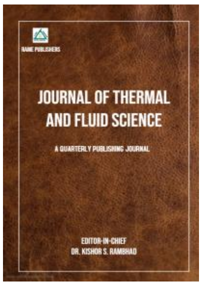

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Numerical Analysis of Screw Turbine

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***Abstract*—This research aims to examine the design parameters for best performance of the Archimedean screw turbine. A 1 blade Archimedean Screw Turbine Inclined Axis has been developed, and theoretical power and efficiency estimates have been computed. The relevance of the Archimedes screw for low-head energy and the very minimal environmental effect of this project is also highlighted. The structural study of the screw pump is also part of this project. For structural analysis of aluminum, mild steel and glass epoxy as screw turbine material. If it is best to find out and aluminum, maximum stress and deformation is suggested.**

Keywords— Screw turbine, Archimedes screw, screw pump, FE Analysis, CFD.

I. Introduction

Archimedes has lately grown in importance as a low-cost, dependable hydropower source that is environmentally beneficial. Due to its complex geometry, the fluid properties inside a screw during operation were very difficult to measure and view. In order to fill this void in the literature, two dynamic computer fluid models have been developed and validated. Turbine power generation and solar power generation are a renewable energy [1]. This article presents an overview of the Archimedes screw history then concentrates on the screws, which are used by hydro-electric generators, and the extant device versions. We have to employ unconventional power to generate electricity every day. Small portable electricity generator is also required. The screw turbine is designed and analysed [2].

Sustainable energy production is one of the world's most important issues. Hydraulic water power is transferred to mechanical power by means of a turbine in hydropower facilities. Inverse usage is recognised as a common method utilised for the generation of electricity from running water using the typical Archimedes screw pump [3]. The AST is a structure that respects the environment and fish, requiring low civil works to be installed even in existing structures. According to a European assessment of around 400 ASTs, the cost of AST for energy generation of around 15% more was around 10% less and its yearly capital cost 22% lower [4].

The average and maximum electrical efficiency of ASTs was also estimated to be 69% and 80%. The impact on the screw diameter was significant in the upstream canal water level [5]. The AST electrical efficiency showed 84 percent of its high efficiency at the tilt angle of 34.8 percent. The majority of research to date have been

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experimental and, in some cases, numerical and experimental in terms of the screw performances [6]. Irrigation canals are one of the best micro power supplies as various energy dissipator structures have been installed to lower water flows' hydraulic energy. Excess energy may be transformed into electricity in irrigation canals in such buildings. in flowing water. The current study examined the performance of the screw using CFD, Open FOAM and screw rotary speeds in a number of flow conditions. The mechanical power and efficiency predicted were good in accordance with the experimental results involved [7].

East Aghili canal is good case to study and optimize AST performance in Khuzestan Province (Iran). The AST system is increasing in the usage of power, and its optimum design and implementation in irrigation channels worldwide does not concern references [8].

II. DESIGN METHODOLOGY

Figure 1 is the sections profile of the Archimedean twin blade screw. By the angle of Transparency θ i.e. the slope of the screw is tan joined by the horizontal direction. Following are two kinds of parameters governing the geometry of the screw.

1. External parameters
2. Internal parameters.

1. External parameters:

a. Outer radius (R_0)

b. Total length (L)

c. Slope of screw (K)

Values of these external parameters depend on the site of the screw and materials available for its construction [2].

2. Internal parameters

a. Inner cylinder radius (Ri) :

$$0 \leq R_i \leq R_o$$

b. Pitch of one blade (P)

$$0 \leq P \leq \frac{2\pi R_o}{K}$$

c. Number of blades (N): N= 1, 2, 3, 4…

The external parameters are taken as fixed here. Now that the blade thickness is negligible, the total water volume increases monotonously with the number of the blades in one cyclone of the screw. If their thickness is not negligible, they occupy a growing fraction of the screw volume as their number increases. An optimum value of N is determined in this case. In modern screws, due to production, weight and cost constraints the sheet number is taken as 1, 2 or 3. The blade number of the screw has been taken as 2 [9](Figure 1).

