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Stator Casing Depth Analysis under Static Loading

Jayesh Janardhanan, Dr. Jitendra Kumar

Abstract— **The titled research paper is to analyse the stator casing of generator by different theories of analysis. The theoretical calculation of stator casing is elaborated in detail by considering it as curved beam. The fabricated stator casing of hydroelectric generator with intermediate ribs which are segmented is considered for formulating the results. These casings are of larger diameters widely used in electrical machines, which can be of varying shape and sizes. And they are applied for carrying out static as well as dynamic loads through-out its span. The Winkler-Bach Theory [1] from the textbook of strength of materials is used to determine the beams depth. This problem is also evaluated by the use of advance software NX Nastran FEM analysis. Comparative graph is plotted to get a better result.**

Index Terms— **Hydroelectric generator, stator casing, Winkler-Bach Theory, NX Nastran FEM.**

I. INTRODUCTION

The powerhouse of a hydroelectric development project is the place where the potential and kinetic energy of the water flowing through the water conducting system is transformed into mechanical energy of rotating turbines and which is then further converted to electrical energy by generators [2]. The purpose of a generator is to convert mechanical energy to electric energy. This electromechanical energy conversion is realized with the magnetic field inside the generator acting as an intermediate coupling. The Michael Faraday’s principle of electromagnetic induction is the basis of the generation of electricity by these generators. The rotor consists of wound conductors on the rotating part of the generator. The copper conductor is stationary called the 'stator' or the 'armature'. This consists of high current carrying copper coils wound on the stationary part of the generator. The rotor's rotating magnetic field cuts the stationary stator copper conductors to produce the electric current. The energy for rotation of the rotor is from a rotating turbine, which is driven by water potential. The spindle of the turbine is connected to the alternator, where rotational power of the spindle is converted into electrical power [3].

Once a hydroelectric complex is constructed, the project produces no direct waste, and has a considerably lower emission of greenhouse gas carbon dioxide (CO_2) than fossil fuel powered energy plants. This power accounts for peak load demands and back-up for frequency fluctuation, so pushing up both the marginal generation costs and the value of the electricity produced. It is a flexible source of electricity since plants can be ramped up and down very quickly to adapt to changing energy demands, in order of few minutes. Power generation can also be decreased quickly when there is a surplus power generation. The limited capacity of hydropower units is not generally used to produce base power except for vacating the flood pool or meeting downstream needs. Instead, it serves as backup for non-hydro generators. The major advantage of hydroelectricity is elimination of the cost of fuel. The cost of operating a hydroelectric plant is nearly immune to increases in the cost of fossil fuels such as oil, natural gas or coal, and no imports are needed [4].

II. GENERATOR STATOR

The generators have been designed based on many conventional methods and regular practices related to the prevailing technology. Moreover, the design of hydro generator depends on the conditions of site, which may vary for two generators of same rating. Out of all the critical items used, stator plays its important role with respect to the performance parameters of the whole system.

A stator consists of stator casing, winding and stator core. The stator casing is made of welded steel construction and manufactured with thick steel plates to prevent distortion during operation. It is adequately designed to prevent deformation during transportation and lifting. Robust and rugged, these casings are designed to withstand the mass of a stator core, bending stresses and deflections. The stator casings are designed to handle mechanical and electrical forces. The casing is machined in a manner to ensure a uniform air gap between the rotor and stator, thereby minimizing the unbalanced magnetic pull. These casings are designed to withstand the extreme stresses due to short circuits. Each machine is designed to be assembled on a robust concrete foundation or steel base. The casing is fabricated from structural steel plates to ensure an extremely robust and rigid support structure. The stator core assembly consists of segmented and insulated laminations of cold-rolled low-loss silicon steel, clamped between substantial side plates. Therefore, the mechanical design of the stator is performed with respect to tangential stresses in the stator core as well as transfer of forces to the concrete foundation. These stresses and forces depend on stator stiffness and temperature in the stator core and stator casing [5].

Jayesh Janardhana, MTech Scholar, Machine Design & Robotics, Mechanical Engineering Department, NRI Institute of Information Science & Technology (RGPV University), Bhopal, India, 9406906075.

