Thermal Modeling and Analysis of High Pressure Steam Turbine Outlet Nozzle

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Abstract - Steam turbine is an excellent prime mover to convert heat energy of steam to mechanical energy. Of all heat engines and prime movers the steam turbine is nearest to the ideal and it is widely used in power plants and in all industries where power is needed for process. In power generation mostly steam turbine is used because of its greater thermal efficiency and higher power-to-weight ratio. Because the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator about 80% of all electricity generation in the world is by use of steam turbines.

Nozzles come in a variety of shapes and sizes depending on the mission of the turbine, this is very important for the understanding of the performance characteristics of steam turbines. Convergent divergent nozzle is the most commonly used nozzle since in using it the turbines. In the steam turbine, solid particle erosion on a nozzle surface will damage the profile and smoothness of surface, which increases the flow loss of steam. In this thesis three different shapes of nozzles namely convergent divergent nozzle, Moore nozzle, Moses and Stein nozzle were analyzed to determine erosion rate, velocity, pressure and temperature distribution. Modeling of all shape of nozzle was done by using CATIA and CFD analysis was carried out by using ANSYS FLUENT.

Key Words: Nozzle, Erosion rate, ANSYS FLUENT

1. INTRODUCTION

Steam turbines are used in all of our major coal fired power stations to drive the generators or alternators, which produce electricity. The turbines themselves are driven by steam generated in 'Boilers 'or 'Steam Generators' as they are sometimes called .Energy in the steam after it leaves the boiler is converted into rotational energy as it passes through the turbine. The turbine normally consists of several stages with each stage consisting of a stationary blade (or nozzle) and a rotating blade. Stationary blades convert the potential energy of the steam (temperature and pressure) into kinetic energy (velocity) and direct the flow onto the rotating blades. The rotating blades convert the kinetic energy into forces, caused by pressure drop, which results in the rotation of the turbine shaft. The turbine shaft is connected to a generator, which produces the electrical energy.

1.1 Nozzle

Nozzle is a duct of varying cross sectional area in which the velocity increases with the corresponding drop in pressure. The flow of steam through nozzles may be regarded as adiabatic expansion. The steam has a very high velocity at the end of the expansion, and the enthalpy decreases as expansion takes place. Friction exists between the steam and the sides of the nozzle; heat is produced as the result of the resistance to the flow.

Types of Nozzles:

1. Convergent Nozzle
2. Divergent Nozzle
3. Convergent-Divergent Nozzle

In a convergent nozzle, the cross sectional area decreases continuously from its entrance to exit. It is used in a case where the back pressure is equal to or greater than the critical pressure ratio. The cross sectional area of divergent nozzle increases continuously from its entrance to exit. It is used in a case, where the back pressure is less than the critical pressure ratio. In Convergent-Divergent Nozzle, the cross sectional area first decreases from its entrance to throat, and then increases from throat to exit. It is widely used in many type of steam turbines.

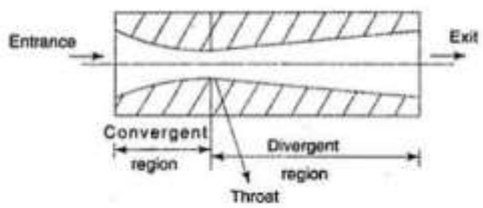

Fig -1: convergent-Divergent nozzle

In the steam turbine, solid particle erosion on a nozzle surface will damage the profile and smoothness of surface, which increases the flow loss of steam.

1.1 Erosion in Nozzle

Erosion is a degradation of material surface due to mechanical action, by impinging liquid, abrasion by slurry, particles suspended in fast flowing fluids, bubbles or droplets. The iron oxide scales exfoliated from the inner wall of the boiler tube and main steam pipe are known to erode the surface of the steam path. The severest erosion may be made in the governing stage nozzles of the steam turbine, which results in a reduction in unit efficiency and an increase in maintenance cost. Although the use of protective coatings and anti solid particle erosion (SPE) steam passage design has improved the erosion resistance of the nozzle, the nozzle life time is still shorter than the overall life of the steam turbine. At present, repairing the eroded nozzle or replacing it with a new nozzle is the most common method to recover the nozzle efficiency to the normal level. As is well known, prolonging the service time of the eroded nozzle will lower the unit efficiency and increase the fuel consumption, whereas shortening the service time of the eroded nozzle will increase maintenance cost. Therefore, a reasonable estimation of the economic lifetime of the eroded nozzle is very critical for reducing the economic losses induced by SPE.

