# Topology Optimization of Pelton Wheel Turbine Bucket Using Ansys

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***Abstract-*** *In Pelton turbines, a nozzle converts the potential energy of water into kinetic energy. The nozzle is placed in line with the water pressure. The water jet enters the entrance and strike on to the symmetrically shaped buckets and splits into two parts. The splited water will rotate the buckets which rotates the shaft connected to the generator.*

*Because of the complex geometry of the Pelton turbine, the design of the Pelton turbine bucket plays a very important role in the efficient working of the Pelton turbine. In this present paper the design and analysis of the Pelton turbine bucket was carried out. Design calculations shall be done by using theoretical formulas and later on a 3D model of the Pelton turbine shall be designed using NX-CAD software. A detailed finite element analysis shall be done by distributing the forces acting on the Pelton turbine bucket to calculate stresses and deflections. Design optimization of the bucket is done by changing the design parameters to withstand the forces. Ansys software is used to do finite element analysis.*

***Keywords***- Optimization, Pelton Bucket Design, Design Calculations, Dynamic Analysis

## I. INTRODUCTION

There are different types of impulse type heater turbines and The Pelton wheel is one of its types. The Pelton turbine works on the principal by converting pressure energy which evolved from water into kinetic energy with the help of convergent jet nozzle and this energy is used to move the runner. The periphery of disc is mounted with Pelton buckets where the pressurized water from the nozzle will come straightly on impact with the buckets.

Thus this high-velocity jet of water emerged from nozzle impinges on the bucket and start the wheel into motion. Pelton turbine is tangential flow impulse turbine.

## II. METHODOLOGY

The jet is directed to the runner buckets of the Pelton wheel. So, the buckets undergo stress due to this jet of water flowing on the bucket of the Pelton wheel.

The Pelton wheel is also rotating with some speed. Due to this speed, some vibrations will be developed. So, the Pelton wheel is analyzed for dynamic vibrations using ANSYS software.

- In this paper, initially design calculations shall be done by using theoretical formulas
- Later on a 3D model of the Pelton turbine shall be designed using NX-CAD software.
- Pelton wheel turbine model is converted to Para solid file.

## III. DESIGN CALCULATIONS OF PELTON WHEEL

**1. Calculation of the net head (H):**

$$\mathbf{H = H_g - H_t\ m}$$

**Where,** assume $H_g = 45$m

$H_t = 0.06 * H_g = 0.06*45 = 2.7$ m

$\mathbf{H = H_g - H_t} = 45 - 2.7 = \mathbf{42.3\ m}$

Net head (H) **= 43m.**

**2. Calculation of the turbine speed (N) :**

The turbine Speed Can be Calculated as:

$$N = N_s * \frac{H^{\frac{5}{4}}}{\sqrt{P}}$$

**Where,** assume $N_s$= 1900 rpm,

Power (P) = 45 kW

$$N = 1900 * \frac{43^{\frac{5}{4}}}{\sqrt{45000}}$$

N = 990 rpm

The Speed of the turbine = 990 rpm.

**1. Modeling Part**

Pelton wheel along with bucket was modeled in NX-CAD software based on the design calculations done using formulae.