Dr. Jitendra Kumar, Associate Professor, Mechanical Engineering Department, NRI Institute of Information Science & Technology (RGPV University), Bhopal, India, 9302377458

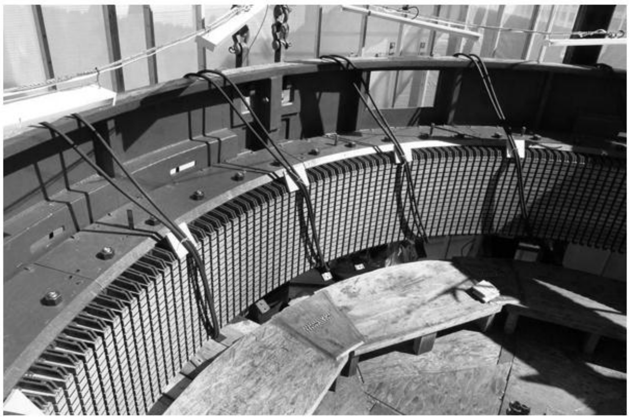


Fig. 1: A Typical Stator of Hydro-electric Generator.

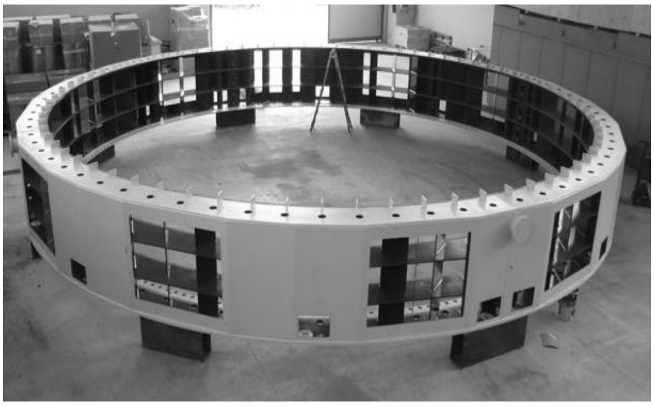


Fig. 2: Fabricated Stator Casing.

The stator casing is usually designed in polygon shapes, which are splited into a number of sections to facilitate transport of the wound segments keeping in view the restrictions on the maximum size and weight of the package that can be transported to site.

III. Design Considerations

There are many factors involved in the designing of stator casing for hydro generators. Apart from technical requirements there are other requirements form surrounding which to a certain extend governs the engineering of stator casing. The same is given below:

The hydro generators are tailor made electrical equipment depending upon various design and technology factors. It determines the type of technology available with the engineer for designing and manufacturing of generators in the shop. The technical design parameters required for a particular generator also rules to determine its dimensions.

A part from electrical performance parameters, project site requirements also governs the limitations regarding the weight, height, length and width of any package that can be safely handled in shop and erection at site.

Even the size of the roads / bridges / high ranges through which the project consignment is transported also determines its basic engineering. In this case the stator casing segment needs to be split into a number of sections to facilitate transport of the wound segments keeping in view the restrictions on the maximum size and weight of the package that can be transported to site.

IV. Research Gap

The purpose of this research initiated with the strategy to find out the research gaps which have been listed below:

From the extensive literature review it has been found that related work has not been done in the field of analysis of stator casing depth during design detailing.

Need has been felt for ease of handling of stator casing and its segment during transportation and erection.

To evaluate the customary practice of prevailing techniques and parameters of stator casing design.

Efficient and effective utilization of space inside the generator barrel.

The need of cost considerations in designing of stator casing without affecting the performance parameters has not been looked to a great extend in prior researches.

The main objective of this research envisages the determination of below mentioned particulars:

Design optimization of stator casing depth for effective utilization of space.

Reduction in material will result in cost saving.

Design evaluation for effective stress distribution.

Stress assurance during transportation and handling in horizontal condition.

Ease of controlling the stator casing during erection at site.

Determination of above parameters without affecting the performance of generators.

By scrutinize the above points and its viability in all aspects of these centuries competitive environment resulted in the need for research on “Stator Casing Depth Analysis under Static Loading”.