In this study the CFD analysis of convergent divergent nozzles, Moore nozzle, and Moses and Stein nozzle was carried out by using ANSYS FLUENT. Modeling of different types of nozzles was done by using CATIA software.

2. Introduction to CATIA

CATIA is 3D modeling software used in mechanical engineering, design, manufacturing, and in CAD drafting service firms. It was one of the first 3D CAD modeling applications that used a rule-based parametric system. Using parameters, dimensions and features to capture the behavior of the product, it can optimize the development product as well as the design itself.

2.1 ADVANTAGES OF CATIA PARAMETRIC SOFTWARE

1. Optimized for model-based enterprises
2. Increased engineer productivity
3. Better enabled concept design
4. Increased engineering capabilities
5. Increased manufacturing capabilities
6. Better simulation
7. Design capabilities for additive manufacturing

2.2 CATIA parametric modules:

- Sketcher
- Part modeling
- Assembly
- Drafting

2.3 Modeling procedure of nozzles

Modeling process of different types of nozzle involve part module. First create the following shape of convergent divergent nozzle in sketcher module.

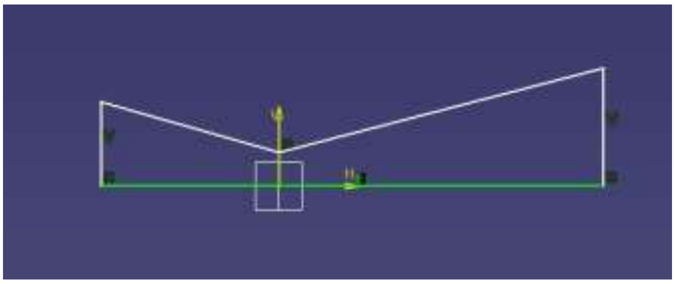

Fig -2: cross section of convergent divergent nozzle

Then go to part module and by taking shaft command convert the sketch in to three dimensional model.

