DESIGN STRESS AND VIBRATION ANALYSIS OF LARGE DIESEL ENGINE RADIATOR COOLING FAN

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ABSTRACT: The effective working of a diesel engine directly depends on the overall efficiency of the cooling system. Large diesel engines of thousands of hp capacity used in railways require radiator cooling fans of diameter 1.676 meters (66") made of cast aluminum, to head out excess heat from engine jacket cooling fluid. Railway sector is one of the fundamental modes of transport and constitute a noteworthy development to the advancement of the nation's GDP. This paper presents evaluation of the blade, to investigate the causes for failure at intersection of blade and flange and to recommend an appropriate elective material for the blade. Linear Static analysis has been carried out, dynamic and thermal analysis can been done separately. In this paper the design data for radiator fan blade is acquired from the locomotive engine specifications. Utilizing the information, the solid model of the radiator fan blade is made using SOLID EDGE ST8 and Analysis was completed utilizing ABAQUS/standard. The axial thrust and torque loads are applied uniformly at several cross sections of blade. Changing the material of the blades to FRP is proposed to withstand structural and dynamic load variations.
Keywords: SOLID EDGE ST8, ABAQUS/standard, FRP (FIBER REINFORCED PLASTIC), linear static analysis, Radiator fan blade.

I. INTRODUCTION

Surrounding conditions play an effective part in the support of effectiveness of a working system. The surroundings or condition states of a system must be good for a system to work progressively. The diesel engine efficiency is exceedingly subject to its cooling system as it needs moment cooling to maintain a strategic distance from the danger of overheating. The cooling system which is an arbiter amongst engine and air must be much proficient with the goal that it can keep up the engine/valves at the allowable temperature. The radiator and radiator fan are two noteworthy parts of the cooling system. Heat delivered by a running engine is scattered by the radiator and radiator fan which exchange heat from engine to atmosphere. The radiator contains circuit of tubes and blades which are in open access of air. The coolant travel through these tubes and fins exchange heat from the coolant by means of tubes with the air. The rotating radiator fan pushes or pulls the cool air over the radiator with respect to its position at front or back of the radiator. Radiator fans have four, five or six blades. These blades may be bolted to the hub or integral it as one piece. The air forced in by fan when comes in contact with the radiator fins exchanges the heat and is then drawn out.

The radiator fan is a device, which sucks the atmospheric air through the radiator panels and removes it to air to cool the engine coolant after release from the engine and keeps up a worthy working temperature by exchanging heat from the engine to the atmospheric air. The radiator fan assembly is fitted at the back/front side of the train, which takes drive from the engine through level shaft, eddy current clutch gearbox and universal shaft arrangement (Fig.1). The radiator fan assembly comprise of a hub to which the blades are screwed at the outskirts and is mounted on the fan shaft and bearing housing assembly.

The engine produces power by changing over chemical energy of fuel into heat energy by combustion. Some portion of aggregate heat created by the combustion is utilized to push the piston downwards and thereby delivering necessary power. Some of heat is diverted by the exhaust gases through the exhaust valve. The rest of the heat is consumed by the engine itself, which increases its temperature. The heat of the engine is absorbed by the coolant in order to bring the engine temperature within its typical working range. An ordinary locomotive engine cooling system comprise of a radiator, fan, water pump, coolant, reservoir, thermostat, heater core and necessary plumbing for both the radiator and heat core. At the point when the engine is started, the water pump associated with it additionally starts to pump the coolant around the engine cylinder from the lower radiator tank into the coolant passage. As an object travels through a fluid, the velocity of the fluid differs around the surface of the object, which prompts a centrifugal force on the body. This centrifugal force on the fluid particles on the upper side i.e. convex side endeavors to move them far from the surface. This diminishes the static pressure on this side beneath the free stream pressure. By virtue of this "suction effect", the convex surface of the blade is known as suction side. This centrifugal force on the lower side i.e. concave side presses the fluid harder on the blade surface, along these lines expanding the static pressure over that of the free stream. Subsequently, this side of the blade is known as the pressure side. The upward force on the blade is the aggregate effect of the positive static pressure on the pressure side and the negative pressure on the suction side. Because of this pressure contrast lift and drag forces are formed.

