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DEVELOPMENT OF COMPACT TYPE TOP COVER OF FRANCIS TURBINE USING FINITE ELEMENT ANALYSIS

Md. Waliullah[1], Arun Patel[2]
[1]PG Student, [2]Asst. Professor,
[1]Department of Mechanical Engineering, NRI Institute of science & Technology,
Bhopal, Madhya Pradesh, India

Abstract: Top Cover is a fabricated structure of carbon steel plates (ASTM A 516 Gr 60, 70/ IS2062 or equivalent). It is an important sub-assembly of Guide Apparatus of Francis Turbine. When the pressurized water enters below the Top Cover, high structural stresses and strain develop and if these stresses and deformation exceed the designed values, the failure take place. Top Cover is designed so as to avoid deformation which may lead to seizure of guide vane movement. Design of Top Cover must provide adequate rigidity against cover deflection, servo reaction loading, G.V. reaction and bearing loads. Top Cover must be designed so as to provide suitable access in the Top Cover for maintenance of the Shaft Seal without removal of the Top Cover. To avoid the structural failure of Top Cover and seizure of guide vane movement, structural stress and deformation must be reduced to safe allowable limits. In this dissertation work an attempt will be made to design a high strength compact Top Cover which will result in small Guide Vane Trunnion and ultimately small power house. The ultimate objective is to reduce the cost of Power house by reducing the size of Top Cover. The Top Cover will be heavily constructed, adequately ribbed and shaped so as to reduce the structural stress and deformation by means of Finite Element Analysis (FEA / FEM). UX NX 3D software have been used for solid modeling. Finite Element Analysis have been carried out by using commercial simulation software, namely NASTRAN / ANSYS. Based on FEM of three variants, shape and dimension have been freeze and finally compact, robust, reliable and maintenance free Top Cover has been designed.

Index Terms: Francis Turbine, Top Cover.

I. INTRODUCTION

Hydro power is a renewable resource for energy. Hydro power is major contributor in green & clean energy. About 50% of total electricity generation in 66 countries of the world is hydroelectricity and 24 countries are also where 90% of total electricity generation is hydroelectricity. Installed capacity of hydro power in our country India is about 12.35% (~ 45.699 GW) of total installed capacity. A recent report by FICCI and Price Waterhouse Coopers has revealed that in the near future, there is a possibility of adding 13 gigawatts hydroelectric power to the installed capacity.

Hydro Power is the only viable option for "clean energy-green energy" and major source of renewable energy. It is the cheapest and pollution free source of electric power. Other advantages of Hydro Electric Power as follows:

- Cheap and immune to inflation.
- In-exhaustible.
- Operate at high efficiency level.
- Ideal peaking partner of base load.
- Robust- reliable- least maintenance.
- Quick loading / unloading flexibility.
- Multi-purpose benefits.
- Pollution free.

Hydro Turbine is large complex machinery, which is tailor-made to suit the discharge and head conditions prevalent at a particular site. Francis Turbine is versatile variant of Hydro Turbine due to its head range. It works between 30 meter to 600 meter. Guide Apparatus is critical assembly of Francis Turbine. Top Cover is important sub-assembly of Guide Apparatus. This work is based on compact, robust, reliable and maintenance free design of Top Cover.

FUNCTIONS OF TOP COVER AND ITS BASIS OF DESIGN

The Guide Apparatus of Francis Turbine imparts to the water the required direction at the entry to the runner blades, and regulates the discharge according to the load and the rotational speed of the generator. The Guide Apparatus is considered to be heart of reaction turbine which distributes the required amount of water in desired direction to the runner.

The Guide Apparatus consists of a Top Cover, a Pivot ring, a Regulating ring, a set of Guide Vanes and Turning Mechanism etc. Top cover is very important and critical component of Guide Apparatus. Therefore, optimum, compact and reliable design of Top Cover is very much essential. Design Considerations of Top Cover

- Top Cover is designed so as to avoid deformation which may lead to seizure of guide vane movement. That means we will have to restrict deformation of Top Cover near Guide vane area in the allowable limit.
- Top Cover must be robust enough to support Shaft Seal, Guide Bearings etc. That means stresses develop must be restricted within allowable limit.
- Top Cover must be designed so as to provide suitable access in the Top Cover for maintenance of the Shaft Seal without removal of the Top Cover.
- Efforts will be made to use RIBS as much as possible in place of solid cylinder or Ring to minimize overall weight of Top Cover.

