Design and Analysis of Steam Turbine Nozzle

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Abstract - In the field of energy conversion, Steam turbines play a crucial part. The design and operational procedures of steam turbine is highly advanced and considered as fully fledged technological components. This steam turbine converts heat energy of steam to mechanical energy. Every industry comprises of these turbines for they regarded as a perfect replacement of many heat engines and prime movers and also used in power plants for possessing greater thermal efficiency and high power to weight ratio.

Above all, the turbine is an assembly of nozzles which were used to generate high kinetic energy. These nozzles are great devices for understanding the working features of steam turbines. A different kinds of sizes and shapes of nozzles are feasible, among those Convergent Divergent nozzle is frequently used. When steam turbine works the flow loss of steam increases as the disrupt of profile and surface smoothness occurs because of solid particle erosion on nozzle surface.

In this project, different shapes of nozzles are considered and were analyzed to determine velocity, pressure and temperature distributions and erosion rate. CATIA software is used for the modeling of all shapes and CFD analysis was executed by using ANSYS FLUENT.

Key Words: steam turbine nozzle, CATIA, 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 Introduction to steam turbine nozzle

Nozzles are wont to guide the steam to hit the moving blades and to convert the pressure energy into the K.E. within the case of small turbine, the nozzles are located within the lower half the casing. But within the case of the larger turbine, the nozzles are located on the upper half the casing. During this work we mainly focused on nozzles and its types.

In a great number of machines the work is performed at the expense of external K.E. of the working fluid. The K.E. of working medium may change during a passage of varying cross-section. If a steam flowing along a passage expands, leading to a decrease in pressure and increase in speed, such a passage or duct is named nozzle. Flow of steam through a nozzle may be a vital aspect of turbine design. The passage of varying cross-section designed to extend the speed of fluid as a results of decrease in pressure is named nozzle. Nozzles are frequently wont to control the speed of flow, speed, direction, mass, shape, and/or the pressure of the stream that emerges from them. During a nozzle, the speed of fluid increases at the expense of its pressure energy.

1.2 Types of steam 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's utilized in a case where the rear pressure is adequate to or greater than the critical pressure ratio. The cross sectional area of divergent nozzle increases continuously from its entrance to exit. It's utilized in a case, where the rear pressure is a smaller amount than the critical pressure ratio. In Convergent-Divergent Nozzle, the cross sectional area first decreases from its entrance to throat, then increases from throat to exit. It's widely utilized in many sorts of steam turbines.
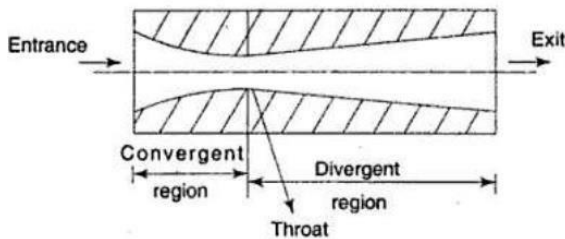
Fig 1: Convergent Divergent Nozzle

1.3 Types of convergent divergent nozzles

1. Convergent-divergent nozzle
2. Moore nozzle
3. Moses and stein nozzle

The objective of this work is to form analysis on the above three differing types of nozzles and suggest which one is best. While making the analysis on the nozzle within the present work we also consider the erosion factor on the surface of the nozzle.

1.4 Erosion in nozzles

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 CATIA parametric modules:
▪ Sketcher
▪ Part modeling
▪ Assembly
▪ Drafting