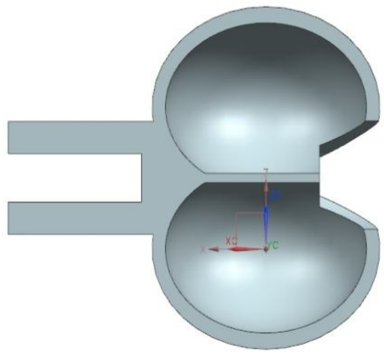


Figure 1. shows the 3D model

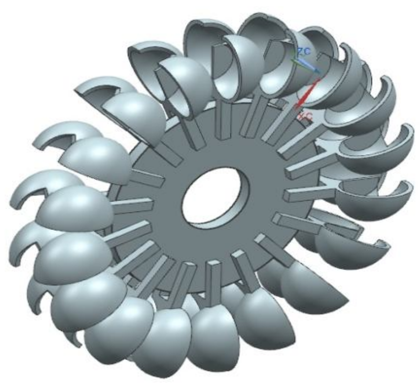


Figure 2. shows isometric view of Pelton wheel with buckets

## IV. FINITE ELEMENT ANALYSIS OF PELTON WHEEL

The best case packages which are efficiently used for mechanical engineering analysis are Finite Element Modeling (FEM) and Finite Element Analysis (FEA). This software's are used as a most popular numerical technique for solving engineering problems. This method is generally best enough to handle any shape of geometry (problem domain) that are resulted complex structures., material properties, boundary conditions and any loading conditions. The generality of the FEM fits the analysis prerequisites of the present complex engineering systems and designs where shut form solutions are administering equilibrium equations are not available. Moreover it is a proficient design tool by which designers can perform parametric design examining different cases (different shapes, material loads etc.) analyzing them and choosing the optimum design.

**2. Material Properties of Stainless Steel Alloy material:**

Density = **7850 Kg/m$^3$**
Young'smodulus = **200 GPA**
Yield strength = **300 MPa**
Poison's ratio **= 0.3**

SOLID92 has quadratic displacement behavior and is well suited to model irregular meshes (such as produced from various CAD/CAM systems). See SOLID95 for a 20-node brick shaped element. The element is defined by ten nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions.

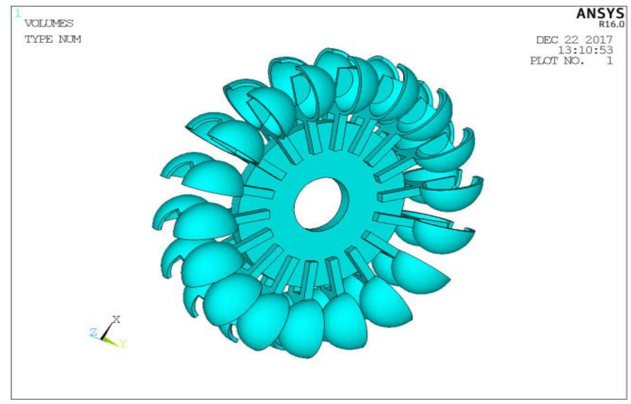



Figure 3. Ansys model of Pelton bucket


Figure 4. shows finite model of pelton wheel

**1. Boundary conditions:**

- A force of 303.6 N is applied on bucket of the Pelton wheel.
- The center of Pelton is constrained in all dof.