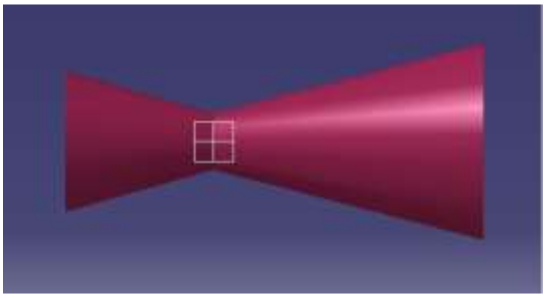

Fig -3: convergent divergent nozzle

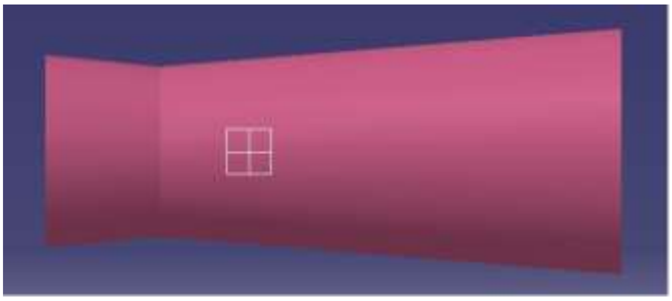

Fig -4: Moore nozzle

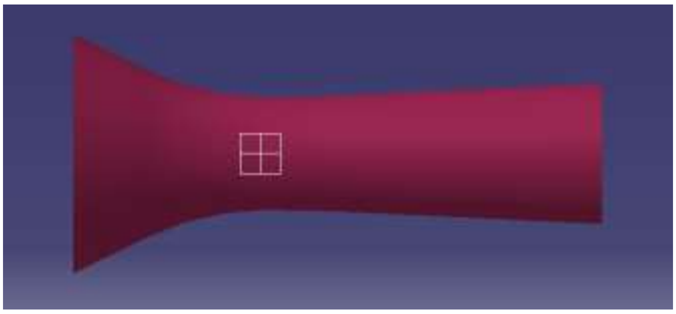

Fig -5: Moses and Stein nozzle

3. Introduction to Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) is an engineering tool that assists experimentation. Its scope is not limited to fluid dynamics; CFD could be applied to any process which involves transport phenomena with it. To solve an engineering problem we can make use of various methods like the analytical method, experimental methods using prototypes. The analytical method is very complicated and difficult. The experimental methods are very costly. If any errors in the design were detected during the prototype testing, another prototype is to be made clarifying all the errors and again tested. This is a time-consuming as well as a cost-consuming process. The introduction of Computational Fluid Dynamics has overcome this difficulty as well as revolutionized the field of engineering. In CFD a problem is simulated in software and the transport equations associated with the problem is mathematically solved with computer assistance. Thus we would be able to predict the results of a problem before experimentation.

CFD is an engineering tool that assists Experimentation.
The following steps were performed in CFD of nozzle:

a. Modeling
b. Meshing
c. Pre-Processing
d. Solution
e. Post-Processing

a. Modeling
The 3-Dimensional modeling of the nozzles was done using CATIA-V5 and file was saved in .igs format. The exported model was imported in to ANSYS Fluent for analysis.

b. Meshing
After importing the nozzle, its meshing was done using ANSYS FLUENT CFD software. The mesh as created of hexahedral shape elements with refines size.

c. Pre-Processing
Pre-processing of the nozzle was done in ANSYS FLUENT. 2-D and double precision settings were used while reading the mesh. The mesh was scaled since all Dimensions were initially specified in mm. The mesh was checked in fluent and no critical errors were reported.

d. Solution
The Solution Was initialized with hybrid method. Problem was submitted for convergence through run calculations option with 1000 number if iterations.

4. Analysis of nozzles using ANSYS FLUENT

- 3d model of nozzle was imported in to Ansys fluent
- Refine meshing was done.
- Bronze as solid material and steam as fluid material was assigned in material property. Steam with iron oxide impurities was considered for erosion analysis.
- Common inlet conditions were considered for all cases of analysis. Inlet velocity of 5 m/s and pressure of 78000 pas was taken as boundary conditions.

5. Results and Discussion

With the above stated input conditions the analysis was done and the required parameters were calculated.

