Design and optimization of distributor of pelton turbine by static structural analysis

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Abstract : For a Pelton type hydro turbine, the distributor is one of the most important assembly.The distributor is designed to provoke an acceleration of water flow the bifurcation towards each of the main nozzle. The distributor of a Pelton turbine consists of pipe segments and wye branches which are then connected to nozzles. Wye branches, where the distributor bifurcates has a very complex shape and is very difficult to design and manufacture. It is also subjected to very high stresses. Earlier, distributors were manufactured by casting. Later on, the design of distributor with cast wye branches and fabricated interconnecting pipes was adopted. In the present work, a fabricated distributor, with wye branches is being designed & developed.

***IndexTerms* - Pelton turbine, Distributor, Wye branch.**

I. INTRODUCTION

At the present time concerns over disruptive fossil fuel markets and uncertain pricing, the current decline of nuclear energy as a viable energy source and the significant environmental consequences of thermal energy sources have placed greater emphasis on sustainable energy policies that include the significant development of nonpolluting, environment friendly, cheaper conventional energy and renewable energy supplies.

Renewable energy technology exists in many forms. Recent thinking often relates renewable energy to electricity from either wind energy, solar energy or geothermal energy. Yet the largest source of renewable energy comes from a proven technology, hydropower. Hydropower is renewable because it draws its essential energy from the sun which drives the hydrological cycle which, in turn, provides a continuous renewable supply of water. Hydropower represents more than 92 percent of all renewable energy generated, and continues to stand as one of the most viable sources of new generation into the future. It also provides an option to store energy, to optimize electricity generation.

1.1 FUNCTIONS OF DISTRIBUTOR AND ITS BASIS OF DESIGN

In a powerhouse equipped with a Pelton type hydro turbine, the distributor is one of the most crucial assemblies since it is a very high-pressure water conductor directing water flow through the nozzles to the runner buckets. The distributor of a Pelton turbine consists of pipes and wye branches connected to nozzles. This whole geometry is very complex and affects the efficiency of turbine. In view of this, the requirement of optimized design of distributor becomes very significant.

1.2 DISTRIBUTOR

The distributor, which is one of the most critical component of a Pelton type hydro turbine, is designed to provoke an acceleration of water flow the bifurcation towards each of the main nozzle. This design has advantage as it contributes to keep a uniform velocity profile of flow. The distributor is joined to main spherical valve via a joint, which is installed for dismantling purpose. This is furnished with telescope flange connection to distributor entrance. The main injector is joined to the bifurcation by means of rigid flange coupling. The automatic relief valve is normally installed on the top of either the distributor entrance section or the dismantling joint. This valve closes automatically when most of the air in the distributor is let out during water filling, and remains closed as long as the distributor is pressurized.

For emergency stop a water jet braking system is provided to obtain a fast reduction of the rotational speed of the runner nozzle is closed. This system consists of one automatically operated needle valve connected to one or two break jet nozzles, which are fed via pipes directly from the penstock. The braking valve is controlled by a solenoid valve operated by an emergency control system actuated by the water pressure from the penstock.

The distributor is completely embedded in concrete when installed in powerhouse. The pressure of water is transferred to concrete through distributor. However, to transfer large axial forces to power house an extension must be welded to inlet flange. This is done for reducing the specific pressure on concrete.

During last few years the distributor is generally cast. However, distributors are being fabricated nowadays. Fabricated distributors reduce the time cycle of manufacturing and they are much cheaper. Also, there are less defects formed in the distributor compared to Casting defects. High tensile plates are now used to fabricate the distributor.

II. CASE HISTORY

The Distributor has a complex geometry. This being the water conductor system of the turbine, the efficiency of the turbine depends on its hydraulic design as well as structural strength. The distributor of a Pelton turbine consists of pipe segments and wye branches which are then connected to nozzles. Wye branches, where the distributor bifurcates has a very complex shape and is very difficult to design and manufacture. It is also subjected to very high stresses. Earlier, distributors were manufactured by casting. Later on, the design of distributor with cast wye branches and fabricated interconnecting pipes was adopted. In the present work, a fabricated distributor, with wye branches is being designed & developed. It is these wye branches, which pose problem of designing as well as manufacturing.

