Structural Analysis of Visco Fan Insert for Automobile Engine Cooling System using Finite Element Method

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***Abstract*- A heavy duty automobile has a cooling module with big fan driven by engine (mounted on crank shaft or driven through belt-pulley) for cooling air flow over the cooling module. As heavy duty vehicle required more traction power hence the engine also big. So reduce consumption of energy by the fan, it has to operate with visco clutch driven by engine itself, the running and stopping of fan occurs many times instead of continuous running during the engine in operation. The load on the fan is thrust due to air flow over it. There is external excitation from the engine or from the bearing unbalance during the assembly. To reduce the weight and cost such a fan can be made of plastic with hub made with higher stiffness to sustain jerk during the starting and stopping of fan during operation. Fan insert is usually made of steel because it is easily put while plastic fan-blade is manufactured by injection molding process. Fan inserts can be directly inserted while injection molding of fan blade. Fan insert is important part of Cooling Visco Fan system as the fan supports the engine cooling or keeping specific engine operating temperature and thus keeping the vehicle on the road. Thus, it is necessary for the designers to provide a better design of parts having maximum reliability under all loading conditions. FEA approach can be applied for the calculation of strength and to check possibility of part failure. 3D model of a fan will be drawn in CATIA V5R19, Meshing will be carried out in MEDINA, and PERMAS will be used for solutions. Model will be fabricated and testing will be done on vehicle or test lab.**

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I.INTRODUCTION

A Visco fan insert is part of an automobiles engine cooling system. It is located in front of the vehicle and it is in between engine cooling system and engine. It is mounted on directly on Visco clutch. The Visco clutch is driven by engine shaft directly or by means of belt-pulley arrangement.

In older days there was use of rigid fan which is directly mounted on the crank shaft which causes over cooling of the engine or decrease in the engine efficiency to overcome this? Problem we use visco-clutch to drive fan "VISCO-CLUTCH" VISCO stands for viscous behavior of operating oil and CLUTCH for engagement and disengagement of clutch parts.

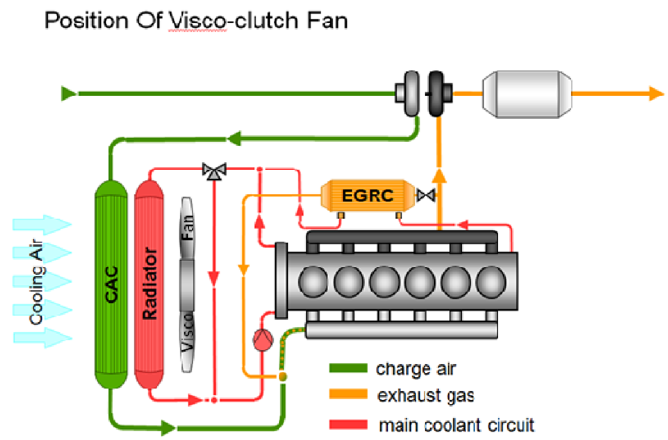

Fig.1.1 Position of Visco-clutch Fan

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The consideration for no damping measures are a logical for undamped systems which generally work well for systems where the damping is too less [5].

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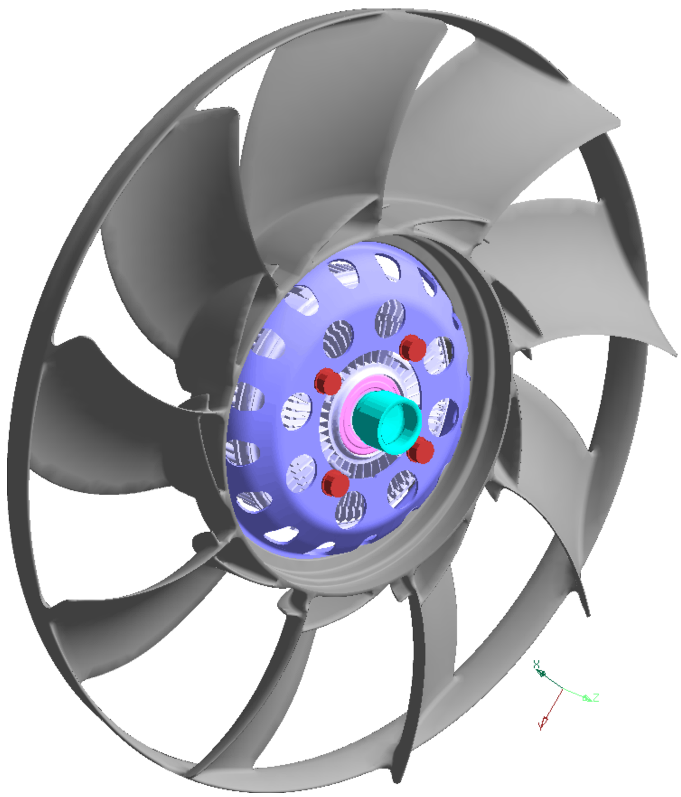
CAD MODEL