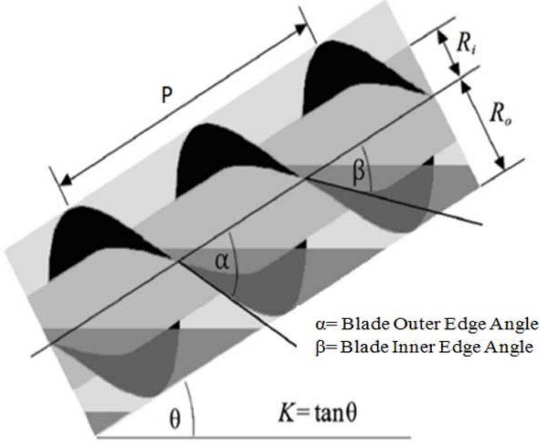

Figure 1. CAD model of screw turbine

In order to optimize the performance of the screw turbine, Maximum volume of water in one cycle of the screw,

$$V_{Tmax} = \pi R_o^2 P \quad ----(1)$$

Volume of one chute,

$$V_c = \frac{\pi(R_o^2 - R_i^2)L}{N} \quad ----(2)$$

Volume of one bucket,

$$V_b = \frac{V_T}{N} \quad ----(3)$$

The bucket is one of the most interconnected areas that occupy the water within any chute, bounding between the two adjacent layers and the internal and external radii of the screw [10].

We now have the fixed R0, L, K and N values and so the Ri and P values to maximise VT can be determined.

Three dimensional parameters are taken into account [2] to simplify the design calculation. These are These Dimensionless Parameters:

a. Radius ratio, $\rho = \frac{R_i}{R_o}\ (0 \le \rho \le 1)\ --(4)$

b. Pitch ratio, $\lambda = \frac{KP}{2\pi R_o}\ (0 \le \lambda \le 1)\ --(5)$

c. Volume ratio, $\vartheta = \frac{V_T}{\pi R_o^2 P}\ (0 \le \vartheta \le 1) - (6)$

From dimensional analysis it can be found that ϑ depends on the values *of N*, ρ *and* λ. So ϑ can be written as $\vartheta(N,\rho,\lambda)$. From the equations (1), (4), (5) and (6), V_T can be expressed in terms of λ and as $\vartheta(N,\rho,\lambda)$ as shown below.

$$V_T = \frac{2\pi R_o^3}{K}\vartheta(N,\rho,\lambda)\ ----(7)$$

For the fixed values of *Ro*, *N and K*, the maximum value of V_T depends on the maximum value of $\lambda\vartheta(N,\rho,\lambda)$ with respect to λ *and* ρ. Let the values of λ *and* ρ that maximize V_T *and* $\rho*$

and λ^* respectively. Now from equations (4), (5) and (6), the optimal values of R_i, *P* and V_T are given by,

$$R_i^* = \rho^* R_o\ \ ----(8)$$

$$P^* = \frac{2\pi R_o \lambda^*}{K}\ \ ----(9)$$

$$V_T^* = \frac{2\pi R_o^3}{K}\lambda^*\ \vartheta(N,\rho^*,\lambda^*)\ ----(10)$$

TABLE 1

OPTIMUM RATIO PARAMETERS [8]

No of Blade (N)	Optimal radius ratio (ρ*)	Optimal pitch ratio (λ*)	Optimal volume per turn ratio (λ*υ(N,ρ*,λ*))	Optimal volume ratio (υ(N,ρ*,λ*))
1	0.5358	0.1285	0.0361	0.2811
2	0.5369	0.1863	0.0512	0.2747
3	0.5357	0.2217	0.0598	0.2697
4	0.5353	0.2456	0.0655	0.2667
5	0.5352	0.2630	0.0696	0.2647
6	0.5353	0.2763	0.0727	0.2631
7	0.5354	0.2869	0.0752	0.2619
8	0.5354	0.2957	0.0771	0.2609
9	0.5356	0.3029	0.0788	0.2601
10	0.5356	0.3092	0.0802	0.2592

Optimal parameters (Table 1) corresponding to N=2, from the table 1 are given below

$\rho^* = 0.5369$

$\lambda^* = 0.1863$

$\lambda^*\ \upsilon(N, \rho^*, \lambda^*) = 0.0512$

$\upsilon(N, \rho^*, \lambda^*) = 0.2747$

We have considered the values of the external parameters as R_0 = 0.25 m, K = tan30, L = 1 m.