The objective of this paper is to optimize the design of Distributor, to describe how different plate segments required to fabricate wye branches are developed and to find the stress pattern in the wye branches to ensure greater reliability and safe working condition .The water path has a gradual transition of sections; hence it is very important to obtain an accurate development of the plate segments, which when rolled and welded together will form the wye branch. In this paper, a segment of distributor is modelled with various arrangements of stiffeners and sickle plate and analyzed to get optimized final segment and same practice can be applied to other segments of distributor also.

The stress analysis of the distributor is invariably complex and it is extremely difficult and tedious to obtain analytical solutions. In these situations, engineers usually resort to numerical methods to solve the problems. With the advent of computers, one of the most powerful techniques that has been developed in the realm of engineering analysis is the finite element method and the method being general can be used for the analysis of structures / solids of complex shapes and complicated boundary conditions.

The introduction of CAD software like UNI-GRAFIX, I-DEAS, NASTRAN, ANSYS, CATIA, etc. have cut down the time requirement for modeling and analysis, which are quite suitable for many industrial problems particularly engaged in the design field. These commercial software are fairly versatile. The results obtained through these software are moderately accurate.

The present competitive environment not only makes the use of finite element method (FEM) in designing of critical components like Distributor a necessity but also as a tool to explore new shapes and geometries for least mass and highest stress bearing capacity. Use of FEM technique for designing Distributor has helped in increasing the strength & rigidity of Distributor by optimum utilization of material. This has helped in reducing the weight of Distributor without sacrificing strength by eliminating the redundant material.

III. METHODOLOGY

3.1 PROJECT DATAS FOR DISTRIBUTOR

For analysis of stresses, a practical case of a distributor of a Pelton turbine unit has been taken. The required input data of the distributor for the analysis are given here:

- Unit Output : 110 MW
- Type of Turbine : Vertical Pelton(5j)
- Direction of Rotation : Clockwise(viewed from generator end)
- Rated Net Head : 640 m
- Gross Head : 665 m
- Rated Speed : 375 RPM
- Elevation of Nozzle/ Runner : 1723 m
- Discharge : 19.45 Cumecs(at rated head rated output)
- Main Inlet Valve : Spherical Valve Dia. 1600 mm

3.2 MAKING A SOLID MODEL

For making a model of distributor, a practical case of a Pelton turbine of 110MW having gross head of 665m has been taken. The inlet & outlet dia. of the distributor are1970 mm (i.e. at just outlet cone of spherical valve) and at 902 mm (i.e. at just inlet of nozzle). The diameters of the distributor varies at different sections from a maximum value of 2363 mm to a minimum value of 902mm .The preliminary thickness is assumed on the basis of previous projects which have the nearly same head & output. The various plate thicknesses used at different section are 28, 30,36,40,45,48,52,56 & 60 mm. The ribs of 56 thick are placed at different sections. Sickle plate of 100, 130 &150 thick are provided at wye sections.

The total weight of distributor model is 85 tons. Since the weight of the model is so high, it creates problems during meshing and analysis. Therefore, the model is fragmented at five segments keeping in to view of the parametric feature of individual model.Fig.5.1.1 shows the model of complete distributor, whereas fig. 5.1.2 shows the model of wye-1.

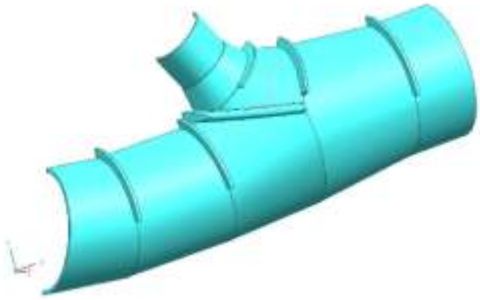

Figure 5.1.1 Solid Model of Distributor **Figure5.1.2 Model of Wye-1**

3.3 MESH GENERATION

Meshing is the stage of the finite element modelling process in which user divide a continuous structure (model) into a finite number of regions. 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.