Prepare a CAD model from input parameters: sketch, photographs and hand measurements, using 3D modeling software like CATIA Tool. Based on input parameter form Company for fan insert, shaft and bearing CAD modeling has carried out.



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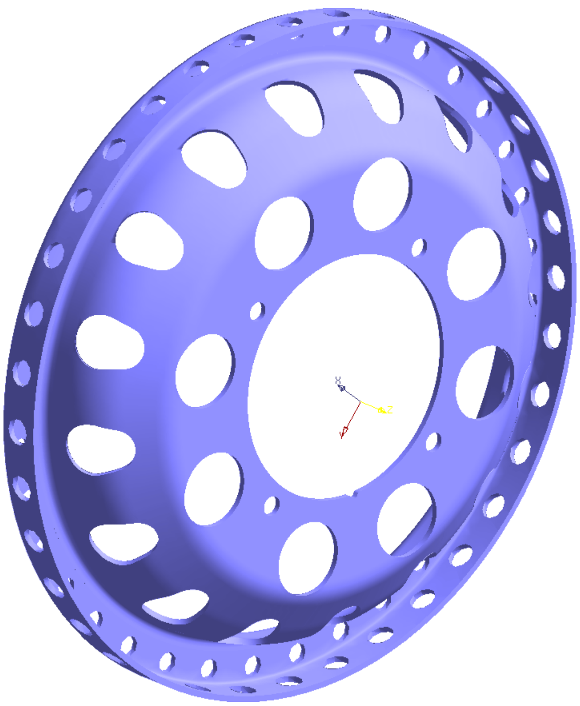
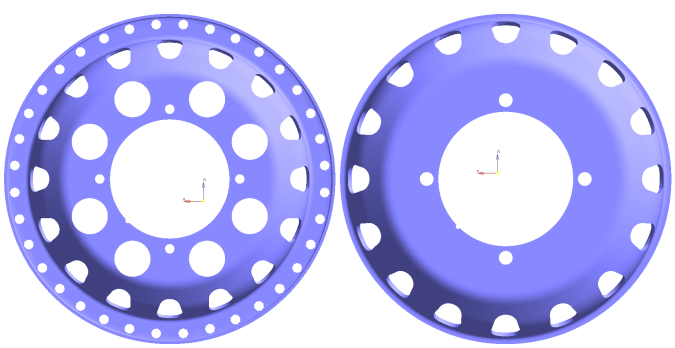


Fig.2.2 Visco Fan Insert

Design Variant:

With the baseline design the component has tested and it fails due to high stresses at fan blade insert, hence design modifications are done. Two new design variants of fan insert are simulated



Baseline design **var0101 – new design**

Fig.2.3 Design variants

var0101 - The holes are removed in baseline

var0201 - Thickness is increased by 25% in Var0101

A General Procedure for (FEM) Finite Element Analysis:

The steps in formulating a finite element analysis of a physical problem are common to all analyses; It may be structural, heat transfer, fluid flow, or some other problem. These steps are included in commercial finite element software packages. Some of the steps are described as follows.

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- Define the geometric domain of the problem.
- Define the element type(s) to be used.

There are different types of elements for discretization. Fig.3.2 shows the different types of elements used for meshing.