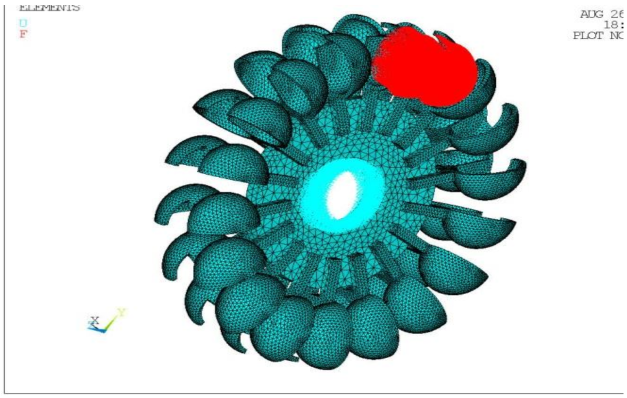



Figure 5. shows boundary and load conditions on pelton wheel

**RESULTS:**

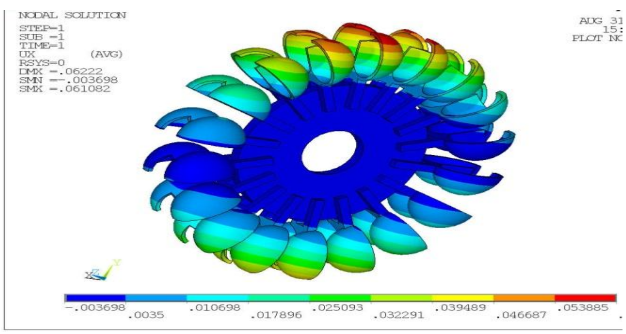



Figure 6.1 shows Von mises stress observed on Pelton wheel and Pelton bucket

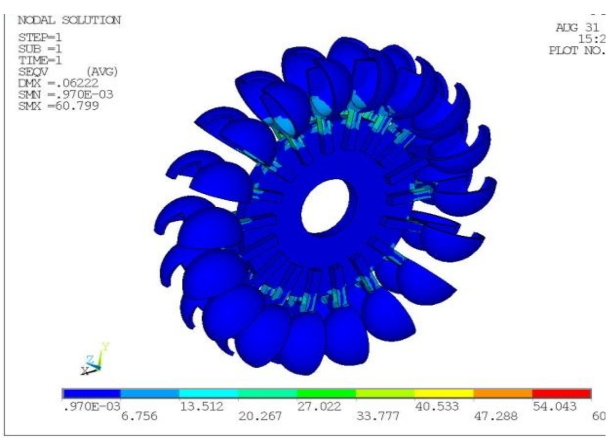



Figure 6.2 shows Von mises stress observed on Pelton wheel and Pelton bucket

From analysis results, the resultant displacement observed on Pelton wheel is **0.06 mm** and Pelton bucket **is 0.06mm**. The Von misses stress observed on Pelton wheel is **60.799MPa** and Pelton bucket is **38.65 MPa.** The yield strength of steel material is **300 MPa**. The Von miss stress of both Pelton wheel and Pelton bucket are less than the yield strength of the material. Hence the Pelton wheel and Pelton bucket are safe in design for static conditions. Further, Pelton wheel is subjected to vibration conditions.

## V. MODEL ANALYSIS OF PELTON WHEEL

Model analysis was carried out on Pelton wheel to determine the first 5 natural frequencies and mode shapes of a structure. From the model analysis, a total of 5 natural frequencies are observed. The total weight of the Pelton wheel considered for the analysis is 0.017 tones.

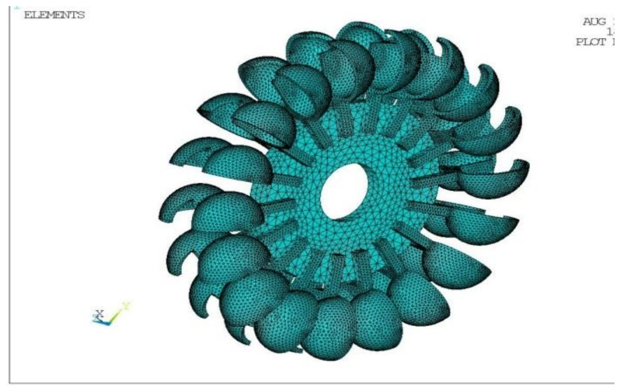



Figure 7. shows the FE Model of the Pelton wheel

**1. Boundary conditions:**

The center of the Pelton wheel is constrained in all DOF.

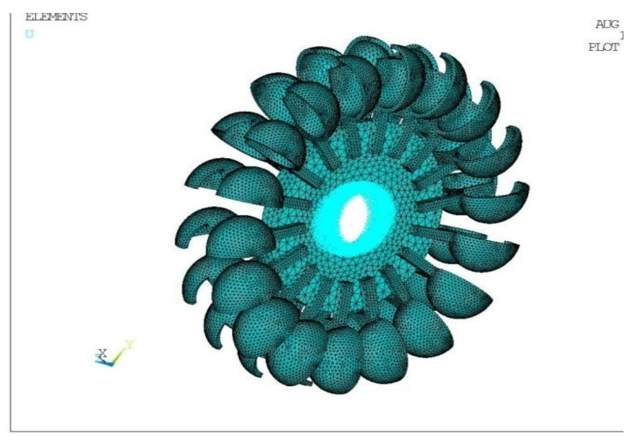



Figure 8. Shows the boundary conditions applied on the Pelton wheel.

The mode numbers and the corresponding frequency values are shown in the below table. The mode shapes for all the frequencies are plotted below.

Table 1. shows the mode numbers and the corresponding frequency values

| MODE | FREQUENCY | PARTIC FACTOR | | | EFFECTIVE MASS | | |
|---|---|---|---|---|---|---|---|
| | | X-Dir | Y-Dir | Z-Dir | X-Dir | Y-Dir | Z-Dir |
| 1 | 334.683 | 5.85 E-05 | 2.26 E-05 | 4.66 E-04 | 3.42 E-09 | 5.11 E-10 | 2.17 E-07 |
| 2 | 335.093 | -2.99 E-05 | 7.14 E-05 | 9.56 E-04 | 8.94 E-10 | 5.10 E-09 | 9.15 E-07 |
| 3 | 340.402 | -2.04 E-06 | -1.38 E-6 | 0.10 81 | 4.17 E-12 | 1.90 E-12 | 1.17 E-02 |
| 4 | 382.396 | -1.63 E-05 | -1.36 E-5 | 1.69 E-04 | 2.67 E-10 | 1.85 E-10 | 2.84 E-08 |
| 5 | 382.409 | 1.03 E-05 | -1.83 E-5 | 4.88 E-04 | 1.06 E-10 | 3.34 E-10 | 2.39 E-07 |