5.1 Moore nozzle

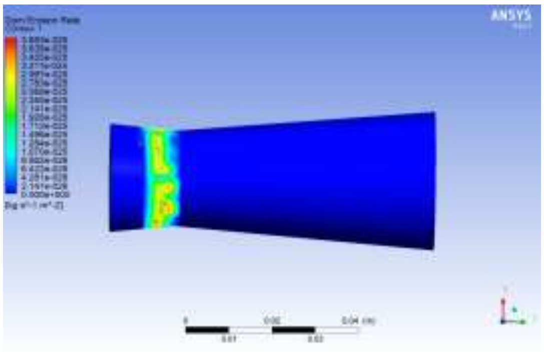

Fig -6: Dpm Erosion rate in moore nozzle

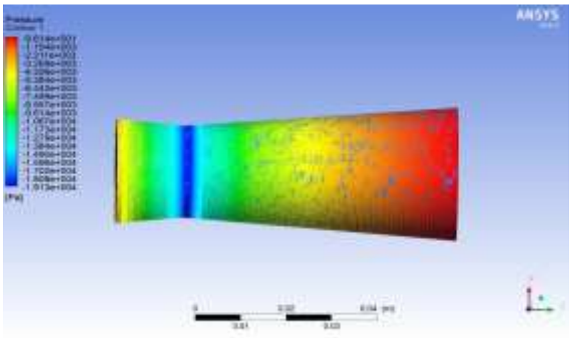

Fig -7: Pressure distribution in moore nozzle

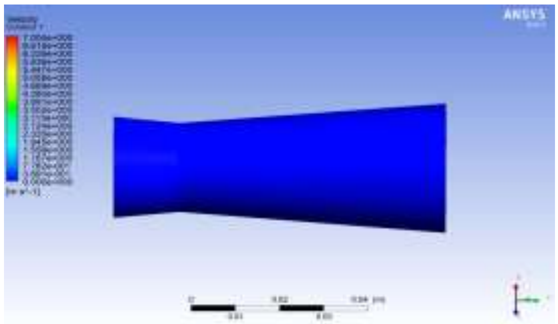

Fig -8: Velocity distribution in moore nozzle

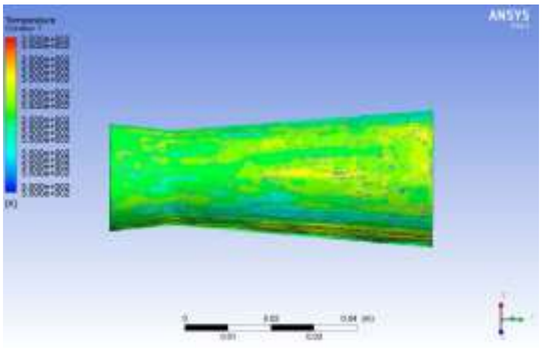

Fig -9: Temperature distribution in moore nozzle

5.2 Moses and Stein nozzle

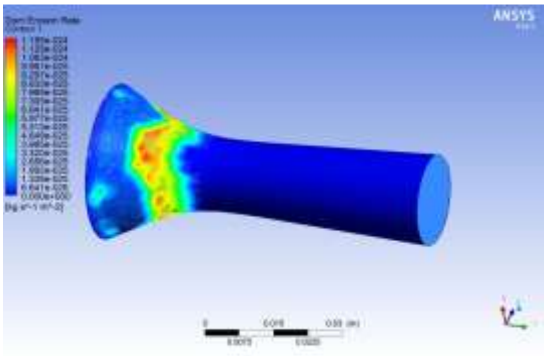

Fig -10: Dpm Erosion rate in Moses and Stein nozzle

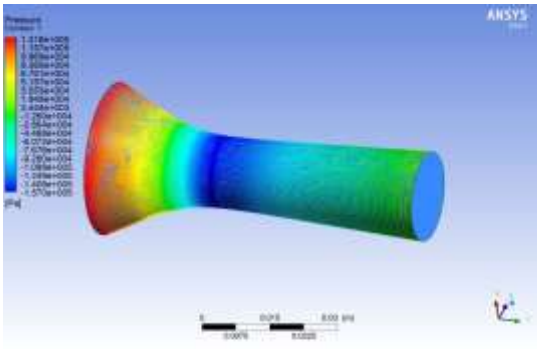

Fig -11: Pressure distribution in Moses and Stein nozzle

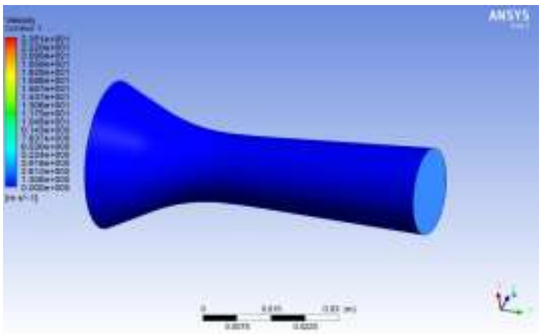

Fig -12: Velocity distribution in Moses and Stein nozzle

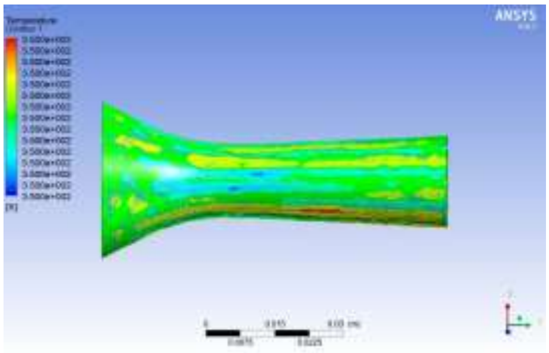

Fig -13: Temperature distribution in Moses and Stein nozzle

5.3 Convergent divergent nozzle

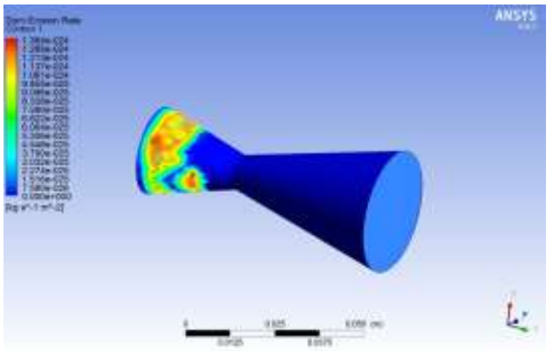

Fig -14: Dpm Erosion rate in convergent-divergent nozzle

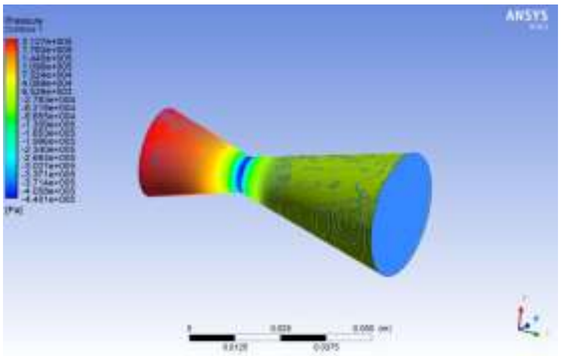

Fig -15: Pressure distribution in convergent-divergent nozzle

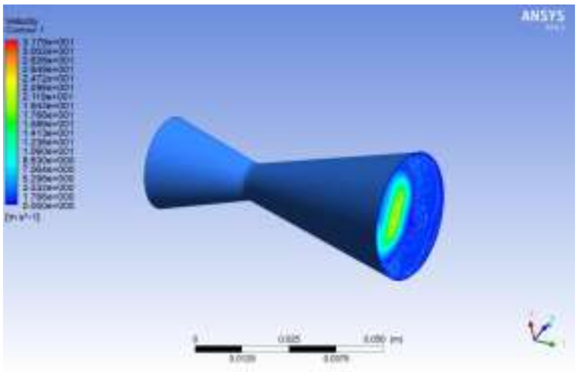

Fig -16: Velocity distribution in convergent-divergent nozzle