TOP COVER

Top Cover is a fabricated structure of carbon steel plates. It is designed so as to avoid deformation which may lead to seizure of guide vane movement. The Top Cover has been heavily constructed, adequately ribbed and shaped so as to give support to the turbine guide bearing, regulation ring, and bearing for the upper stems of the guide vanes. Ribs of Top Cover have been designed to provide suitable access in the Top Cover for maintenance of the Shaft Seal without removal of the Top Cover. It is designed to provide adequate rigidity against cover deflection, servo reaction loading, Guide Vane reaction and bearing loads. It is made in single piece The Top Cover is used to seal off the region above the turbine runner and to direct the flow down through the runner. It is bolted to the stay ring. Top stationary labyrinth is also housed in top cover which reduces the leakage and thus saves the water which otherwise would have gone waste without producing energy. In the regionadjoining the guide vanes in the closed position the top coversurface is provided with stainless steel liner/facing plates. These liner plates are of screwed type for the purpose of replacement. It is replaceable and spare liner plates are supplied for this purpose.

II. LITERATURE REVIEW

The literature review contains various works and studies in the field of Top Cover design (Head Cover) of Guide Apparatus for Francis Turbine and stress analysis / finite element method. It emphasizes on use of finite element method / analysis on different engineering disciplines, optimization, approaches and latest trends.

I have taken forward the research work of Shri BalendraChhetry, BholaThapa, Biraj Singh thapa and Ravi koirala from Department of Mechanical Engineering, Kathmandu University, Nepal on “Design Optimization of Head Cover of Vertical Francis Turbine from Maintenance Perspective in Context to Sediment Laden River Projects”, their paper works published in Fluid Mechanics Research International Journal, Med Crave in January 2018.

Research work on “Stresses and relative stiffness of the head cover bolts in a pump turbine” by Yongyao Luo, Funan Chen, Liu Chen, Zhengwei Wang, Jixing Yu, Chengzong Luo, Zhiwen Zhao, Shaocheng Ren, JinweiLi,Dezhi Deng from (1) Department of Energy and Power Engineering, Tsinghua University, Beijing 100084, China. (2) China Institute of Water Resources and Hydropower Research, Beijing 100048, China. (3) ZHE JIANG XIANJU Pumped Storage Co., Ltd., State Grid XINYUAN Company, Zhejiang 310014, China has also been referred by me published in 2nd International Conference on Frontiers of Materials Synthesis and Processing, IOP Conf. Series: Materials Science and Engineering 493 (2019) 012113, IOP Publishing.

Finally based on above mentioned work in the field of Top Cover design and design tool Finite Element Analysis, I have moved forward to take the challenge of “DEVELOPMENT OF COMPACT TYPE TOP COVER OF FRANCIS TURBINE USING FINITE ELEMENT ANALYSIS”

The Top Cover is an important and critical assembly of Guide Apparatus of Francis Turbine. Optimum design of Top Cover is very important. Top Cover not only seal the area above Runner but also supports various other assembly of Francis Turbine like Shaft Seal, Turbine Guide Bearing, Nut Guard etc. Deformation of Top Cover near Guide vane bore is very much required to avoid the complication of guide vane rotation. Top cover virtually acts as load carrying equipment. Therefore, Top Cover is heavily ribbed and bulky structure. In past, Top Cover was heaviest mechanical structure. Our objective is to reduce the weight of Top Cover to save the material without compromising the function. Top Cover design should also take care of easy erection and maintenance of other peripheral assemblies like shaft seal and Turbine Guide Bearing. In recent various works and studies in the field of Top Cover design (Head Cover) of Guide Apparatus for Francis Turbine and stress analysis / finite element method was done. It emphasizes on use of finite element method / analysis on different engineering disciplines, optimization, approaches and latest trends.