For meshing of wye-1

Total number of meshes in the part: 1

Total number of elements in the part: 43290

Total number of nodes in the part: 92411

Element type: C Tetra (10)

Element size: 140

Max. Jacobian: 10

3.4 APPLYING BOUNDARY CONDITIONS

The symmetric boundary condition is applied for the entire segment as the segment is fragmented in two parts. The fixed boundary condition is applied at the edges of the fragmented segment. Now the pressure of 77 $kg/cm^2$is applied all over the model for segment of distributor.Fig.3.4.1, shows the model of fragmented segments of wye-1, when the boundary & loading condition has been applied.

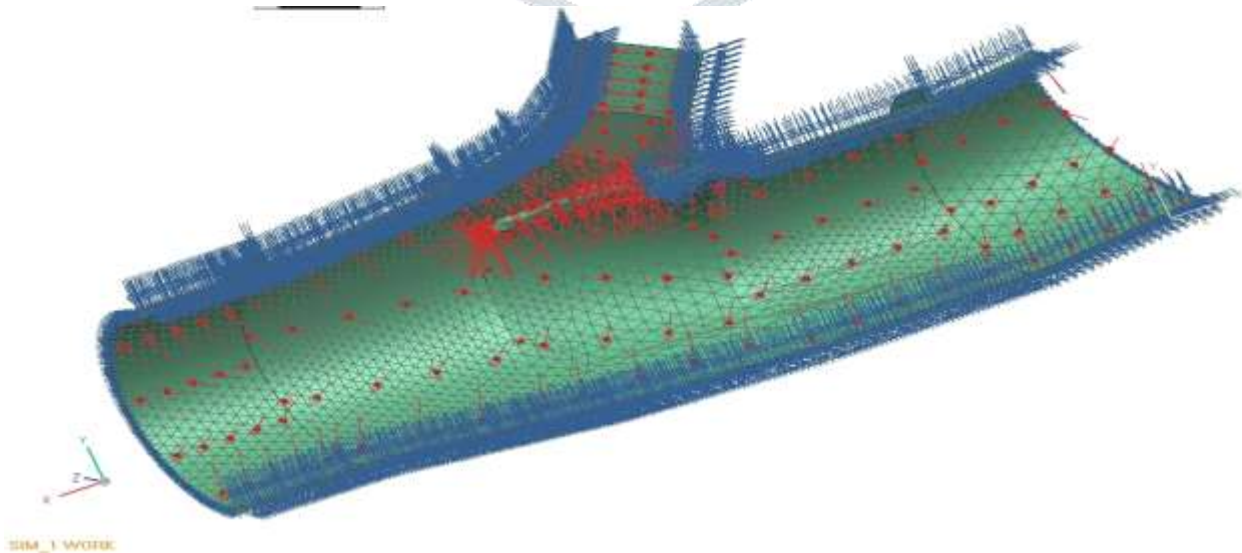

Figure3.4.1 Loading & Boundary condition on Wye-1

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.
- ANSYS — Constraints are stored in the main solution and loads are stored in sub steps, except for Nonlinear Statics and Thermal solves, where constraints are stored in sub steps.
- ABAQUS — Loading histories are divided into steps. For linear analyses, each step is essentially a load case. All loads and constraints are grouped in named steps. Steps may contain any number of loads and constraints of any type.

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.

IV. RESULTS AND DISCUSSION

Stress analysis for all the segments of distributor is done successfully using NASTRAN SOLVER. For this purpose, the models are prepared using parametric modelling method. Advantage of parametric modelling is that any change is any dimension, model updated automatically.

The result of various segments is shown in figures 5.1 in which

Red Colour- shows region of maximum stress.

Blue Colour- shows region of minimum stress.

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

If the maximum stress as indicated by red colour exceeds the maximum allowable stress, then plate thickness is increased by next available value of plate thickness. Again the program is run with new sets of inputs and analysis is performed. The process is repeated again & again until the maximum stress in all the segments of the distributor is less than the maximum allowable stress. The last set of inputs values gives the minimum thickness of various segments of the distributor.