By calculating the optimal values of R_i^*, P^*, V_T^* and V_b^* equations (3), (8), (9) and (10),

R_i^* = 0.042m

P^*=0.082m

V_T^*= 0.008706 m^3

V_b^*= 0.004353 m^3

So the flow rate is Q = 0.008706 m^3/s

Hydraulic power developed,

$$P_{in} = \rho g Q H$$

Where,

ρ = density of water = 1000 kg/ m3

g = acceleration due to gravity= 9.81 m/s^2

Q = flow rate in m^3/s

H = height of fall water = Lsin30 = 0.5m

$$P_{in} = 1000 * 9.81 * 0.008706 * 0.5$$

$$P_{in} = 42.70\ w$$

Now efficiency is given by,

$$\eta = \frac{P_{out}}{P_{in}}\ ----(11)$$

Where,

P_{in} hydraulic power

P_{out}= Output power

P_{out} = Output power = Tω =T ($2\pi N$) ----- (12)

Where, T = torque developed in the shaft (Nm), ω = angular speed (rad/s),

n= rotational speed (rev/s)

There is a correlation for efficiency with respect to outer diameter of the screw, flow rate and the rotational speed of the shaft [2]

$$\eta = \frac{1 - \frac{0.01125 D_O^2}{Q}(2n+1)}{2n+2}\ ---(13)$$

$$n = \frac{0.85}{n^{2/3}}\ ---(14)$$

III. FEA ANALYSIS

A. *Computational fluid dynamics (CFD) Analysis*

Modeling turbulent structures in the flow field is the most significant task in the calculation procedure. This chaotic structure takes place at many timelines and lengths and it cannot be readily practised to create a model that can assess all these possibilities. For turbulent flow, many turbulence models are provided simulation. The model employed in this work is a model called the renormalized group k-epsilon model, which is the conventional k-epsilon model (Figure 2).

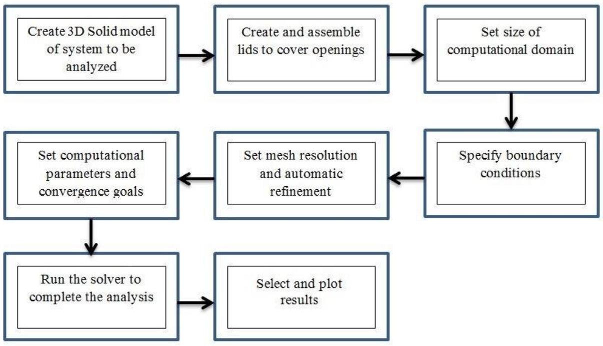

Figure 2. CFD process

B. *Navier-Stokes Equation*

This equation may be used to describe the weather, ocean currents, water flow in pipes and airflow in the wing. The complicated and simplified Navier-Stokes's equation can assist to build power stations, turbines and much more.

With regard to the inertial reference, the general form of the motility equation of fluid T is a symmetrical tensor unless when the fluid consists of freedom levels, which rotate like a vortex. T has the form of the equation in general (in three dimensions):

$$\rho\left(\frac{Dv}{Dt}\right) = -\nabla p + \nabla . T + f \text{ .....} \textbf{(15)}$$

$$T = \begin{pmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{pmatrix}$$

Where σ: normal stress and tangential stress (shear stress)

C. *k-ε (k-epsilon) Turbulent Model*

For turbulent flow modelling there are several turbulence models available. The model utilized here is a version of the k-epsilon standard. Due to high-speed flow and erratic movement of fluids, this turbulent flow arises. Variable k equations with the variable ε equation:

$$\rho\frac{Dk}{Dt} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + G_k + G_b - \rho\epsilon - Y_M \text{ ....} \textbf{(16)}$$

$$\frac{D\epsilon}{Dt} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_i}\right] + C_{1\epsilon}\frac{\epsilon}{k}(G_k + C_{3\epsilon}P_b) - C_{2\epsilon}\rho\frac{\epsilon^2}{k} + S_\epsilon \text{ ....} \textbf{(17)}$$

D. *Turbine Archimedes Geometry*

The turbine geometry was developed by use of the program SolidWorks. CFD calculations rely largely on the quality of the mesh used in the analysis of flow. The findings are created with precision. Hexahedra, tetrahedral, square pyramids and extruded triangles are the most prevalent element types.