2.2 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
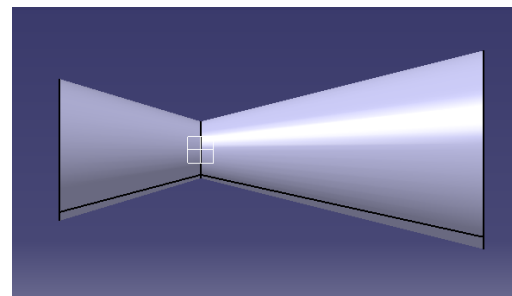7. Design capabilities for additive manufacturing
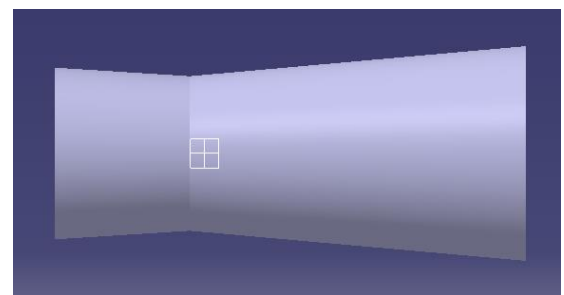

Fig 2: convergent divergent nozzle
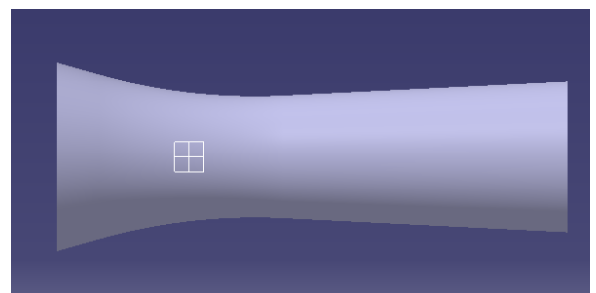

Fig 3: Moor nozzle

Fig 4: 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

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.
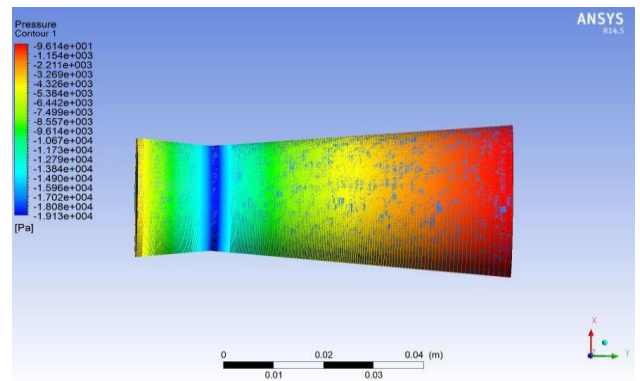

Fig -6: Dpm Erosion rate in Moore nozzle

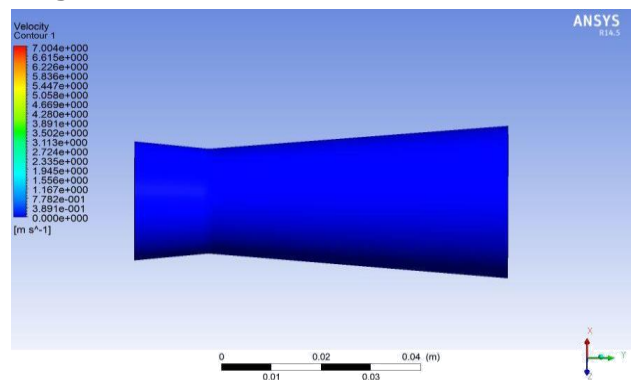**Fig -7:** Pressure distribution in more nozzle