A. Drag force

Drag is the force that opposes a fan motion through the air. Drag is generated by every part of the radiator fan assembly. Drag is generated by the difference in velocity between the solid object and

B. Thrust force

Thrust is generated most often the fluid. through the reaction of accelerating a mass of gas. The fan does work on the gas and as the gas is accelerated to the rear, the engine is accelerated in the opposite direction.

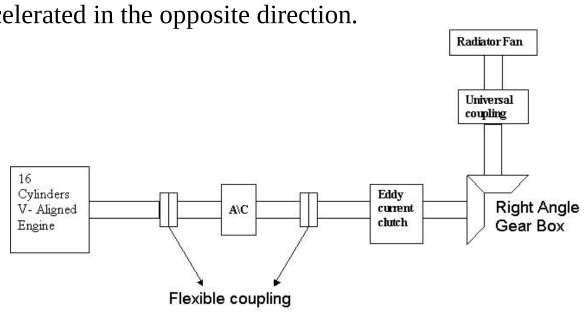

Fig. 1: Locomotive radiator fan drive system

II. LITERATURE REVIEW

Lovedeep Garg and Ramanjeet Singh [1] investigated that the automobile engine efficiency is exceptionally subject to its cooling framework as it needs moment cooling to keep away from the danger of overheating. The cooling framework which is a mediator of motor and air must be much productive with the goal that it can keep up the cooling of engine. The radiator and radiator fan are two noteworthy parts of the cooling framework. Heat created by a running motor is disseminated by the radiator and radiator fan which exchangeheat from the engine. The radiator contains circuit of tubes and blades which are in open access of air. The coolant travel through these tubes and blades exchange heat from the coolant by means of tubes with the air. The pivoting radiator fan pushes or pulls the cool air over the radiator as for its situation at front or back of the radiator. Radiator fans have four to six cutting edges. These sharp edges might be rushed to the center of the radiator fan or joined to it as one piece. The air constrained in by fan when interacts with the radiator blades exchange the heat and is then drawn out.

AvinashGudimetla et al [2] have studied that the radiator fan all together comprise of a center with six cutting edges screwed on its outskirts and is mounted on the fan shaft and bearing housingassembly. As an object travels through a liquid, the speed of the liquid fluctuates around the surface of the object, which initiates a centrifugal force on the body. This divergent power on the liquid particles on the upper side i.e. convex side endeavors to move them far from the surface. This diminishes the static weight on this side beneath the free stream weight. Because of this "suction impact", the raised surface of the sharp edge is known as suction side. This radiating power on the lower side i.e. concave side presses the liquid harder on the sharp edge surface, therefore expanding the static weight over that of the free stream. Hence, this side of the sharp edge is known as the pressure side. The upward weight on the sharp edge is the total impact of the positive static pressure on the pressure side and the negative pressure on the suction side. Because of this pressure distinction lift and drag powers are made.

III. FAILURE ANALYSIS OF BLADE

Despite the fact that the quantity of failures of a specific segment might be little, they are imperative since they may influence the manufactures reputation for dependability, especially when the failure brings about individual damage or death, it will prompt costly claims. In any failure examination it is important to get however much data as could be expected from the failed part itself along with an examination of the conditions at the time of failure.

The possible reasons for failures in the case of fan blades are as per the following.

- Improper heat treatment of the radiator fan blade.
- Pressure variations along the length of the blade.
- Other sundry causes

A. Improper heat treatment of the radiator fan blade

Appropriate heat treatment must be done subsequent to casting process i.e., precipitation hardening, in order to expand the strength of the material. The reason for precipitation hardening is to expand strength and hardness of heat treatable aluminum alloys, and is accomplished through a grouping of arrangement heat treatment, quenching and natural/artificial ageing. However, certain alloys, which are generally intensive to cooling rates during quenching, can be solidified either via air-cooling or by water quenching specifically from the elevated temperature forming process followed by ageing treatment.

By leading certain research facility tests it is watched that that the heat treatment isn't done appropriately and a few deformities, for example

- Pin openings/porosities have been uncovered (in bunches at the basic zones and in scattered example over different areas of the fan-blades).
- Notches/profound marks have been seen at and close-by to the center closures of the fan blades. One can see that the cracked appearances uncover two particular zones having dull and splendid in nature. Cracked faces of the broken blade are totally crystalline in nature.