E. *Meshing*

Due to the three-dimensional shape of the mesh for the test item, the mesh process was employed in this research as a mesh hybrid for the volume area. Most object volumes may be meshed straight into TGRID type tetrahedral / hybrid without being split into particular volumes.

F. *Input Data Parameters*

The data utilised were designed based on the input data, while the fluid physical data follows current literature fluid characteristics. As demonstrated in Table 2, the data are given.

TABLE II

BOUNDARY CONDITIONS

Properties	**Value**
Fluid Viscosity,	0.001003 kg/m.s
Fluid Density, ρ	998.2 kg/m^3
Solid (copper) Density, ρ	8030 kg/m^3
Inlet velocity, V_{in}	0.01579 m/s
Initial Gauge Pressure, P_{in}	9810 Pa

This research offers the simulation findings in the form of pressure, speed and turbulent kinetic energy contour that happens in Archimedes' 7, 9 and 11 screw turbines. The momentum changes in each type of the turbine may be noticed by looking at the difference in the pressure that takes place. The higher the stress, the bigger the rotation of the shaft.

IV. STRUCTURAL ANALYSIS

A. *Steps in Structural Analysis*

Ansys offers engineering software for the quick and effective resolution of difficult structural engineering challenges. Businesses may save cost by using our software, reduce the number and decrease the number of design cycles (Figure 3).