III. METHODOLOGY

3.1 PROJECT DATAS FOR TOP COVER

The required input data of the Top Cover for the analysis are given here:

Transport limitation :4000(L) x 5000 (W)x 800 (H)
Type of turbine:vertical Francis Turbine
Max head water level: EL 631.50 m
Elevation of G.V Centre line : EL 510.30 m
Pressure rise : 35% of maximum static head
Speed rise : 40% of rated speed
Design pressure : 17 Kg/cm2
Rated speed : 250 rpm
Test pressure : 25.5 kg/cm2
Runaway speed: 470rpm (59.7m), 446(53m), 359(34.2m)
Rated net head: 109.65 m

Max.Net head (one m/c running): 117.5 m
Direction of rotation: anti-clockwise (viewed from top)
Top cover outer diameter: 3970 MM
Top cover inner diameter: 1208 MM
Material: ASTM A516 Gr.70
Ultimate Tensile Strength :485 - 620 MPa
Yield Strength : 260 MPa
Maximum allowable Stress : 1/4th of UTS
= 485/4 MPa
= 1237 kg/cm2

3.2 MAKING A SOLID MODEL OF TOP COVER

Solid model of all the variants were made using UG-NX software. All variants are different from other with respect to feature and dimensions. Solid model was parametric in nature. Change in any dimension gets reflected in automatically updated model.

NX Modeling provides a system to enable rapid conceptual design. User can create and edit complex, realistic, solid models interactively. User can change and update solid bodies by directly editing their dimensions or by using other construction techniques.

User can work in either a history-based mode, where user create and edit model in an ordered sequence, or in an open, history-free mode, where we create and edit the model based on its current state, and we do not have to plan modeling steps in advance.

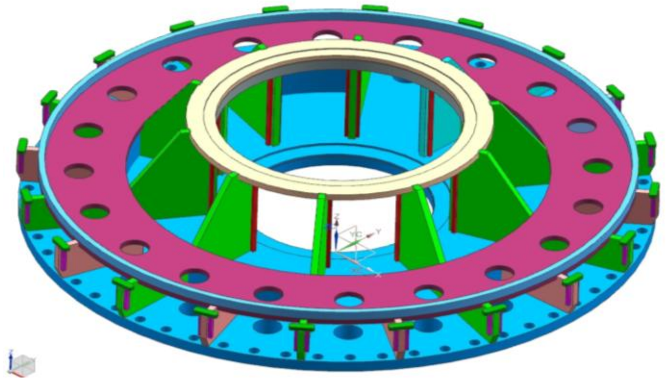
Figure 3.2.1 Solid Model of Top Cover (Top View)

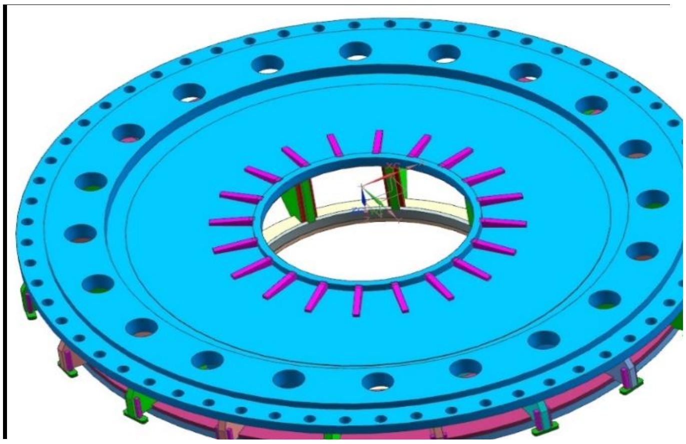
Figure 3.2.2 Solid Model of Top Cover (Bottom View)