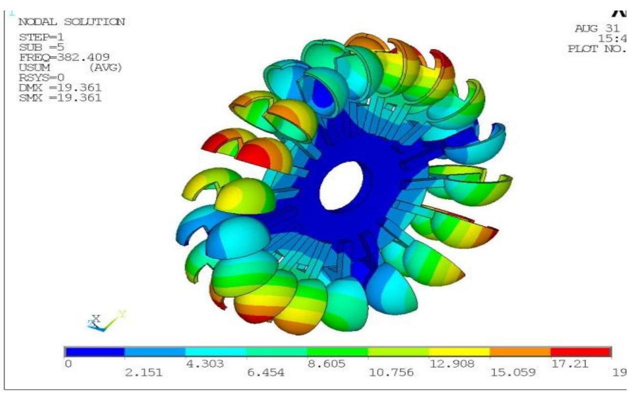



Figure 9. Shows the results of model analysis

From the above results of model analysis, following observations are made:

- The total weight of the Pelton wheel is observed for the analysis is 0.017 tonnes.
- It is observed that the maximum mass participation of 3.42E-09Tones in X-direction for the frequency of 334.6Hz.
- It is observed that the maximum mass participation of 5.10E-09Tones in Y-direction for the frequency of 335Hz.
- It is observed that the maximum mass participation of 0.011Tone in Z-direction for the frequency of 340.4Hz.

To check the structure response at the above mentioned frequency due to the operating loads, Pelton wheel is also subjected to harmonic analysis.

## VI. HARMONIC ANALYSIS OF PELTON WHEEL

Harmonic response occurs at force frequencies that match the normal frequencies of your structure. Before getting the consonant arrangement, you should first decide the regular frequencies of your structure by acquiring a modular arrangement. A consonant investigation, by definition, expects that any connected load shifts pleasingly (sinusoidal) with time. To totally determine a consonant load, three snippets of data are typically required: the sufficiency, the stage edge, and the compelling recurrence run.

Harmonic analysis was carried out on the Pelton wheel to determine the deflections and stress of a structure for first 5 natural frequencies. Natural frequencies obtained from the model analysis.

### HARMONIC ANALYSIS:

- A force of 303.6 N is applied on bucket of the Pelton wheel.
- The center of Pelton is constrained in all dof.
- Pelton wheel rotates with an angular velocity of 13.09 m/s.

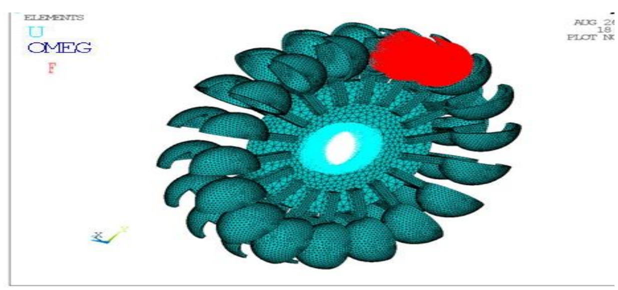
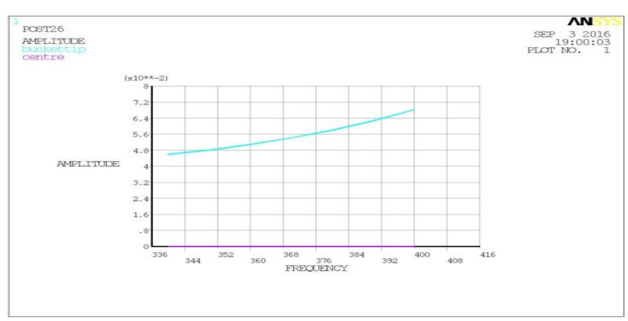
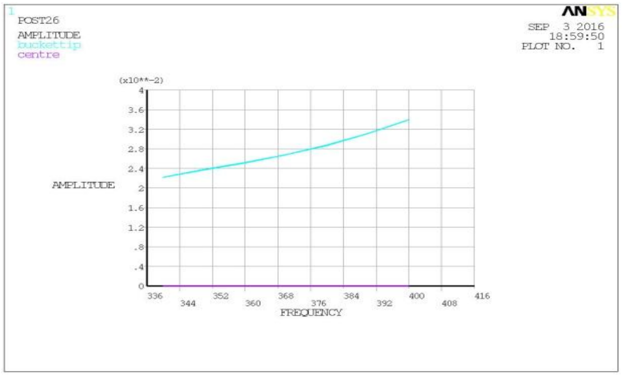