V. Problem Formulation

The problem formation for the analysis of stator casing segment is based on its handling in shop floor and strength during transportation. The stator casing is designed with multiple numbers of faces in a regular or non-regular polygon shape. In this case 12 number of stator casing faces are considered. The hydroelectric generators are of larger diameters and are very heavier. Due care to be taken during its design, manufacturing and installation. For analysis purpose the inner diameter of stator casing is kept around 3000mm approximately. In conventional design the depth of the casing segment is kept in between 400 to 450mm, but in optimized design the depth is reduced to 300 and 350mm. The section should be sufficiently designed to take all the stress during transportation and tilting of the same form horizontal to vertical position.

The stator casing assembly is divided into number of segments say three in this case. The total weight of the complete stator assembly is 100tons including the stator casing weight with 350mm depth. Each segment is weighing around 33.3 Tons each. It is considered that this stator casing segment is transported horizontally on a trailer. The casing segment is resting its side faces on the trailer with sufficient fixing on bottom face. The whole load of stator core, winding and its hardware is transferred to the structural stator casing. In this case the depth of the stator casing comes in to picture.

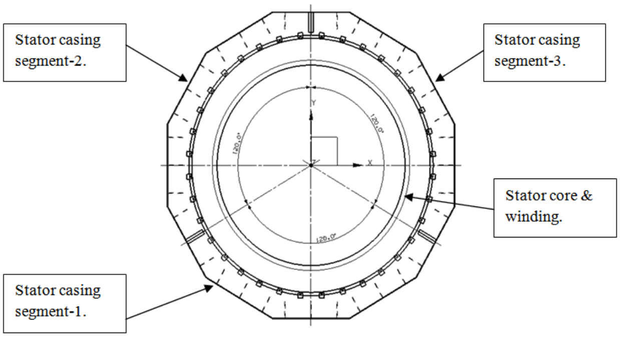


Fig. 3: Stator Casing Assembly.

Table 1: Weight of stator casing with different depths

Sl. No.	Depth, MM	Wt. of stator core + winding, KG (Approx.)	Wt. of stator casing, KG (Approx.)	Total loading on stator casing, KG (Approx.)
1	300	91000	8000	99000
2	350		9000	100000
3	400		10000	101000
4	450		11000	102000

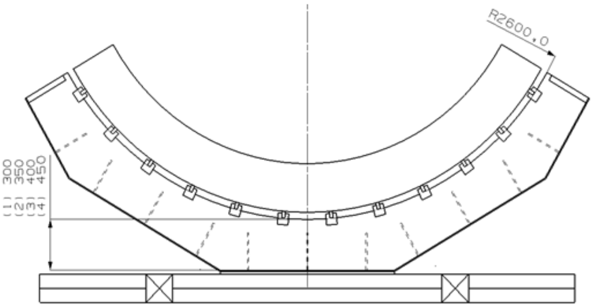


Fig. 4: Casing segment (All Dim in mm).

Fig. 5: Stator casing loaded on a trailer without core and winding.

For the analysis purpose half segment of stator casing loaded on trailer is considered. The loading on stator casing segment includes weight of core, winding and self-weight of stator casing.

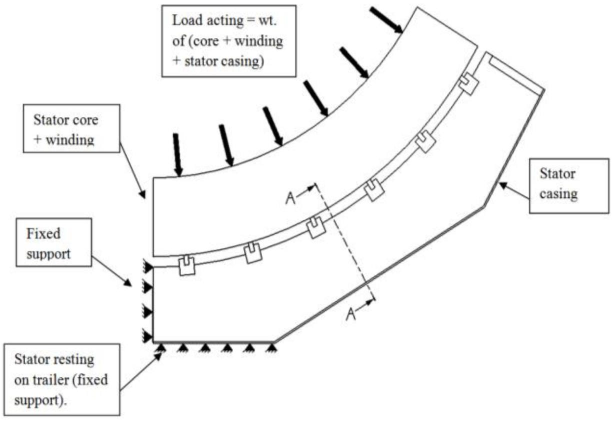


Fig. 6: Stator segment half portion under loading.

