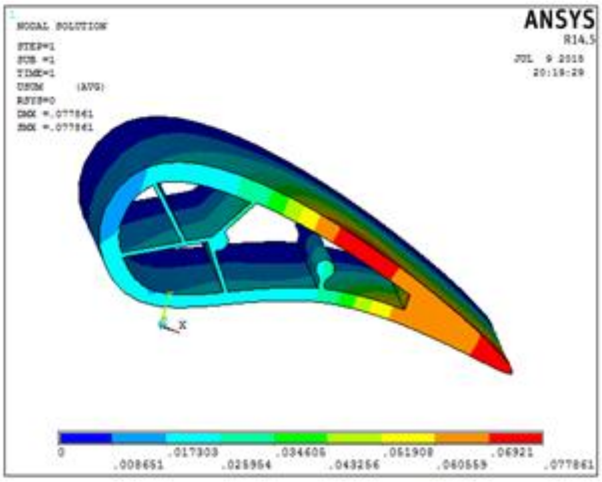

Figure 7: Displacement Analysis on Guide Vane with Showerhead Cooling Design

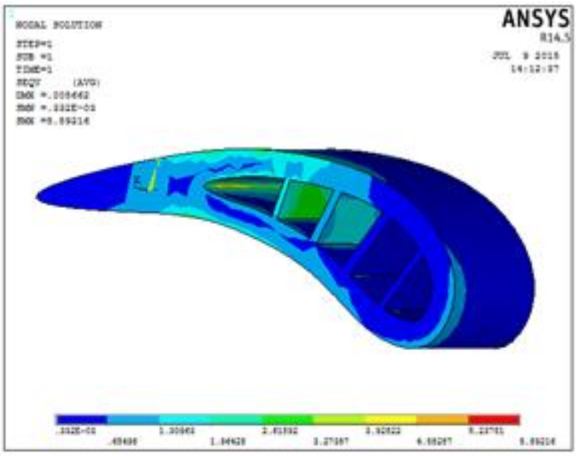

Figure 8: Stress Analysis on Guide Vane with Impingement Cooling Design

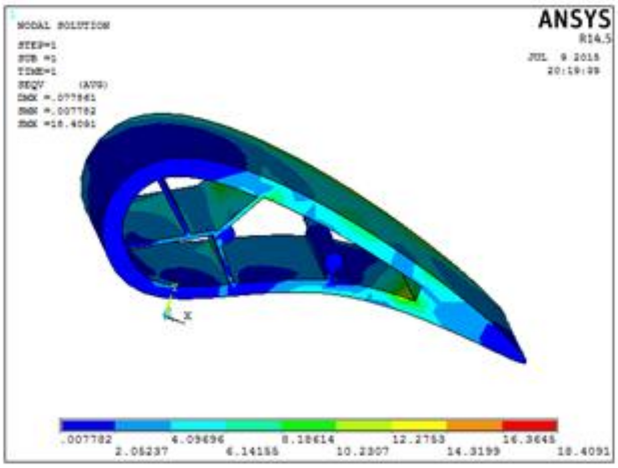

Figure 9: Stress Analysis on Guide Vane with Showerhead Cooling Design

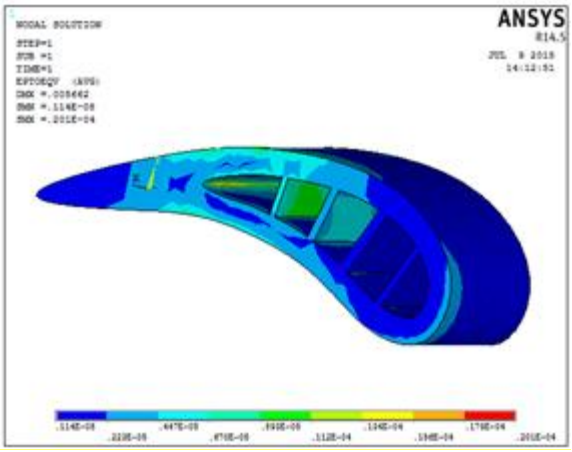

Figure 10: Strain Analysis on Guide Vane with Impingement Cooling Design

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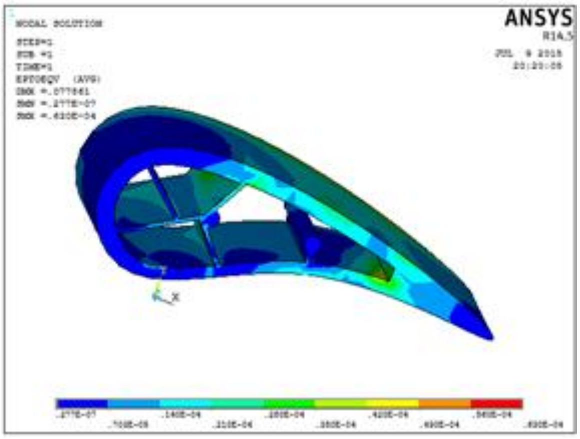