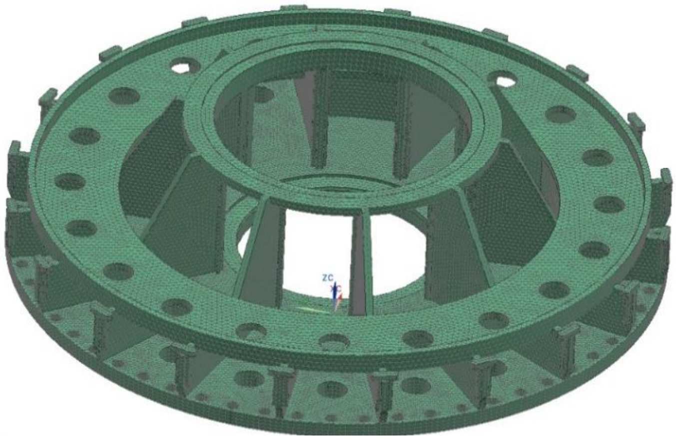
Figure 3.2.3 Meshed Model of Top Cover

3.3 DISCRETIZATION OF SOLID MODEL OF TOP COVER (MESHING)

This method divides a domain into simply shaped portions called finite elements. This division of a domain into elements is called discretization or meshing (nodes and elements).

The finite elements may be triangles, groups of triangles or quadrilaterals for a two dimensional continuum. For three-dimensional analysis, the finite elements may be tetrahedral, rectangular prisms or hexahedral. These regions are known as elements and are connected together by nodes. Each element:

Is a mathematical representation of a discrete portion of the model's physical structure?

Has an assumed displacement interpolation function?

Creating a good finite element mesh is one of the most critical steps in the analysis process, as the accuracy of finite element results depends partly on the quality of the mesh.

The meshing capabilities available in Advanced Simulation which user automatically generates:

0D elements on selected points.

1D (beam) elements on edges.

2D (shell) elements on faces.

3D (solid) elements on volumes.

Advanced Simulation also contains a number of tools that helps for user to create specialized types of meshes. User can also use tools, such as Mesh Mating Condition to connect two separate meshes at a given interface.

The software creates all meshes directly on the model's polygon geometry. The software stores all meshes and mesh related data, such as the mesh's material and physical properties, in the FEM file.

User can define a mesh on geometry:

Created in the Modeling application.

Imported from other CAD modeling packages.

The solid model is discretized by using parabolic Tetra 10 elements. Different variants of solid model of Top Cover were meshed with following details.

Element family: Tetra10
Element: 439824
Nodes: 773377

3.4 APPLYING BOUNDARY CONDITIONS ON MESHED MODEL OF TOP COVER

Loads, constraints, and simulation objects are all considered boundary conditions. The Simulation Navigator provides tools through which user create, edit, and display boundary conditions. User can also create boundary conditions using icons on the Advanced Simulation toolbar.

The options that appear on the boundary conditions dialog boxes are specific to the active solution and its associated solver.

For example, if the active solution uses the NX Nastran solver, the Create Force dialog provides options that are specific to the NX

Nastran FORCE card.

User can create boundary conditions before or after user create a solution: If user create a solution first, the loads, constraints, and simulation objects are stored in their respective containers in the Simulation: The Load Container, Constraint Container, and Simulation Object Container. They are also stored in the solution. If user create the loads, constraints, and simulation objects first, they are stored in their respective containers in the Simulation. User can then drag and drop individual boundary conditions into solutions user create.

Boundary conditions can be applied to both geometry (edges, faces, vertices, points) and FEM objects (nodes, elements, element faces, and element edges). In particular, FEM-based boundary conditions are useful for imported meshes with no underlying geometry, locations that are not defined by geometry, and areas where small edges and faces were removed during abstraction.

The tables list the Advanced Simulation boundary conditions (loads, constraints, simulation objects), the associated analysis types, and the Nastran bulk data entries to which they correspond.

Constraints

(i) Fixing of bolting holes of Top Cover with Stay Ring (P.C.D- 3850)

Loading

(i) Hydraulic pressure / Design Pressure applied on the bottom surfaces of Top Cover as shown in Fig.- (Pressure P = 17 Kg/cm2).