Figure10. shows the harmonic analysis

**1. Harmonic response at center of Pelton wheel and tip of bucket in X-dir:**



**2. Harmonic response at center of Pelton wheel and tip of bucket in Y-dir:**




**3. Harmonic response at center of Pelton wheel and tip of bucket in Z-dir:**

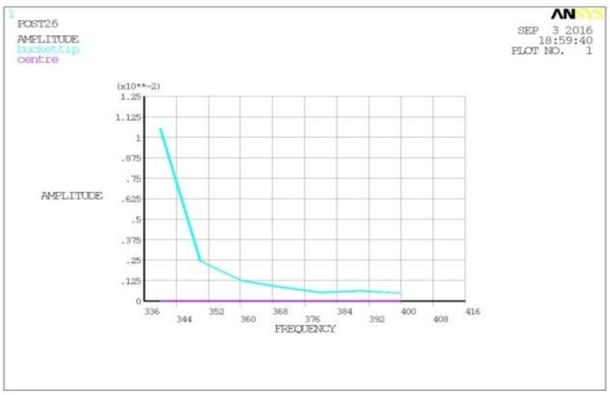



Table 2.shows Deflections and von misses stress for critical frequencies

| | PELTON WHEEL | | PELTON BUCKET | |
|---|---|---|---|---|
| FREQUENCY | DEFLECTIONS (mm) | VON MISSES STRESS (MPa) | DEFLECTIONS (mm) | VON MISSES STRESS (MPa) |
| 334.6 | 0.119 | 103.9 | 0.119 | 65.9 |
| 335 | 0.162 | 102.7 | 0.162 | 78.6 |
| 340.4 | 11.124 | 2637 | 11.121 | 2568 |

## VII. FINITE ELEMENT ANALYSIS OF MODIFIED PELTON WHEEL

### 1. STATIC ANALYSIS OF MODIFIED PELTON WHEEL

A static analysis can however include steady inertia loads and time varying loads that can be approximated as static equivalent loads. The 3D model of the modified Pelton wheel is created in NX-CAD and converted into parasolid. The parasolid file is imported into ANSYS and finite element analysis is carried out using ANSYS software.

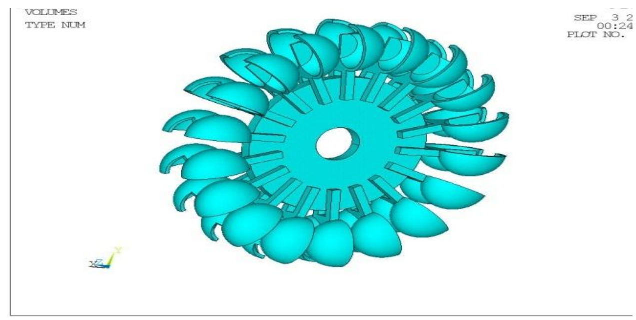



Figure11. shows the geometric model of the modified Pelton wheel

## VIII. MATERIAL PROPERTIES

**Material used for modified Pelton wheel is Stainless steel alloy:**

Young’s Modulus: **200 GPa**, Poisson’s Ratio: **0.3**
Density: **7850 Kg/m3**, Yield strength: **300 MPa**

**BOUNDARY CONDITIONS:**

- A force of 303.6 N is applied on bucket of the pelton wheel.
- The centre of pelton is constrained in all dof.