B. Pressure variations along the length of the blade

As the fan is turning past the fluid (air), this fluid applies some pressure variety along the cross-segment of the blade, because of this pressure changes lift and drag forces will be made, these forces relies on the outline and working conditions. For the radiator fan, lift constrain must be least, else it might prompt the breakage of the blade.

C. Other Causes

The radiator fan of locomotive is required to work in an exceptionally dangerous condition with increment of oil residue and rain. It can be presented to the roadside residue or fiber of different natural materials that can be in the environment of the train activity, for example, calcium carbonate, silica sand, aluminum, carbon dark, fiber of different natural materials, oil, trains brake shoe dust, and so on.

Failures may happen because of splits created with the effect of tools, hardware things like cinches, funnels and so forth during engine running .Fig. 2&3 show the aluminum radiator fan which has been failed due to above mentioned conditions.

Fig 2

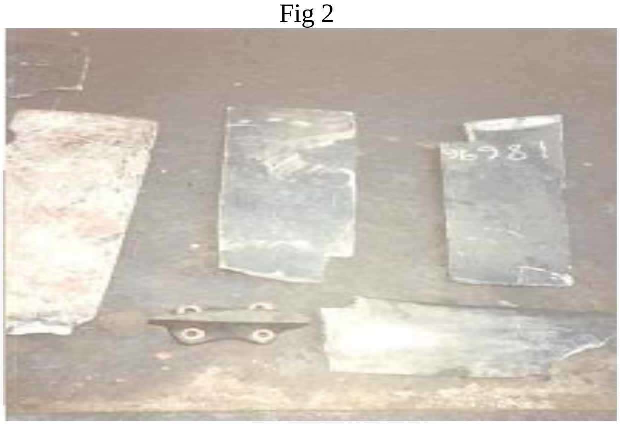

Fig 3

IV. MODELING OF RADIATOR BLADE

The fan model has been created in the SOLID EDGE ST8. The fan blade geometry is a integrated blade disk with 5 blades. The Blade is a twisted blade with fillet of 2 mm and a round stiffener integrated at the blade root. Blade has a height of 290 mm Outer diameter of the fan is 1.676 m .Integrated disc has 5 holes with 20 mm diameter for weight reduction. Fig 4, 5, 6 show the isometric view, front view, and the top view of the fan model.

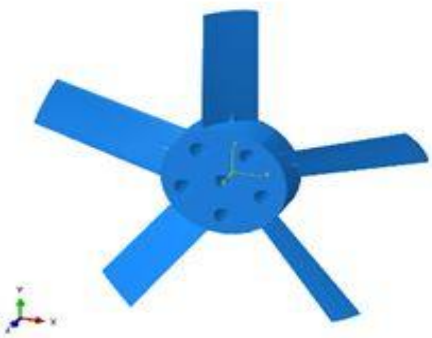

Fig 4

Fig 5

Fig 6

A. Material Information[FRP NYLON TYPE 6 (30% GLASS FILLED)]

Nylon is a standout amongst the most broadly utilized plastics in light of its extraordinary quality, wear obstruction, and self-greasing up properties. Nylons are additionally known to be strong and non-damaging, have high effect obstruction and has a nonstop working temperature of around 180º F, and a moderately light weight that makes it perfect for use in mechanical and electrical equipment to ease support and substitution techniques. Nylon is usually utilized as a substitution for bronze, brass, aluminum, steel and different metals to lessen weight and noise from metal to metal contact. Nylon 6 tends to ingest dampness yet is the slightest penetrable to gas/mineral oil/fluorocarbon-refrigerant, the most grounded, and most broadly utilized, everything being equal. Its high crystallinity brings about a sharp dissolving point, making its mechanical properties less influenced by temperature. It can be found as pole, tubing, or plate.30% glass filled nylon type 6 is a glass fortified extruded nylon 6. The glass support gives the material higher compressive quality and unbending nature, and in addition enhanced frictional attributes. Theyare widely used in Washers and stampings, Timingsprockets, Speedometergears, Coolingfans, Brake fluid reservoirs, Bearings and Industrial equipment. There commendable properties are as follows

- Light weight
- Ability to operate without lubrication
- High tensile strength
- High elasticity
- High heat distortion temperature

- Resist wear, abrasion, and vibration
- Can withstand sustained contact with a wide range of chemicals, alkalis, dilute acids, or oxidizing agents
- Absorbs moisture
- Low permeability to gasoline, mineral oil, and fluorocarbon-refrigerant.