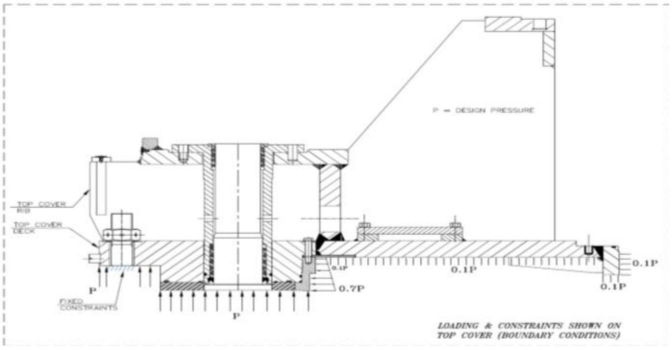

Figure 3.4.1 Loading & Boundary condition on Top Cover

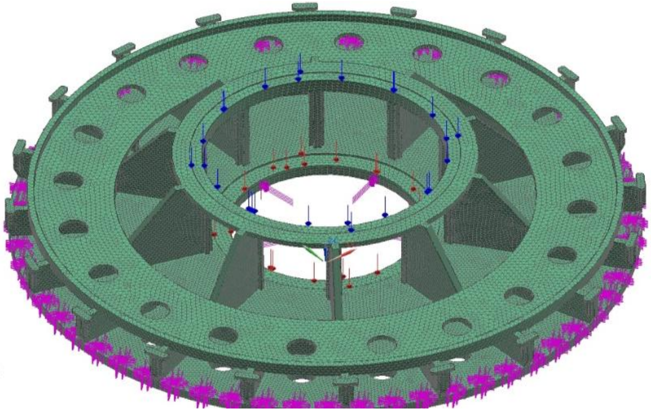

Figure 3.4.2 Loading & Boundary condition on Top Cover (Top View)

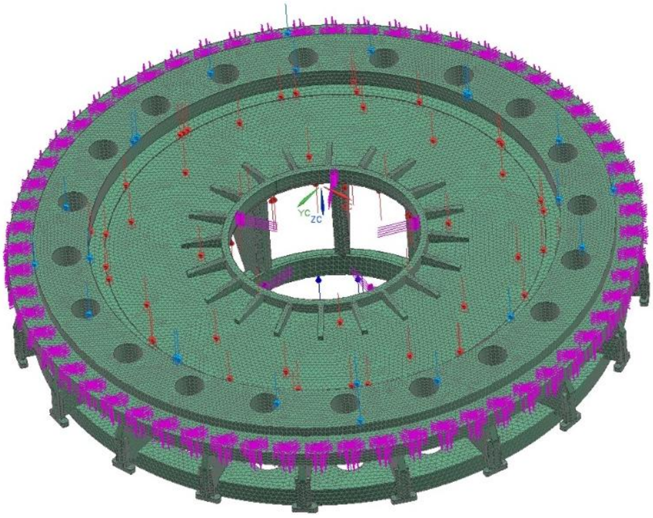

Figure 3.4.2 Loading & Boundary condition on Top Cover (Bottom View)

IV. SIMULATION

When user create a solution, user select the solver (such as NX Nastran), analysis type (such as Structural), and solution type (such as Linear Statics). A solution, which is stored in the Simulation file, contains a set of loads, constraints, and simulation objects. User can then solve using these conditions, or create new solutions defined by different conditions. User can use an unlimited number of solutions per Simulation.

For each solution, the selected solver determines which options are displayed, as well as the language used on the dialogs. Examples of solver-specific data include:

Loads, Constraints, Simulation objects, Solution options Solution parameters

Solution Steps or Subcases

Each solution contains additional storage elements called steps or subcases, depending on the solver. Each step or subcase holds solution entities such as loads, constraints, and simulation objects.

NX Nastran, MSC Nastran — For structural solves, constraints can be stored in the main solution or in the subcases; loads are stored in subcases. For thermal solves, loads and constraints are both stored in subcases.

