Evaluating Performance of Steam Turbine using CFD

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Abstract- CFD study was carried out for evaluating the performance of a utility Steam Turbine IP Module. The flow in a turbine blade passage is complex and involves understanding of energy conversion in three dimensional geometries. The performance of turbine depends on efficient energy conversion and analyzing the flow path behavior in the various components IP Steam Turbine. The CFD analysis of the turbine flow path helps in analyzing the flow and performance parameters and their effects on performance parameters like temperature, pressure and Power output. The CFD analysis of the Intermediate Pressure turbine module has helped in predicting the turbine performance and comparing with experimentally verified values.

Keywords – CFD, Steam Turbnie, Internediate Pressure

I. INTRODUCTION

Steam turbine plays a vital role in power generation as a prime mover [1,2], which converts Kinetic Energy of steam to Mechanical Energy. Many of the utility steam turbines are of three cylinder constructions i.e. High pressure cylinder in which pressure is maximum with minimum specific volume and so blade height is minimum, Intermediate pressure cylinder in which pressure is intermediate so the blade height is intermediate and Low pressure cylinder which has a minimum pressure level & maximum specific volume and hence LP cylinder blade height is maximum.

A typical Intermediate pressure Turbine of utility steam turbine is chosen to carry out the CFD analysis**.** The analysis requires solving of fluid problem in bladed region. This can be done in three approaches, Analytical, Experimental and Numerical. Analytical methods which assume a continuum hypothesis are more suited for simple problems and are not suited for complex fluid flow problems. Experimental methods are suited for complex fluid flow problems but the expenditure for carrying out the analysis is high. The other limitation is that the determination of the fluid characteristics in the interiors becomes complex and difficult. Hence, Numerical approach is more feasible approach for analysis of a particular design because it overcomes the limitations of the two methods and it gives a close approximate for complex form of fluid problems too. Numerical approach involves discretization of the governing mathematical equations gives numerical solutions for the flow problems [3,4].

The analysis is carried out by identifying the flow domain. The domain is modelled; discretized and governing equations are solved using commercially available software. The results are post processed and compared with 2 dimensional program results which were experimentally verified.

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II. STEAM TURBINE

A steam turbine is a mechanical device that extracts thermal energy from pressurized steam and converts it into rotary motion. It has almost completely replaced the reciprocating piston steam engine primarily 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. The efficiency of a turbine is largely dependent on its aerodynamic performance. Hence, the design of blade profiles for stators and rotors are continuously improved over the decades to achieve better overall efficiency for the turbine.

A further explanation of Turbine is that it is a rotary device that affects an exchange of energy between a flowing fluid and a rotating shaft. In a steam turbine, electricity generation takes place in 3 steps [5]:

- The available energy in the hot and high pressure steam is first converted into kinetic energy by the expansion of steam in a suitably shaped passage known as nozzle from which it issues as a high velocity jet having a high tangential component.
- Then a part of this kinetic energy and sometimes part of the pressure energy are converted into mechanical energy by directing the jet at a proper angle, against curved blades mounted on a rotating disc.

The rotor coupled to generator produces the electricity.