B. Analysis of radiator fan blade

The radiator fan blade with the FRP material is analyzed to study induced stresses are within the safe limits or not. Further a better alternative material is studied with the same input parameters. The material is chosen in such a way that it is least effected to the above said causes of failure. The first part of analysis is to calculate the various forces acting on the blade at different cross sections. Then the blade model is created and analyzed in ABAQUS/standard.

Assumptions for the design

- The fluid (air) is considered to be incompressible.
- The turbulent effect i.e., stall conditions are neglected.

C. Forces acting on the different sections of the fan blade.

Because of extensive variety in the stream conditions and the blade area along the traverse, it is partitioned into various small sections, radial thickness. The flow through such a segment is thought to be free of the move through different components.

Velocities and blade forces for the flow through an elemental section are shown in Fig.7. The flow has a mean velocity W and direction β (from the axial direction). The lift force ΔL is normal to the direction of mean flow and the drag ΔD parallel to this. The axial (ΔFx) and tangential (ΔFy) forces acting on the element are also shown, (ΔFR) is the resultant force inclined at an angle ϕ to the direction of lift.

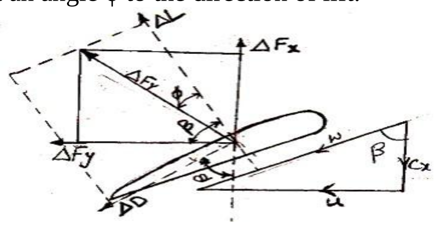

Fig.7

Resolving the forces in the axial and tangential directions,

$\Delta F_x = \Delta L \sin\beta - \Delta D \cos\beta$------- (1)

$\Delta F_y = \Delta L \cos\beta + \Delta D \sin\beta$------- (2)

By definition lift and drag forces from the eq

$\Delta L = ½ C_a \rho \omega^2 (ldr)$

$= ½ *0.4588*1,225*125.66^2*0.194$

$= 860.845$ N

$\Delta D = ½ C_d \rho \omega^2 (ldr)$

$= ½*0.0.335*1,225*125.66^2*0.194$

$= 62.856$ N

From these ΔL and ΔD values the ΔF_x and ΔF_y are calculated from the Eq (1) & (2) as:

The axial thrust $\Delta F_x = 98.950$ N

The torque force $\Delta F_y = 857.446$ N

R (mm)	ΔL (N)	ΔD (N)	ΔF_x (N)	ΔF_y (N)
835	860.845	62.856	980950	857.446
750	950.722	75.259	121.956	945.866
650	1078.388	93.781	160.536	1070.488
550	1241.838	121.493	216.744	1228.798
450	1453.648	149.992	315.124	1426.985
350	1730.256	202.359	460.688	1680.030
250	2073.600	268.328	690.958	1973.422
150	2361.815	342.306	913.246	2204.841

Table 1. Axial thrust and torque forces at different radii of the blade

D. Mesh details and analysis results

Fig 8

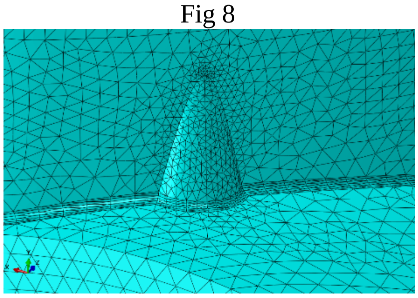

Fig 9

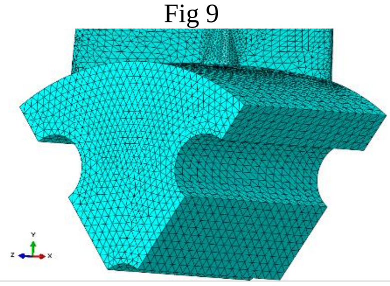

Fig 10

For present analysis a single blade is imported to ABAQUS /standard (Fig.8) in IGES format. The blades are subjected structural loads. The blade is meshed with quadratic tetrahedral elements of type c3d10. The meshed model is as shown in Fig.8, 9, 10. In structural analysis the blade is considered as a cantilever beam (flange end fixed to hub). The loads i.e. the lift and drag forces which are resolved in F_x and F_y directions are applied.