To simulate problems in which the results of one step are the initial conditions for the next step, user must ensure that the loads and boundary conditions of the previous step are also included in subsequent steps.

V. RESULTS AND DISCUSSION

Stress analysis of Top Cover was done successfully for three variants using NASTRAN SOLVER modeled in Uni-Graphic (UG). All variants are different from other with respect to feature and dimensions. Solid model was parametric in nature. Change in any dimension gets reflected in automatically updated model. The results were reviewed in each variants and improvement in dimension made accordingly in next variant of model. Finally, all variants were compared and most suitable variant selected for final design.

Results Summary of final variant of Top Cover:

Red Colour- shows region of maximum stress.

Blue Colour- shows region of minimum stress.

Intermediate Color - shows regions having stress values between maximum and minimum.

If the maximum stress and deflection exceeds the maximum allowable, then plate thickness of ribs, decks and others were increased by next available value of plate thickness. Again the program is run with updated model and analysis was performed. The process is repeated again & again until the maximum stress and deflection everywhere in model of Top Cover is less than the maximum allowable.

Detail analysis of results of are as follows:

Coordinate System : Absolute Rectangular

Number of load cases : 1

Subcase - Static Loads 1 : Number of Iterations = 1								
	Displacement - Nodal (mm)				Stress - Element-Nodal (mN/mm^2(kPa))			
	X	Y	Z	Magnitude	Von-Mises	Min Principal	Max Principal	Max Shear
Static Step 1								
Max	3.333e-001	3.207e-001	1.020e+000	1.020e+000	3.694e+005	1.042e+005	4.547e+005	1.939e+005
Min	-2.972e-001	-3.120e-001	-5.924e-002	0.000e+000	3.980e-001	-3.811e+005	-1.010e+005	2.180e-001

Result interpretation:

1. As opposed to an average value of stress, as obtained in close form formulations, FEM shows a stress or deflection pattern.

2.Representative filleting has been carried out for simpler mathematical modeling. Since fillets help in reducing stress concentrations, therefore, the results obtained are on the conservative side.

3. Although the color bar alongside the stress & vibration pattern plot shows all the colours, stresses at higher color are not present in the actual plot.

4. It is seen from the results that the stress patterns are well within acceptable limits.

The explanation of the higher stress values at few places (local) are as follows.

The filleting which will actually be carried out cannot be exactly modeled due to mathematical limitations. This leads to higher values at the boundary of the filleting done. Again, these high values are mathematical point occurrences. The high stresses are averaged out over the elements and in the stress patterns; the red zone cannot be seen.

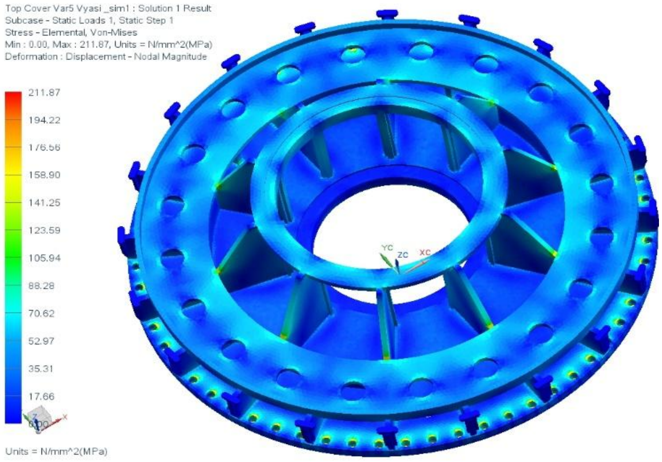

Figure 5.1 Von Mises stress pattern in Top Cover (Top View)