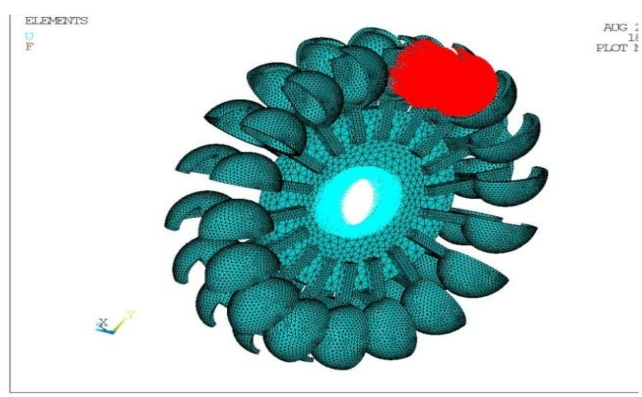



Figure12. shows the harmonic analysis

**RESULTS:**

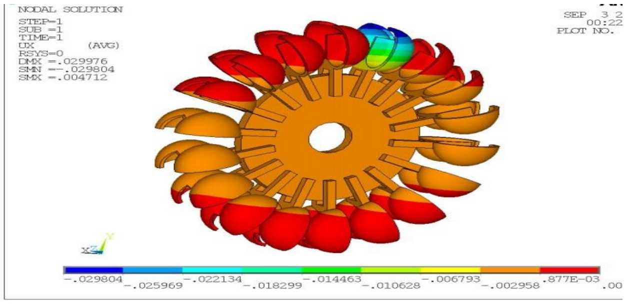



Figure13. shows displacement of modified pelton wheel

From analysis results, the resultant displacement observed on modified Pelton wheel is **0.02 mm** and modified Pelton bucket **is 0.02mm**. The Von misses stress observed on modified Pelton wheel is **24.8MPa** and modified Pelton bucket is **16.05MPa.** The yield strength of steel material is **300 MPa**. The Von mises stress of both modified pelton wheel and modified pelton bucket are less than the yield strength of the material. Hence the modified pelton wheel and modified pelton bucket are safe in design for static conditions. Further, pelton wheel is subjected to vibration conditions.

## IX. MODEL ANALYSIS

Modified Pelton wheel is subjected to model analysis to determine the natural frequencies and mode shapes of a structure for first 5 natural frequencies of the structure.

### 1. Boundary Conditions:

- The centre of the pelton wheel is constrained in all DOF.

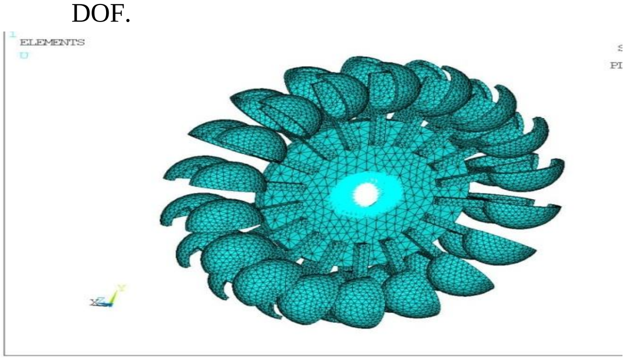



Figure 14. shows Applied Boundary conditions on modified Pelton wheel

## X. HARMONIC ANALYSIS OF MODIFIED PELTON WHEEL

Harmonic response occurs at force frequencies that match the normal frequencies of your structure. Before getting the consonant arrangement, you should first decide the regular frequencies of your structure by acquiring a modular arrangement.

### 1. HARMONIC ANALYSIS:

- A force of 303.6 N is applied on bucket of the pelton wheel.
- The centre of pelton is constrained in all dof.
- Pelton wheel rotates with an angular velocity of 13.09 m/s.