Fig. 8 Imported blade model in ABAQUS/standard cross sections of the blade obtained (Table.1). The applied loads

and boundary conditions on blade are presented in Fig.11.The analysis is carried out for the FRP material giving its properties by applying all the loading conditions.
The boundary conditions has been applied as shown in the Fig 11

- Symmetry planes are constrained in theta directions using Cylindrical Coordinate System.
- Center hole is constrained in radial and axial directions using Cylindrical Coordinate System
- Axial thrust (Z), and centrifugal load (Theta) are applied on the sections
- Symmetry cut planes and radial loading cut planes are considered.

The displacement has been found to be maximum at the tip of the blade Fig 12, von mises stress for tension and compression can be seen in Fig 13 and 14.
The operating range of the blade is 1210 to 1260 rpm. Hence, the natural frequencies of the blade should not match the frequencies corresponding to these rpm values, which are found to be 20.17 to 21 Hz. Modal analysis is done to find the first six natural frequencies of FRP and are shown in Table 2.The mode shapes of FRP are shown in Fig. 15, 16, 17, 18, 19 & 20.
FRP radiator fan shall be manufactured from nylon 6 reinforced with a combination of E-glass unidirectional roving, chopped strand mat and woven roving either by RTM (resin transfer moulding) or compression moulding process. FRP radiator fan shall be free from, blowholes, pinholes, porosities etc. Catalyst pigment and accelerator should suit the above resin. The color of the pigment shall be either blue or green. The glass reinforcement used shall not be less than 35% in content. The above resin has been specified to obtain high tensile and flexural strength, in view of the fact that the standard deviation of tensile strength in FRP is very high.

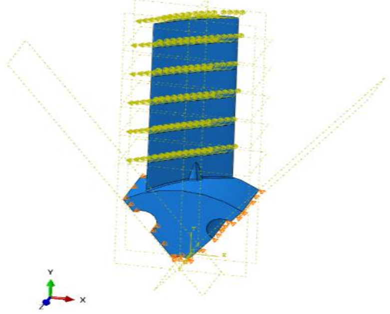

Fig 11

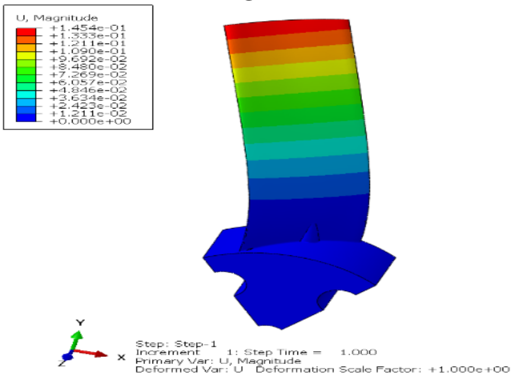

Fig 12

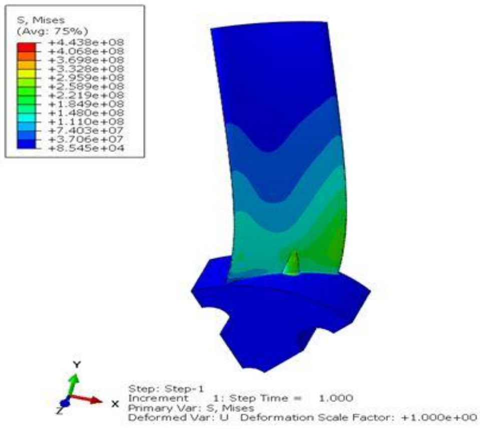

Fig 13

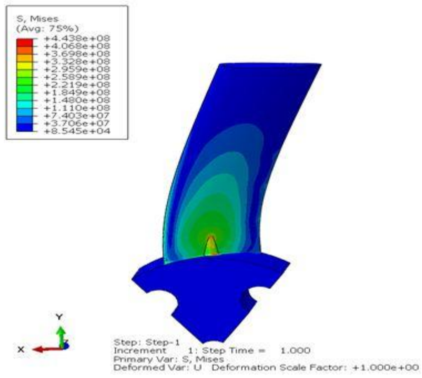

Fig 14

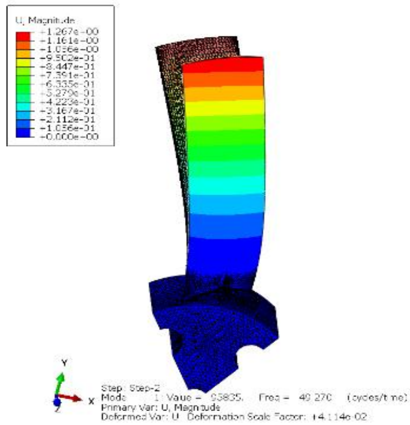

Fig 15 (mode 1)