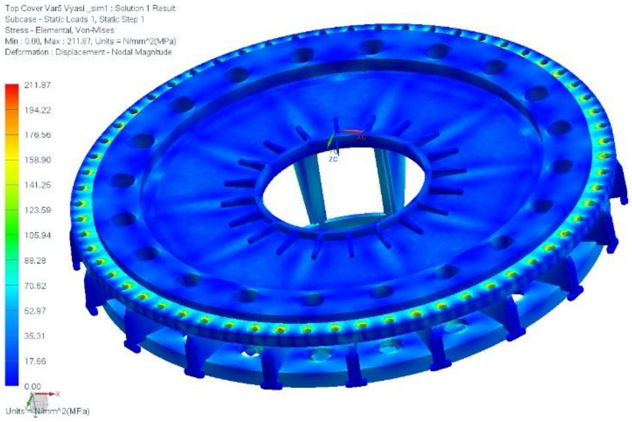

Figure 5.2 Von Mises stress pattern in Top Cover (Bottom View)

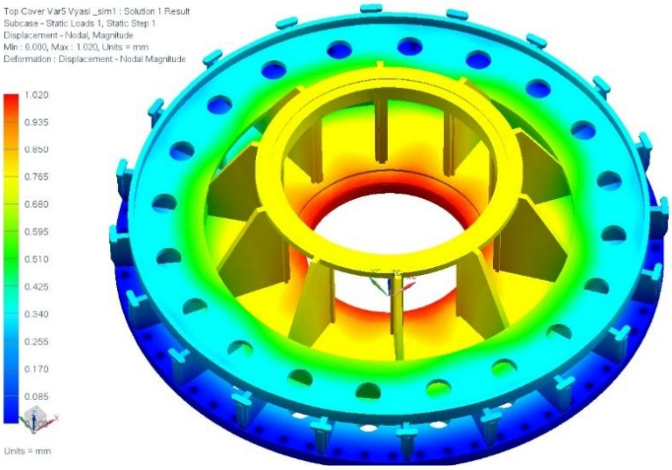

Figure 5.3 Deflection Pattern in Top Cover (Top View)

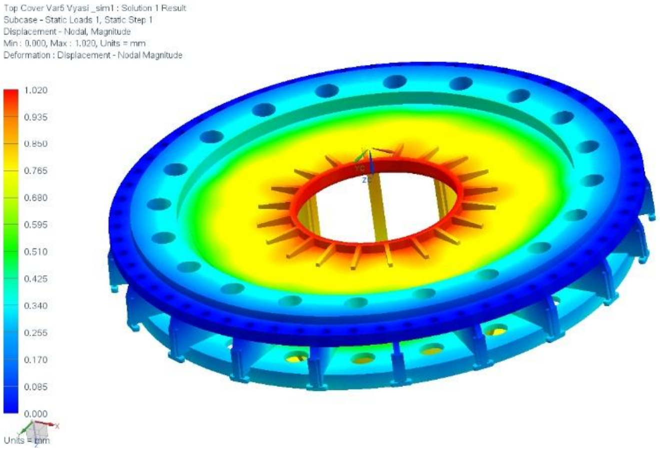

Figure 5.4 Deflection Pattern in Top Cover (Bottom View)

VI. CONCLUSION

Three different variants of Top Cover have been analyzed using FEA. Improvement in design has been carried out after feedback of testing of each variant keeping objectives in mind. Finally, we arrived at third and final variant. Third variant has been adopted for final design, manufacturing, erection and commissioning.

From the analysis it is revealed that

- Optimum thickness for deck, ribs etc. has been

obtained for given boundary conditions.
- Maximum indigenous plates are used.
- Weight of Top Cover has been reduced by approx. ~40% over conventional design.
- FEM has a very effective tool for designers in the field of structural design of hydraulic components.
- Area of stress concentration are recognized & stresses are reduced under 1/3rd of yield point of material.
- Better safety margins achieved.
- Stress pattern to be obtained for various plate thickness of Top Cover plate.
- Average stress is less than the allowable stress.
- Deformation near guide vane bore is approx. 1 mm which is allowed.
- Better approach for Shaft Seal and Guide Bearing maintenance.

This design has been successfully adopted in two different projects. One project with this improved optimized design of Top Cover has been successfully recently commissioned and generating power and revenue. Guide Apparatus of second project with this design has been manufactured and successfully tested and is under commissioning.

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