VI. WINKLER-BACH THEORY (CURVED BEAMS) [1]

Considering as case of element of machine members and its structures subjected to bending along the central axis of the curved beams. A simple flexure formula may be used for curved beams for which the radius of curvature is more than 5 times the beam depth. For deeply curved beams, the neutral and centroidal axes no longer coincide and the simple bending formula is not applicable.

The following assumptions are made in this analysis:

Plane transverse sections before bending remain plane after bending.

Limit of proportionality is not exceeded.

Radial strain is not negligible.

The material considered is isotropic and obeys Hooke’s law.

Consider a portion of a beam ABCD initially curved in its unstrained state as shown in Figure 6.

R- Radius of curvature of the centroidal axis GH.

y - Distance of the fiber EF from GH.

Let ABC`D` be the strained portion of the beam.

R1- Radius of curvature GH`.

Y1- Distance between EF` from GH` after straining.

M- Uniform bending moment applied to the beam, assumed positive when tending to increase the curvature

φ - Original angle subtended by the centroidal axis GH at its centreof curvature O.

θ - Angle subtended by GH` (after bending) at the center of curvature O`.

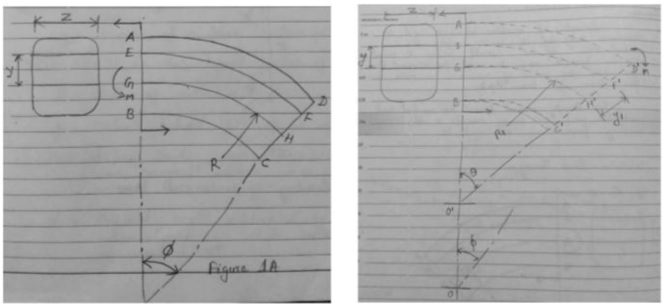


Fig. 7: Bending of a curved beam (before and after).

Let breadth of the beam section perpendicular to y be z, and let A be the constant area of cross-section.

$$\sum \delta A = \sum z dy$$

Compressive Stress,

$$\sigma_c = \frac{M}{AR}\left[1 + \frac{R^2}{h^2} \times \frac{y}{R+y}\right]$$

Tensile Stress,

$$\sigma_t = \frac{M}{AR}\left[1 - \frac{R^2}{h^2} \times \frac{y}{R+y}\right]$$

Position of neutral axis:

At the neutral axis, σ = 0

$$\frac{M}{AR}\left[1 + \frac{R^2}{h^2} \times \frac{y}{R+y}\right] = 0$$

$$y = -\left(\frac{Rh^2}{R^2 + h^2}\right)$$

Hence, the neutral axis is located below the centroidal axis.

Value of h^2:

$$h^2 = \frac{1}{A}\int \frac{y^2 dA}{\left(1 + \frac{y}{R}\right)}$$

After substitutions and iterations,

$$= \frac{R^3}{A}\int \frac{dA}{(y+R)} - R^2$$

Stator casing segment section: Considering a stator casing segment as a T-section. The equation of Section-AA is given below:

Let, z = R + y

dz = dy

$$h^2 = \frac{R^3}{A}\left[\int_{r_1}^{r_2} \frac{dA}{R+y} + \int_{r_2}^{r_3} \frac{dA}{R+y} + \int_{r_3}^{r_4} \frac{dA}{R+y}\right] - R^2$$

$$= \frac{R^3}{A}\left[\int_{r_1}^{r_2} \frac{b_2\, dz}{z} + \int_{r_2}^{r_3} \frac{t_1\, dz}{z} + \int_{r_3}^{r_4} \frac{t_3\, dz}{z}\right] - R^2$$