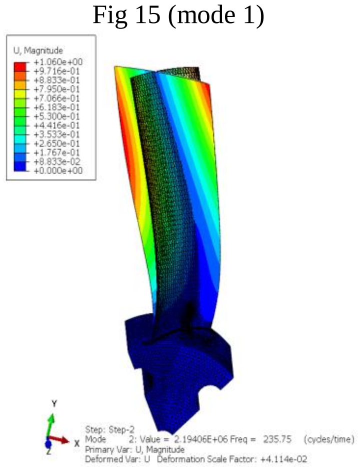

Fig 16(mode 2)

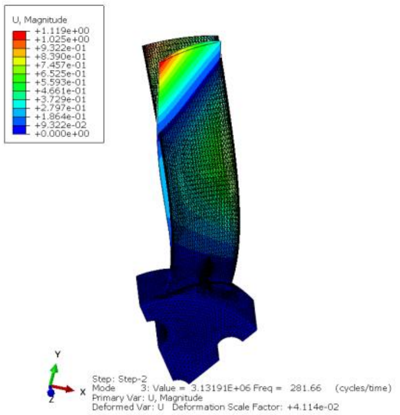

Fig 17(mode 3)

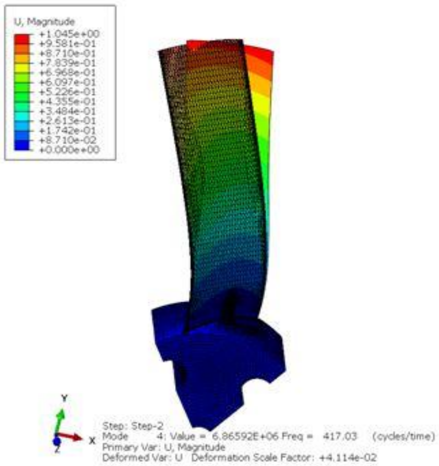

Fig 18(mode 4)

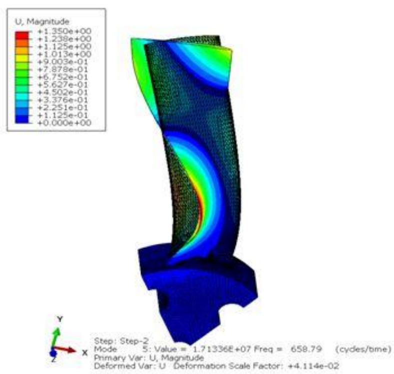

Fig 19(mode 5)

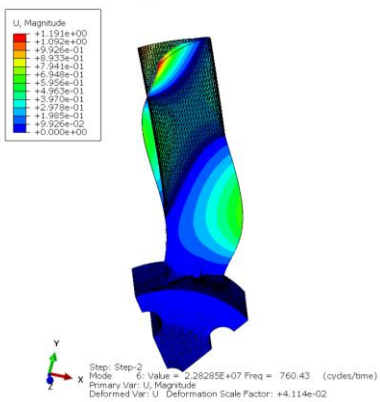

Fig 20(mode 6)

V. RESULTS AND CONCLUSIONS

The maximum displacement and the stress at the cross sections of the blade in Global X, Y, and Z directions for FRP material has been tabulated below. The induced stresses are tabulated in Table.2. The marginal rise in stresses as well as deformations is observed in case of FRP. But the values are within the safe limits. To prevent the failure of blades due to environmental and other sundry reasons as discussed, FRP can be considered as suitable alternate material.

Material	Displacement	Stress (von misses)	Vibration (modal analysis)
FRP Fiber reinforced plastic (Nylon 6 with 30 % Glass fibre)	0.145 m (Maximum displacement is found at the tip of the blade)	148 Mpa (Maximum stress in tension at the root)	Mode 1 = 49.3 Hz
			Mode 2 = 235.8 Hz
			Mode 3 = 281.7 Hz
			Mode 4 = 417.0 Hz
			Mode 5 = 658.8 Hz
			Mode 6 = 760.4 Hz

Table 2. Results obtained from analysis

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