Fig -8: Velocity distribution in more nozzle
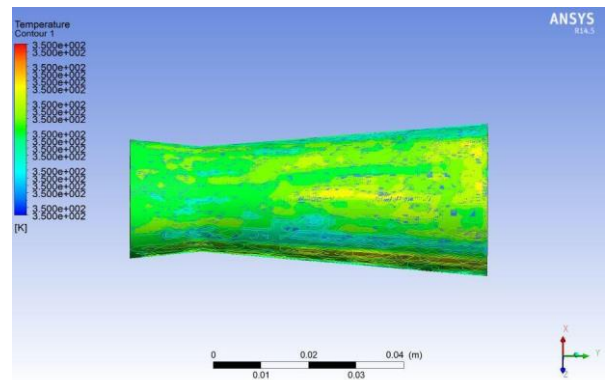
Fig -9: Temperature distribution in more nozzles
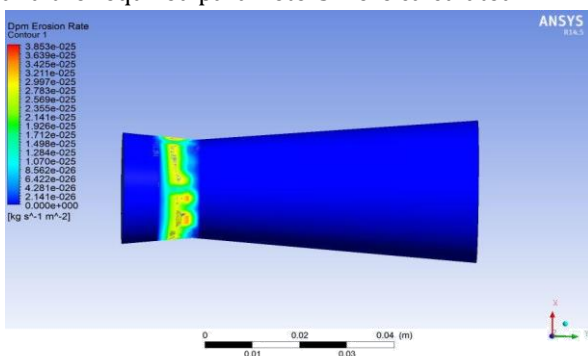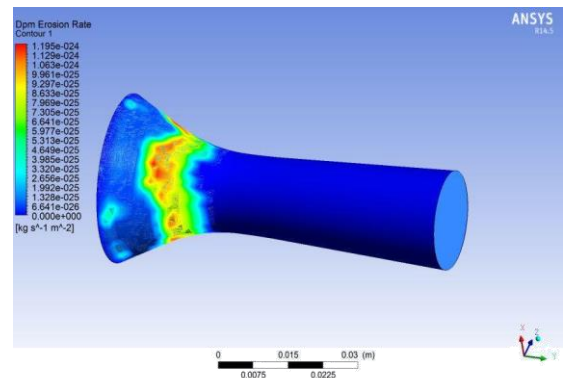

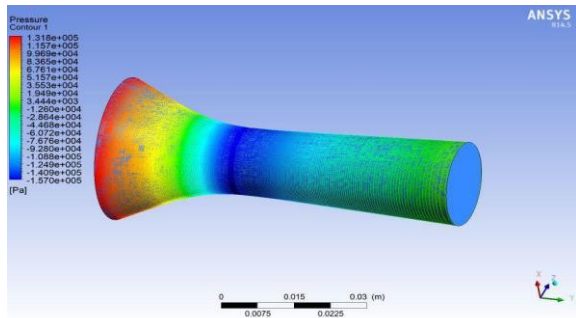**Fig -10**: DPM Erosion rate in moses & stein nozzle

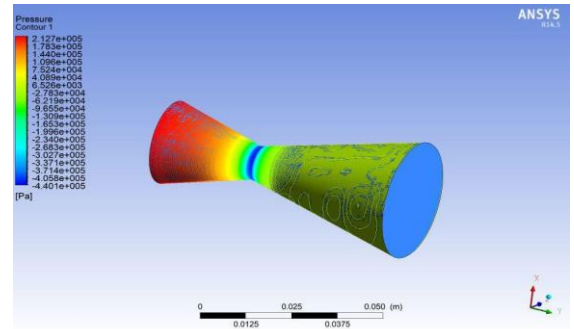**Fig-11**: pressure distribution in moses & stein nozzle

Fig-15: pressure distribution in convergent divergent nozzle
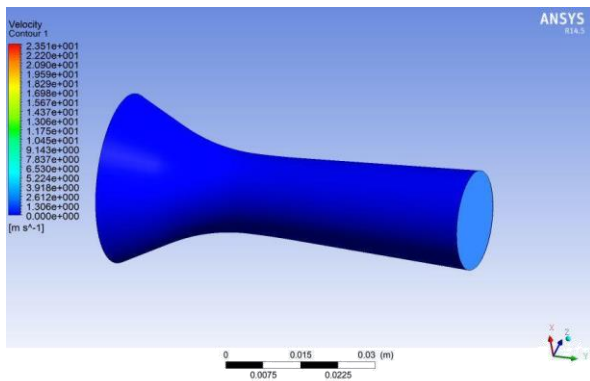