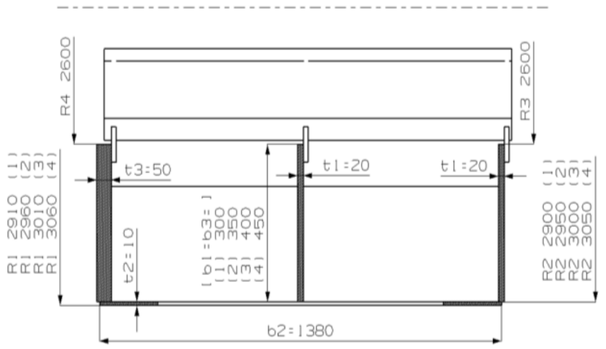


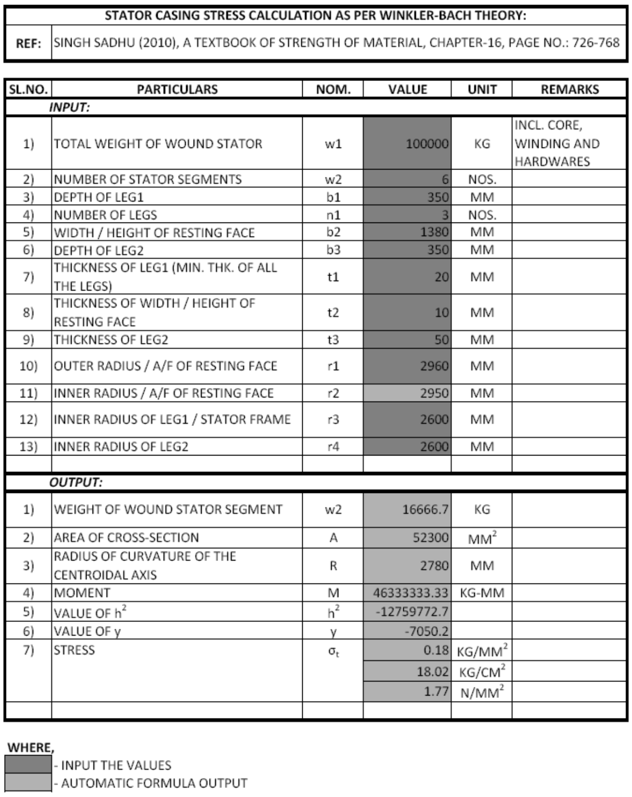
Fig. 8: Section-AA (Stator casing section, All Dim in mm).

$$h^2 = \frac{R^3}{A}\left[b_2 \left|\log z\right|_{r_1}^{r_2} + \left(t_1 \left|\log z\right|_{r_2}^{r_3}\right) * 2 + t_3 \left|\log z\right|_{r_3}^{r_4}\right] - R^2$$

Where, A= 2(b1t1) + b2t2 + b3t3

Theoretical calculation of the research paper problem as per the above theory is given below: (for 300mm depth)

Table 2: Theoretical Calculation for 300 Depth Stator Casing.



STATOR CASING STRESS CALCULATION AS PER WINKLER-BACH THEORY:	
REF:	SINGH SADHU (2010), A TEXTBOOK OF STRENGTH OF MATERIAL, CHAPTER-16, PAGE NO.: 726-768

SL.NO.	PARTICULARS	NOM.	VALUE	UNIT	REMARKS
INPUT:					
1)	TOTAL WEIGHT OF WOUND STATOR	w1	100000	KG	INCL. CORE, WINDING AND HARDWARES
2)	NUMBER OF STATOR SEGMENTS	w2	6	NOS.	
3)	DEPTH OF LEG1	b1	350	MM	
4)	NUMBER OF LEGS	n1	3	NOS.	
5)	WIDTH / HEIGHT OF RESTING FACE	b2	1380	MM	
6)	DEPTH OF LEG2	b3	350	MM	
7)	THICKNESS OF LEG1 (MIN. THK. OF ALL THE LEGS)	t1	20	MM	
8)	THICKNESS OF WIDTH / HEIGHT OF RESTING FACE	t2	10	MM	
9)	THICKNESS OF LEG2	t3	50	MM	
10)	OUTER RADIUS / A/F OF RESTING FACE	r1	2960	MM	
11)	INNER RADIUS / A/F OF RESTING FACE	r2	2950	MM	
12)	INNER RADIUS OF LEG1 / STATOR FRAME	r3	2600	MM	
13)	INNER RADIUS OF LEG2	r4	2600	MM	
OUTPUT:					
1)	WEIGHT OF WOUND STATOR SEGMENT	w2	16666.7	KG	
2)	AREA OF CROSS-SECTION	A	52300	MM^2	
3)	RADIUS OF CURVATURE OF THE CENTROIDAL AXIS	R	2780	MM	
4)	MOMENT	M	46333333.33	KG-MM	
5)	VALUE OF h^2	h^2	-12759772.7		
6)	VALUE OF y	y	-7050.2		
7)	STRESS	σ_t	0.18	KG/MM^2	
			18.02	KG/CM^2	
			1.77	N/MM^2	