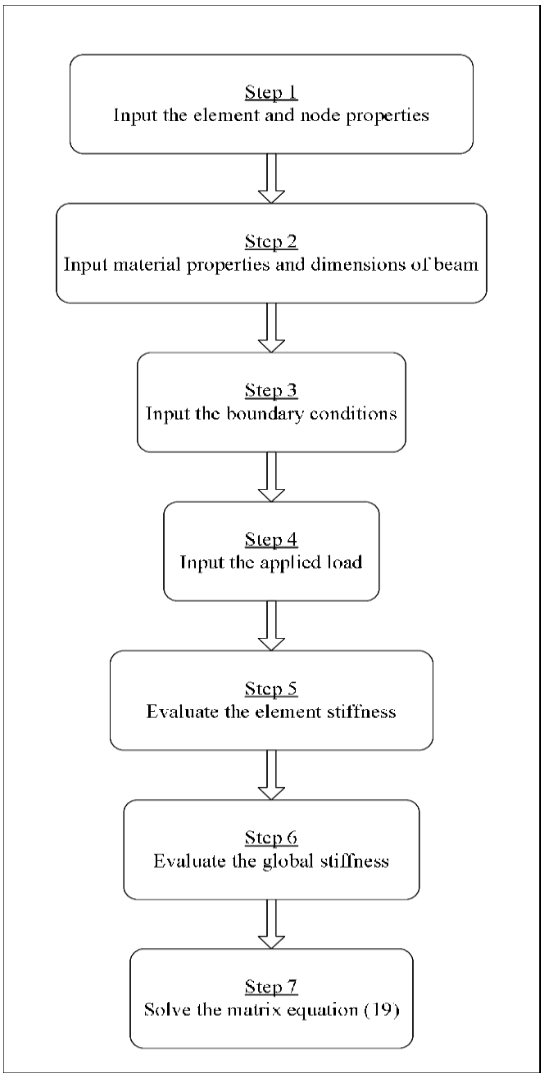

Figure 3. Steps in structural analysis

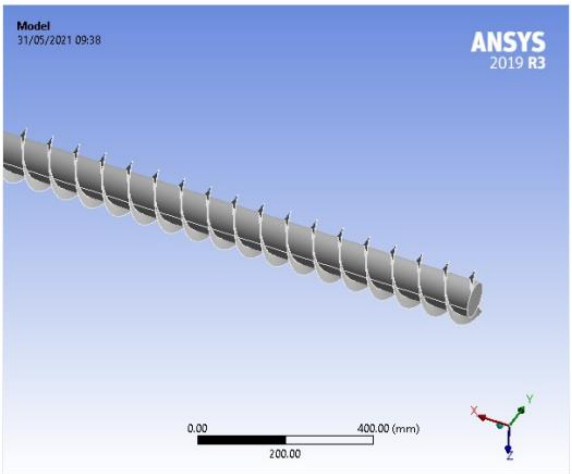

Figure 4. Geometry of the screw turbine

1. Meshing

The meshing technique divides an item into thousands or more of forms via continuous geometric space, which correctly defines its physical form. The closer a grid is, the more precise the 3D CAD model is, therefore high reliability simulations are possible (Figure 4-12) Table 3 shows equivalent Stress.

Details of meshing used

- Element Size: 5.0 mm
- Minimum Edge Length: 0.41406 mm
- Nodes: 159258
- Elements: 73740