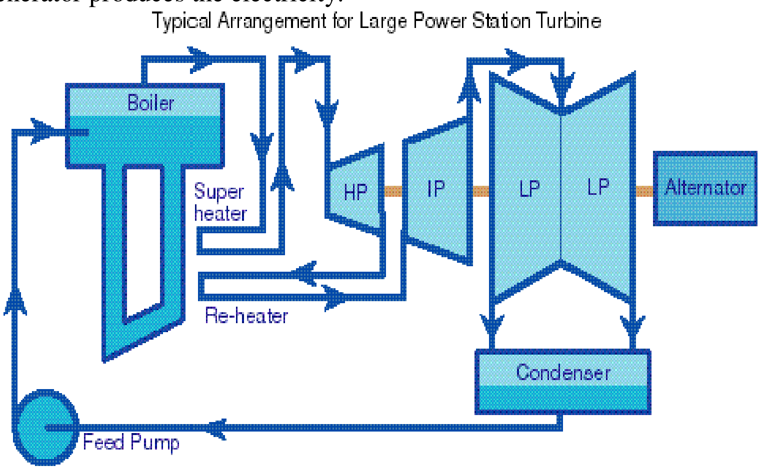

Fig 1: Typical Arrangement for Large Power Station Turbine

A. Working Principle of Operation –

The motive power in a steam turbine is obtained by the rate of change in momentum of a high velocity jet of steam impinging on a curved blade which is free to rotate [2,3,6]. The steam from the boiler is expanded in a nozzle, resulting in the emission of a high velocity jet. This jet of steam impinges on the moving vanes or blades, mounted on a shaft. Here it undergoes a change of direction of motion which gives rise to a change in momentum and therefore a force.

Steam Turbines are widely used for the generation of electricity in a number of different cycles, such as Rankine cycle, Reheat cycle, Regenerative cycle and Combined cycle. Consider the steam turbine shown in the cycle above. The output power of the turbine at steady flow condition is:

$$\mathbf{P = m\,(h_1\text{-}h_2)}$$

Where **m** is the mass flow of the steam through the turbine and **h1** and **h2** are specific enthalpy of the steam at inlet and outlet of the turbine respectively.

An ideal steam turbine is considered to be an isentropic process or constant entropy process, in which the entropy of the steam entering the turbine is equal to the entropy of the steam leaving the turbine. The efficiency of the steam turbine is often described by the isentropic efficiency for expansion process. No steam turbine is truly “isentropic”, however, with typical isentropic efficiencies ranging from 20%-90% based on the applications of the turbine. The presence of water droplets in the steam will reduce the efficiency of the turbine and cause physical erosion of the blades. Therefore the dryness fraction of the steam at the outlet of the turbine should not be less than 0.9. Steam Turbine consists of several stages. Each stage can be described by analyzing the expansion of steam from a higher pressure to a lower pressure. The steam may be wet, dry saturated or superheated.

IV. RESULTS AND DISCUSSION

The analysis is carried out in two stages. First, individual stage analysis is done and later combined analysis for all the 5 stages has been carried out. The stage analysis has been carried out for the turbine stages with the constant mass flow and it consists of stator, rotor, and seals. The various performance parameters like pressure, temperature distribution and velocity profiles on the blades, isentropic efficiencies, Power have been computed using the CFX Macros and with the help of Mollier Chart. As the eight stages consisting of Guide blade, Moving blade with a stage interface between the blades is simulated, and the solution is obtained with high resolution convergence up to 1e-5.The analysis is carried out without and with seals for 8^{th} stage.