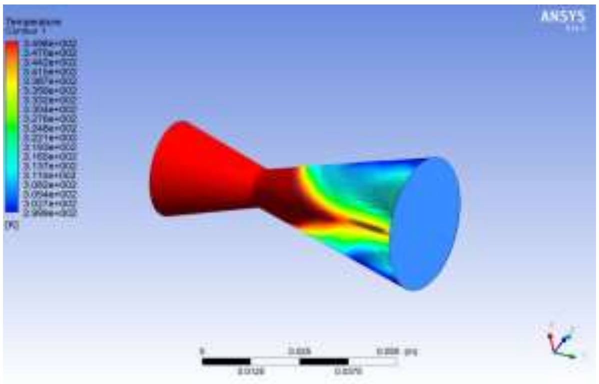

Fig -17: Temperature distribution in convergent-divergent nozzle

The three different types of nozzle ware analyzed. The comparative results were tabulated in the following table.

Table -1: comparison of three types of nozzle

Type of nozzle	Erosion rate Kg/m2-s	Velocity m/s	Pressure pa	Temperature k
Moore nozzle	3.85e-25	7.0	-9.61e1	350
Moses &Stein nozzle	1.19e-24	23.51	1.31e5	350
Convergent divergent nozzle	1.36e-24	31.95	2.12e5	300

6. CONCLUSIONS

Thermal modeling and analysis of high pressure steam turbine nozzle was done by using ansys fluent. Erosion rate, velocities, pressure and temperatures were calculated for three different types of models. From the above results it is observed that the erosion rate is minimum in Moore nozzle, but outlet velocity is minimum when compared with other models. Velocity is maximum in convergent divergent nozzle and erosion rate is also comparatively minimum. Finally it is concluded that among the three types of nozzles convergent divergent nozzle will gives us better performance.

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