Figure 11: Strain Analysis on Guide Vane with Impingement Cooling Design

3. Results and Discussion

The displacement analysis resulted that 0.772948 mm higher than the conventional design. This means that the new design offers additional flexibility when load applied. Hence the lesser chance to break. In case of stress analysis 12.19884 MPa higher than conventional guide vane, which results that improved cooling design gives additional strength to withstand. The strain is 0.429E-04 more than conventional vane. This implied that the load bearing capacity increased significantly. The results are tabulated in Table 2. The results are compared, the displacement analysis results in Figure 12, stress analysis results in Figure 13 and strain analysis results in Figure 14.

Table 2 : Results of Structural Analysis

Results	*Impingement Cooling Design*	*Showerhead Cooling Design*
Displacement (mm)	0.005662	0.77861
Stress (N/mm^2)	5.89216	18.4091
Strain	0.201e-4	0.630e-4

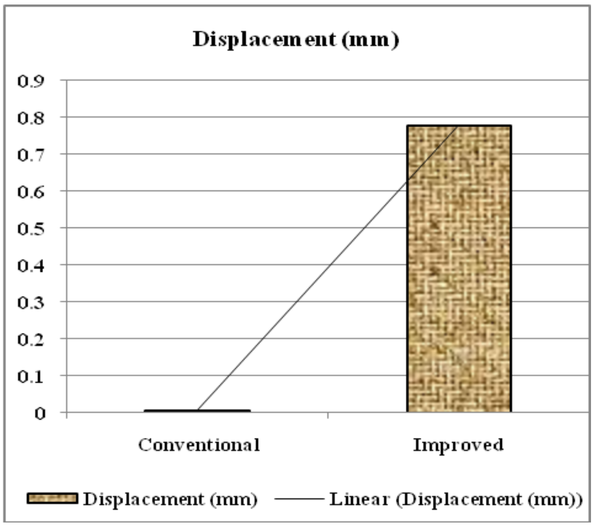

Figure 12: Comparative Results of Displacement analysis

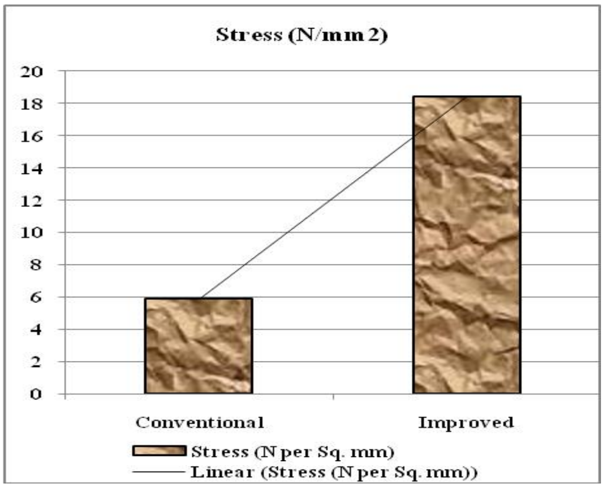

Figure 13: Comparative Results of Stress analysis

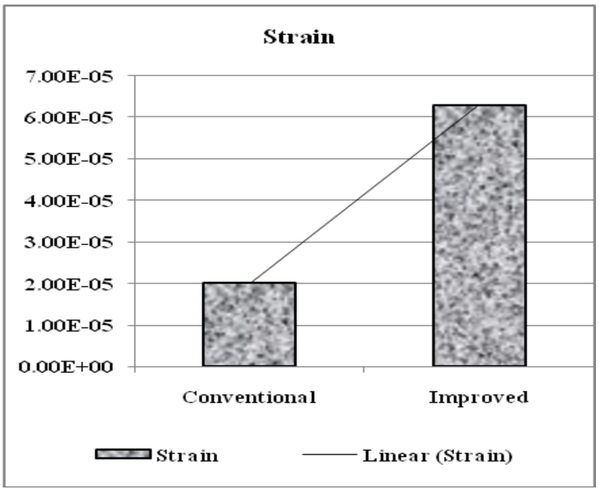

Figure 13: Comparative Results of Strain analysis

4. Conclusion

The cooling design influences on structural stability of CMSX-4 made gas turbine blades are considered for investigation. The displacement analysis, stress analysis and strain analysis were conducted successfully by using Pro-E and ANSYS. The results reveal that proposed blade design with showerhead cooling on of CMSX-4 made gas turbine blade is more stable, flexible and high stress bearing capacity than the conventional impingement cooling design on CMSX-4 made gas turbine blade. Hence it is ensured the stability of Present investigation ensures the structural stability of proposed blade design with showerhead cooling on of CMSX-4 made gas turbine blade. Some further investigation to be performed to ensure the desired cooling performances of the proposed design.

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