WHERE,

▓ - INPUT THE VALUES

░ - AUTOMATIC FORMULA OUTPUT

VII. SOFTWARE COMPLIANCE

The stator casings of hydro generator have been designed using prevailing conventional methodology. But nowadays there are many software's prevailing in the market for modeling of components. NX modeling has been used for proceeding further with the designing of hydro generator components followed by the analysis in NX Nastran. And the other important factor for further analysis lies in meshing. The basic concept underlying the finite element method is based on the principle of discretization and numerical approximations to solve scientific and engineering problems which are facets of life.

The parametric 3-D modeling of stator casing segment is done in UGNX software. The step-by-step process involves the sketching part first. In this basic sketch of stator casing segment is drawn out by linking all the required dimensions. The linking of dimensions helps to modify the sketch in future. The part file of different components of stator casing segment assembly is called in an assembly file along with the sketch file. In assembly file the part files are linked to sketch file via Wave-Linker geometry. Now with modeling command, the components of stator casing segment are built up to form a parametric model of stator assembly.

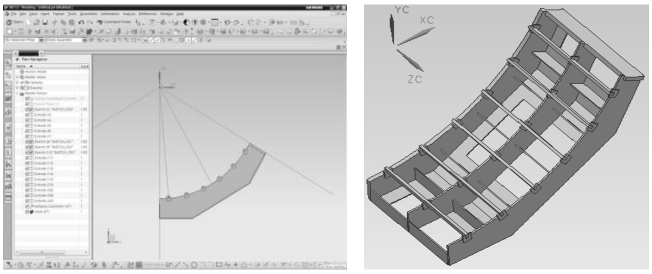


Fig. 9: NX sketching and 3-D view of stator casing. Section-AA.

VIII. MESHING OF STATOR CASING

Meshing is one of the most critical aspects of engineering simulation. Too many cells may result in long solver runs, and too few may lead to inaccurate results. This technology provides a means to balance these requirements and obtain the right mesh for each simulation in the most automated way possible. The strongest aspects of these separate tools have been brought together in a single environment to produce some of the most powerful meshing available. A consistent look and feel for performing multiphysics simulations help you easily build coupled solutions on the same mesh using common element types, properties, boundary conditions, and solver controls and options. Adaptive meshing provides you with better solution convergence and accuracy of structural solutions.

3D Finite Elements - Tetrahedral Family: The tetrahedral family exhibits the properties similar to those of the triangular elements. It is a polyhedron composed of triangular faces, three of which meet at each corner or vertex. It has six edges and four vertices. The tetrahedron is one kind of pyramid, which is a polyhedron with a flat polygon base and triangular faces connecting the base to a common point. In the case of a tetrahedron the base is a triangle (any of the four faces can be considered the base), so a tetrahedron is also known as a "triangular pyramid". The complete polynomials in three coordinates are achieved at each stage. Then faces are divided in a manner identical with that of previous triangle, the same order of polynomial in two coordinates in the plane of the faces is achieved and element's compatibility is ensured [6].

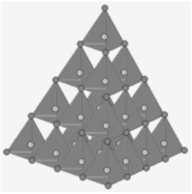


Fig. 10: Tetrahedron structure.

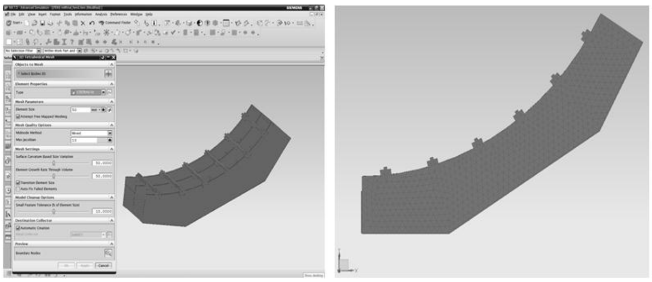


Fig. 11: Stator casing meshing.