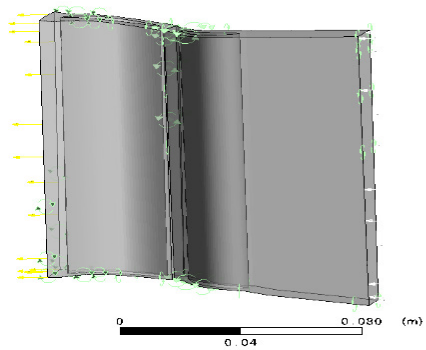

Fig 2: 8th stage with seal

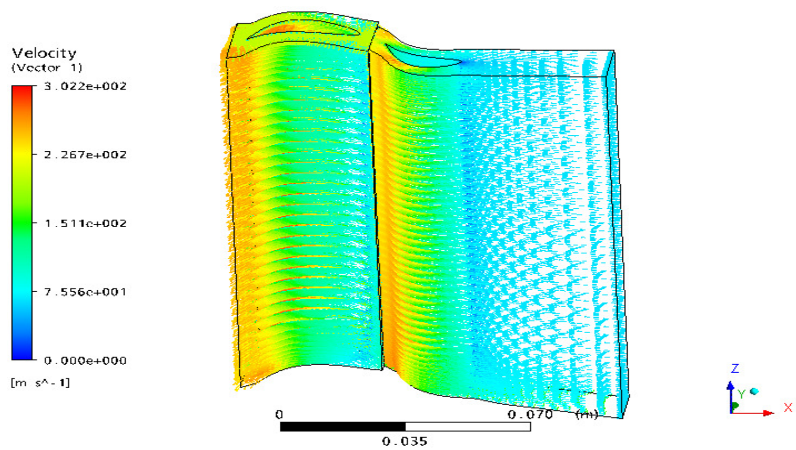

Fig 3: 8th stage vector plot without seal

shows the variation of the velocity across the eighth stage without seals. This vectors plot, which is a collection of vectors drawn to show the direction and magnitude of a vector variable on a collection of points are defined by arrows. From the figure, it is obvious that the velocity is minimum at the entrance which is of 7.556 m/sec and maximum at the blade throat of the stage which is around 302.2 m/sec.

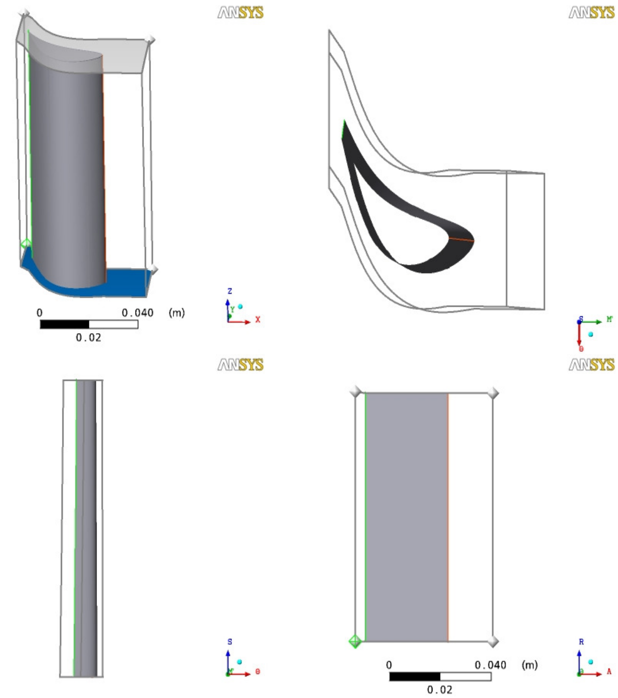

Fig 4: Views for 8th stage guide blade

The figure shows the variation of Mach number across the 8th stage without seals. From the figure it is obvious that Mach number is increasing from the entry to exit and Mach number is minimum of the order of 0.05438 occurred at the entrance of the guide blade and is maximum of 0.4894 is occurred at the blade throat of guide and moving blade. The variation of pressure across the stage is seen in the figure, the pressure contour plot which is a series of lines linking points with equal values of a given variable pressure. The variable values can quickly be associated with the colored regions of the plot. It is shown in the figure that the pressure goes on decreasing from entry to exit of the stage. At the entrance the maximum of 18.67 bar is observed and a minimum of 14.59 bar is obtained at the exit is obtained.

In the pre processing the following fluid domains and boundary conditions are specified for the eight stage analysis.

1. Boundary Conditions:
   - Inlet : Guide blade inlet
   - Outlet : Moving blade outlet
   - Inlet Mass Flow : 1.199795 kg/sec
   - Inlet Static Temperature : 688.8 K
   - Wall : smooth
   - Outlet Static Pressure : 18.04 bar
   - Rotational Speed : -3000 rpm
   - Reference pressure : 0 bar
2. Fluid Properties:
   - Working Fluid : Steam5 (Dry steam)
   - Dynamic Viscosity : 25.0746e-6 Pa s
   - Thermal Conductivity : 0.0581942 W/m. ºc
3. Turbulence Model:
   - Turbulence Model : Standard k-Epsilon Model
   - Heat transfer Model : Total Energy
4. Interface between Guide and Moving Blade:
   - Type : Fluid -Fluid
   - Frame Change Option : Stage Interface(G8M8 Blade stage interface)
5. Pitch Change:
   - Option: Specified Pitch Angle
   - Pitch angle side 1: 2.465753