The various other important parameters which govern to selection of optimum thickness for particular segment of distributor are following: -

1. No. & position of ribs
2. Thickness of Ribs.
3. Thickness of sickle plate.

- The final value of plate thickness used in distributor model are36, 56, & 60 mm.
- Thicknesses of all ribs are 56 mm.
- Thicknesses of sickle plate are 130 & 150 mm.

The thickness is assumed on the basis of previous projects which have the nearlysame head & output. The preliminary thickness is also calculated by hoop stress formula, which is given below: -

Hoop Stress: -pd/2t

Here, p - pressure over distributer segment(i.e.77 kg/cm²)

d -dia. of particular section

t- Thickness of particular section

Now this thickness is refined by doing various no. of iterations. In case of segment -1, for first iteration the model has been prepared without using the sickle plate and ribs, the FEM & stress analysis is carried out, the maximum stresses are 4800 kg/cm² at y-section&average stresses are 3200 kg/cm². The thickness of various section are taken 56 & 36 mm.

For second iteration thickness of one of the section (near y-section) is increased from 56 to 60 mm. Ribs of 56tk are placed at three position (to reduce the average stress and a sickle of 130tk is placed at y –section. Now the fem & stress analysis is carried out, the maximum stresses are 4100kg/cm² at sickle plate &average stresses are 2000 kg/cm².

For third iteration thickness of sickle plate increased from 130 to150mm & ribs are provided at four positions. Now the fem & stress analysis is carried out, the maximum stresses are 3800kg/cm² at sickle plate &average stresses are 1600 kg/cm².

For fourth iteration width of ribs in radial direction is increased by 150mm.Now the fem & stress analysis is carried out, the maximum stresses are 3400kg/cm² at sickle plate &average stresses are 1400 kg/cm².

For fifth iteration one more rib of 56tk is provided. Now the fem & stress analysis is carried out, the maximum stresses are 2800 kg/cm² at sickle plate &average stresses are 1300 kg/cm².

As per the design norms, if the average stress is less than $1/5^{th}$ of theultimate tensile strength of material or $1/3^{rd}$ of the yield strength of the material it is taken as acceptable design. Here, as the value of average stress (i.e.1300 kg/cm²) is below the $1/5^{th}$of the ultimate tensile strength of material (i.e.7000kg/cm²) or $1/3^{rd}$ of the yield strength of material (i.e.4500kg/cm²). So this value has been accepted.

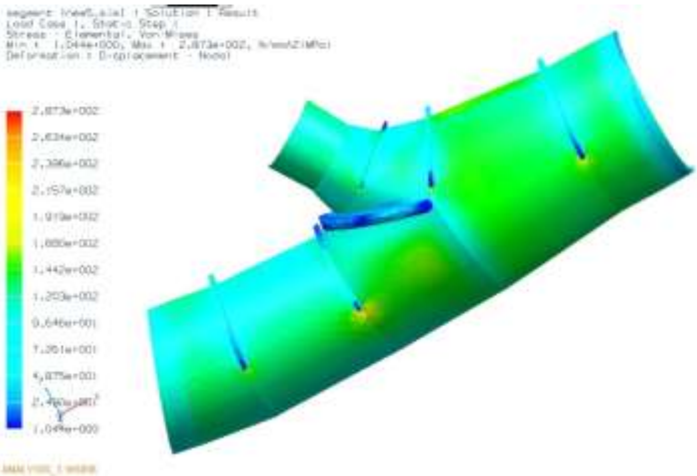

Figure5.1 Analysis of Wye-1

V. Conclusion

In the present work Distributor wye segment has been analyzed to check effectiveness of various design features and the optimization of structure under various conditions. From the analysis it is revealed that

- FEM has a very effective tool for designers in the field of structural design of hydraulic components.
- Area of stress concentration is recognized & stresses are reduced under $1/3^{rd}$ of yield point of material.
- Better safety margins achieved.
- Stress pattern to be obtained for various plate thickness of distributor plate.
- Average stress has been found 1300 kg/ cm² or below for different segments of the distributor against the ultimate tensile strength of material (i.e.7000kg/cm²) or yield strength of material (i.e.4500kg/cm²).
- Optimum thickness has been obtained for given boundary & loading conditions by using stiffeners and sickle plate at suitable location.

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