IX. NX NASTRAN ANALYSIS

The integrated NX Nastran analysis software is a modern, multi-discipline computer aided engineering environment for appropriate analysis of the research paper problem. During the analysis three files are created namely part file, fem file and simulation file. The part file is the assembly file having the parametric sketch for possible modification during analysis. Fem file is for allocation of material and meshing of the model in NX Nastran. And the simulation file is for the application of boundary condition and fem analysis. NX Nastran solves most structural analysis problems for linear and nonlinear analysis, dynamics, acoustics, rotor dynamics, aero-elasticity and optimization. The advantage to having all of these solutions available in a single solver is that input/output file formats are the same for all solution types, greatly simplifying modeling processes. It also enables designers to rapidly evaluate many more design concepts that can be accomplished with physical prototype. It helps to better understand and optimize design trade-offs for quality, cost and performance [6].

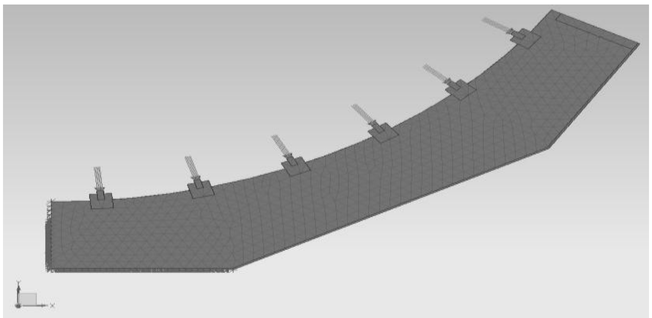


Fig. 12: Stator casing FEM analysis.

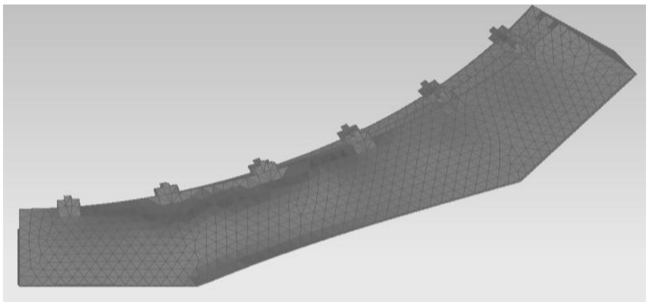


Fig. 13: Stator casing stress distribution.

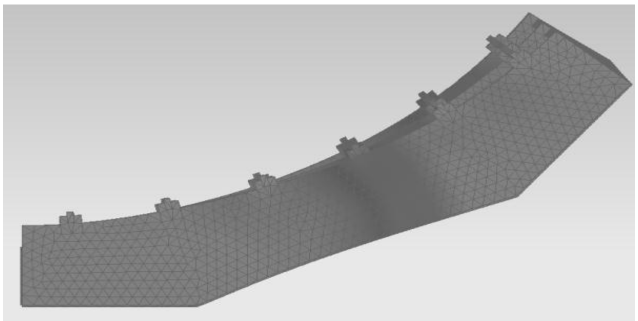


Fig. 14: Stator casing displacement.

X. RESULT

The important part of this research paper is the valuation of theoretical and fem analysis result. It needs to be crucially examined that the repurcation of the variation in the depth of the stator casing segment. The results of theoretical calculation of stresses according to Winkler-Bach Theory are given below:

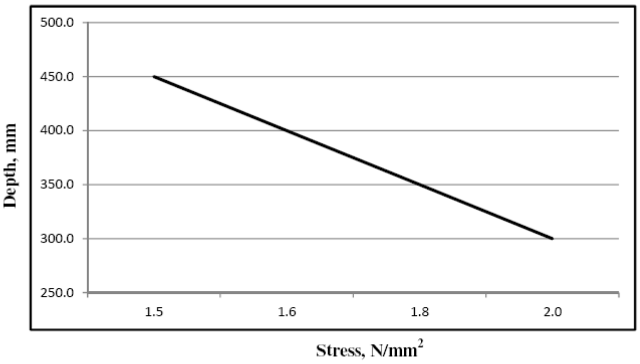
σ_t= 2.0 N/mm2 (with 300mm depth)