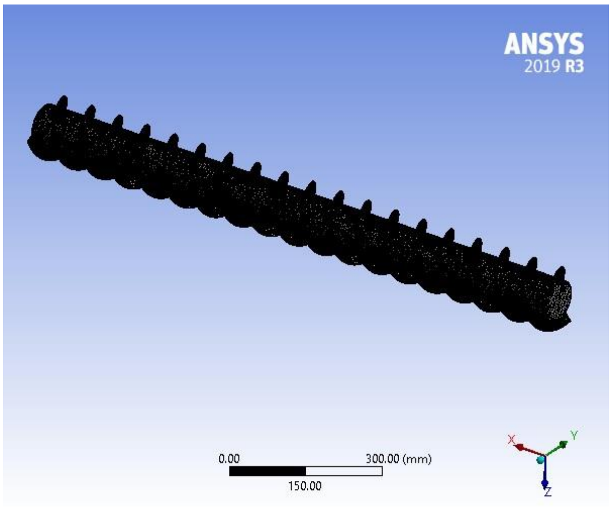

Figure 5. Meshing

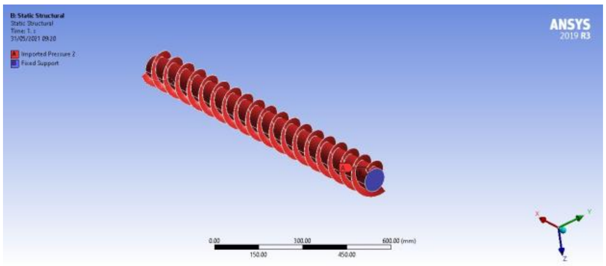

Figure 6. Load applied

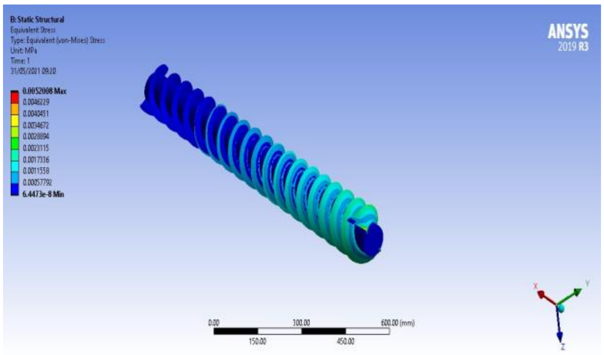

Figure 7. Equivalent Stress on Aluminum model

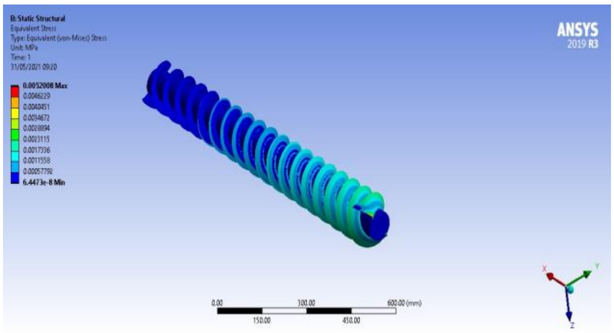

Figure 8. Equivalent Stress on Mild steel model

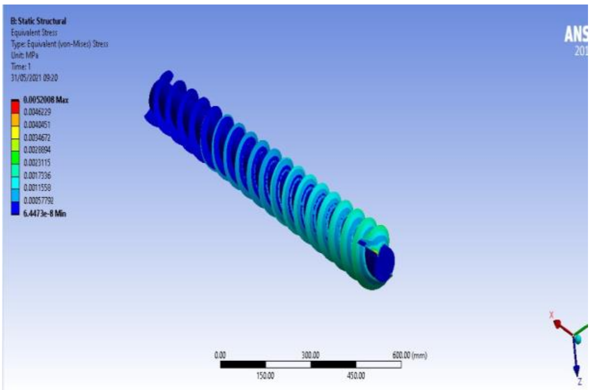

Figure 9. Equivalent Stress of Glass epoxy

TABLE III

EQUIVALENT STRESS

Parameters / Material	Al	Steel	Glass Epoxy
Minimum Equivalent (von-Mises) Stress (MPa)	0.0 mm		5.37e-008
Maximum Equivalent (von-Mises) Stress (MPa)	1.6618e-005mm		5.2175e-003
Average Equivalent (von-Mises) Stress (MPa)	2.4055e-006 mm		3.5256e-004

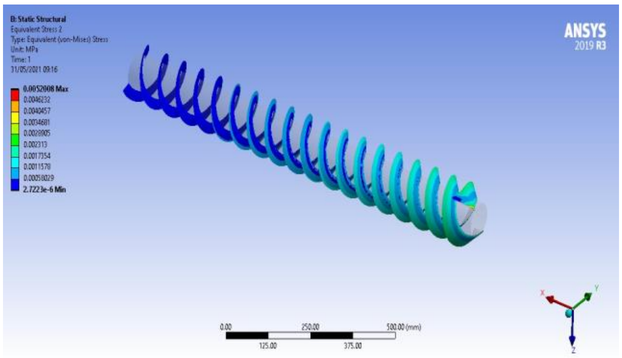

Figure 10. Total deformation in aluminum

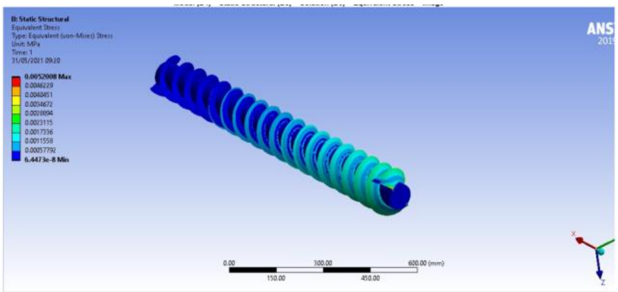

Figure 11. Total deformation in mild steel

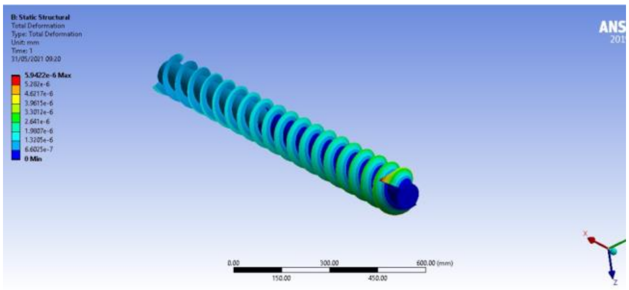

Figure 12. Total deformation in glass epoxy

TABLE 4.

TOTAL DEFORMATION

Parameters / Material	Al	Steel	Glass Epoxy
Minimum deformation	0.0 mm	0.0 mm	0.0 mm
Maximum deformation	1.6618 e-005 mm	5.9422 e-006 mm	1.6467 e-005 mm
Average deformation	2.4055 e-006 mm	8.4393 e-007 mm	2.2335 e-006 mm

V. CONCLUSION

There was a simple analysis model for the Archimedes screw's inflow parameters. The leakage flow from the space between the screw and the external cylinders and also the discharge over the central tube was taken into account when the tube was overfilled. Because of the geometry of the screw, an algorithm was given to determine the inflow head to ensure optimum functioning of a screw when the screw was completed without overflow to its volume. For the turbine screw is performed structural analysis and model analysis. Total deforestation and safety factor, equivalent stressors are controlled. Design is safe.

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