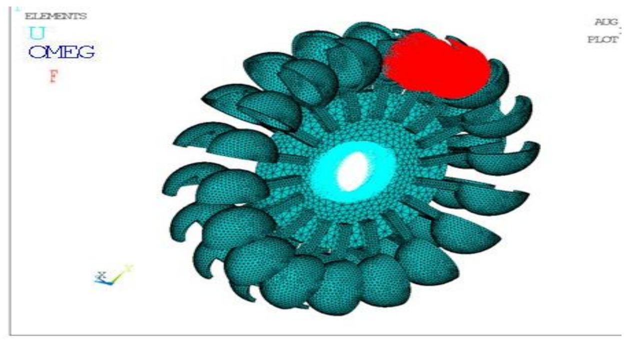
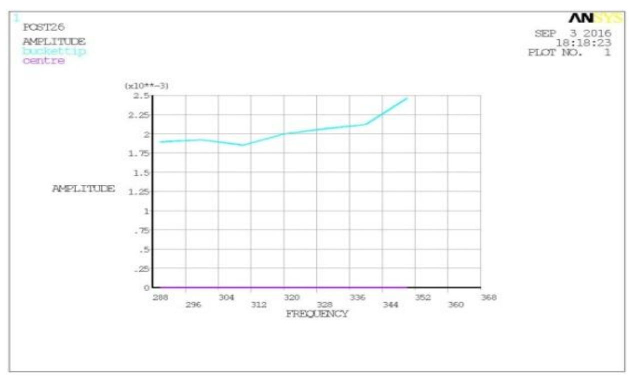
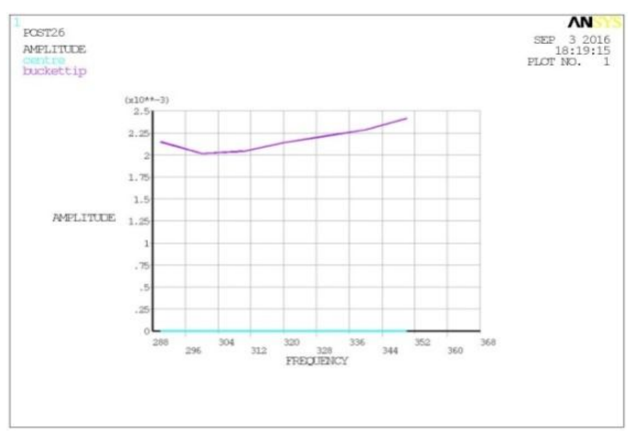



Figure15. Boundary conditions and loading of modified Pelton wheel

**Harmonic response at centre of modified Pelton wheel and tip of bucket in X-dir:**




**Harmonic response at centre of modified Pelton wheel and tip of bucket in Y-dir:**



**Harmonic response at centre of modified Pelton wheel and tip of bucket in Z-dir:**

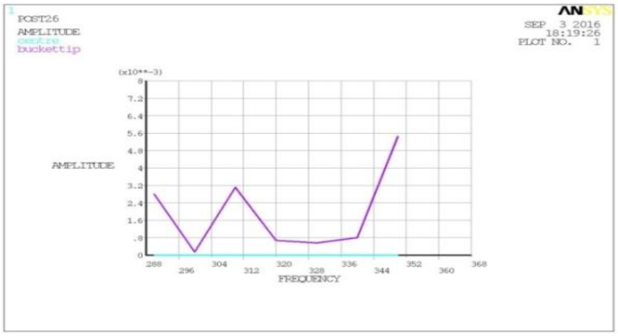



Table 3. shows Deflections and von misses stress for critical frequencies

| | MODIFIED PELTON WHEEL | | MODIFIED PELTON BUCKET | |
|---|---|---|---|---|
| FREQUENCY | DEFLECTIONS (mm) | VON MISSES STRESS (MPa) | DEFLECTIONS (mm) | VON MISSES STRESS (MPa) |
| 290.7 | 0.05 | 36.8 | 0.05 | 26.31 |
| 291.0 | 0.59 | 164.8 | 0.57 | 118.6 |
| 308.3 | 0.33 | 112.9 | 0.32 | 109.6 |

## XI. CONCLUSION

In the present paper, pelton wheel has been designed in NX-CAD software and analyzed for structural behavior in ANSYS software. From the analysis results, it was concluded that the pelton wheel has stresses and deflections within the design limits of the material used for static analysis but considering for harmonic analysis, the stress at critical frequency is greater than design limits of the material. So, the 3D model was modified and analyzed for structural behavior. From the results, it can be concluded that that the modified pelton wheel has stresses and deflections within the design limits of the material used for both static and harmonic analysis. From the obtained results, it is concluded that the 3D model of modified pelton wheel is better compared to 3D model of pelton wheel.

## REFERENCES

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