σ_t= 1.8 N/mm2 (with 350mm depth)

σ_t= 1.6 N/mm2 (with 400mm depth)

σ_t= 1.5 N/mm2 (with 450mm depth)

Graph 1: Stress vs Depth for Winkler-Bach Theory



Now as per the NX FEM analysis the values of stress and displacement is given below. In NX the stress calculation is as per Von-Misses theory.

The stress value of fem analysis result for 300 mm depth is 104.8 N/mm2.

The stress value of fem analysis result for 350 mm depth is 92.2 N/mm2.

The stress value of fem analysis result for 400 mm depth is 84.1 N/mm2.

The stress value of fem analysis result for 450 mm depth is 75.4 N/mm2.

The displacement value after fem analysis for 300 mm depth is 3.3 mm.

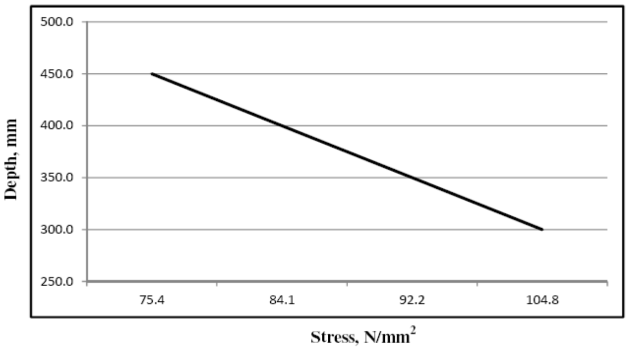
The displacement value after fem analysis for 350 mm depth is 2.5 mm.

The displacement value after fem analysis for 400 mm depth is 1.9 mm.

The displacement value after fem analysis for 450 mm depth is 1.5 mm.

A comparative graph of the above stress value in case of NX FEM analysis is plotted for better understanding:

Graph 2: Stress vs Depth as per NX FEM Analysis



XI. CONCLUSION

The stator casing segment has been designed using NX software. The FEM analysis of the same is done on NX Nastran. The boundary conditions for the analysis are applied in such a way that the stator casing segment is transported in horizontal condition in a trailer. In theoretical calculation only the casing section come into picture, the additional ribs and supports are not considered. But for FEM analysis the casing segment model is having additional reinforcement ribs and supports. Therefore the result of both the analysis will have a conventional difference.

The analysis concludes that the there is a significant increase in the stress and displacement values by decreasing the depth of stator casing segment. These values are under the acceptable limits. The space inside the barrel containing the stator casing is drastically increased. Better utilization of space inside and outside the stator. The material costing for stator casing segment fabrication is economical. The overall weight of the stator casing is reduced for ease of handling of the same in shop, transportation and erection at site. It also reveals that up to certain extend only the depth of stator casing can be decreased.

This research paper is only the structural analysis the stator casing segment. The future scope of this research paper is to undergo electromagnetic analysis of the stator casing. The projection of this analysis would be to evaluate the electrical parameters of the system under design and execution.

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Jayesh Janardhanan, MTech Scholar, Machine Design & Robotics, Mechanical Engineering Department, NRI Institute of Information Science & Technology (RGPV University), Bhopal. He did his B.E. in Mechanical Endineering from OIST-Bhopal (RGPV University) in 2004. Thereafter have hands on experience in the field of design and engineering of hydro generators for more than 8 years. Membership of IEI (India) AM100357-5.

Dr. Jitendra Kumar, working as Associate Professor in Mechanical Engineering Department in NRI Institute of Information Science & Technology (RGPV University), Bhopal**.** He did his Ph.D in Industrial Engineering & Management from MANIT, Bhopal and has vast expertise in this field. Holds a Membership of IEEE. He has published numerous research papers in international journals.