- Pitch angle side 2: 3.130435

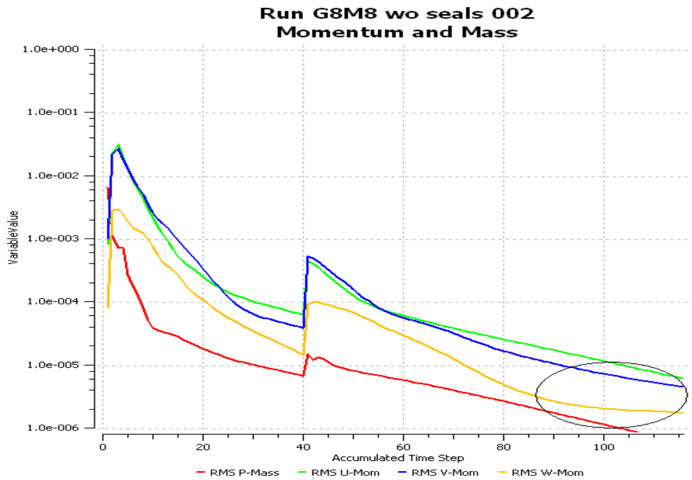

Fig 5: Convergece Graph for with seal

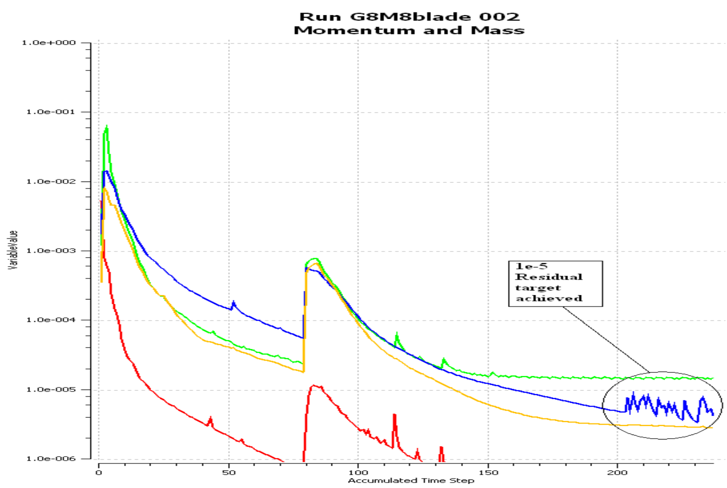

Fig 6: Convergece Graph for with out seal

Table 1 : Table showing different physical parameters

Torque (one blade row)	-233.017 kg m^2 s^-2
Torque (all blades)	-26769.6 kg m^2 s^-2
Power (all blades)	-8.03908 +06 kg m^2 s^-3
Total-to-total isen. efficiency	0.925874
Total-to-static isen. efficiency	0.851417
Total-to-total poly. efficiency	0.924548
Total-to-static poly. efficiency	0.848757

V. CONCLUSION

The results are analyzed for mass flow rates, temperature and pressure distributions on blades, power developed by stage and isentropic efficiency of the stage. The results are compared with Two-Dimensional program validated by experimentally and found to be in agreement with the 2D analysis. The CFD analysis of the Intermediate Pressure turbine module has helped in predicting the turbine performance and comparing with experimentally verified values. The analysis provided insight in to the flow field of the turbine blade path. Though the stage's performance is reasonable scope exists for further improving the performance by reducing the leakage losses and modification of the blade profiles. The analysis also helps to carry out low pressure turbine blade path which uses cylindrical and twisted blades.

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