Fig-12: Velocity distribution in moses & stein nozzle
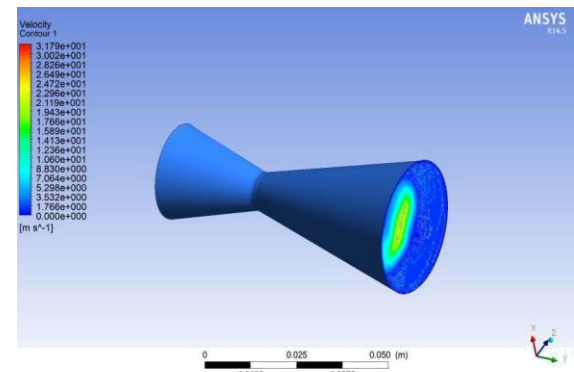

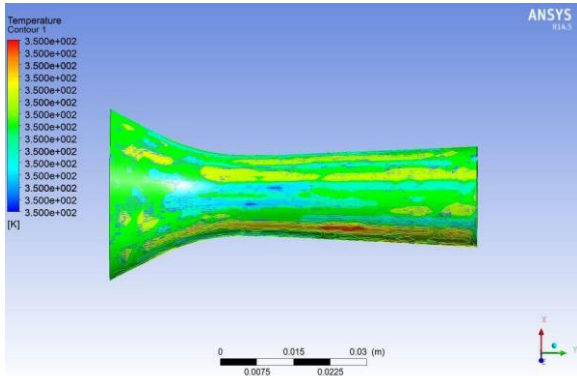**Fig-16**: Velocity distribution in convergent divergent nozzle

Fig-13: Temperature distribution in moses & stein nozzle
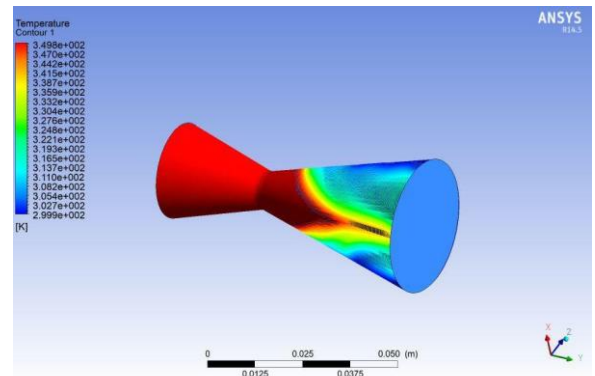

Fig-17: Temperature distribution in convergent divergent nozzle

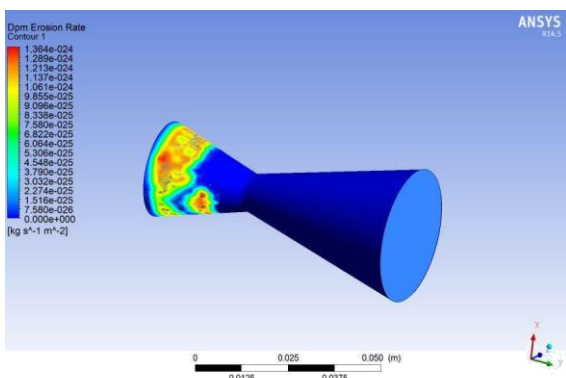**Fig -14**: DPM Erosion rate in convergent divergent nozzle

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

Table-1: comparative results of 3 types of nozzles

6. CONCLUSIONS

In the present work, by using ANSYS Fluent flow analysis on steam turbine nozzle was done. Velocities, pressure, temperatures and Erosion rate, were determined for three types of nozzles i.e Moore nozzle, Moses nozzle and convergent divergent nozzle. From the obtained results it was found in Moore nozzle the rate of erosion 3.85e-25 Kg/m^2-s is minimum, and velocity at outlet 7.0 m/s is less when compared with other nozzles. Outlet Velocity 31.95 m/s is maximum in convergent divergent nozzle and erosion rate 1.36e-24 Kg/m2-s is also comparatively less. At the end of this work it was concluded that among the three nozzles convergent divergent nozzle will be preferable.

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