1) 1D Element: Rod, Bar, Beam
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3) 3D Element: Solid

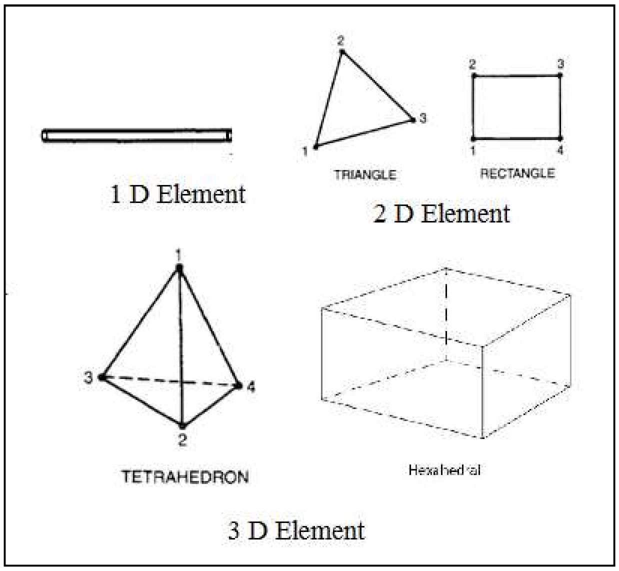

Fig.2.4 Different types of elements

- Define the material properties of the elements.
- Define the geometric properties of the elements (length, area, and the like).

After meshing, material (e.g. Young’s Modulus) and property information (e.g. thickness values) are assigned to the elements. In Model, basically Fan blade is made up of plastic material, Visco clutch body is made of aluminium and fan insert is made up of Steel material. The material and their properties are shown in table 4.1.

Material	Young's modulus(E) $(N/mm2)$	Passions ratio (μ)	Density (tonne/ mm^3)
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Table 2.1 Material and their properties of component

- Define the element connectivity's (mesh the model).

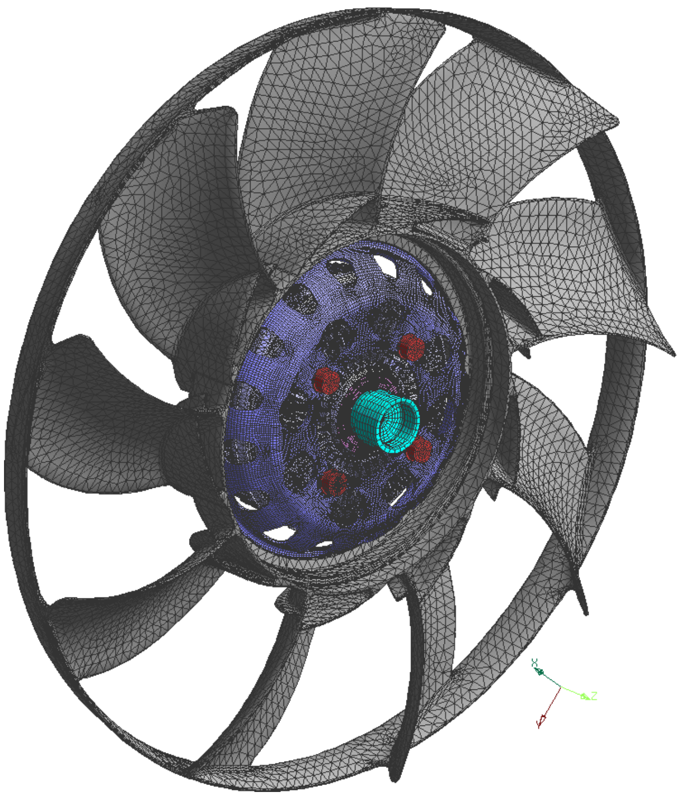


Fig.2.5 Mesh model of Visco fan

- Define the physical constraints (boundary conditions).

The shaft of the visco fan (shaft) is fixed in all directions except rotation about its own axis is free for centrifugal load and fixed for thrust load.

The thrust force is more (10-20%) at tip of the fan blade [6].

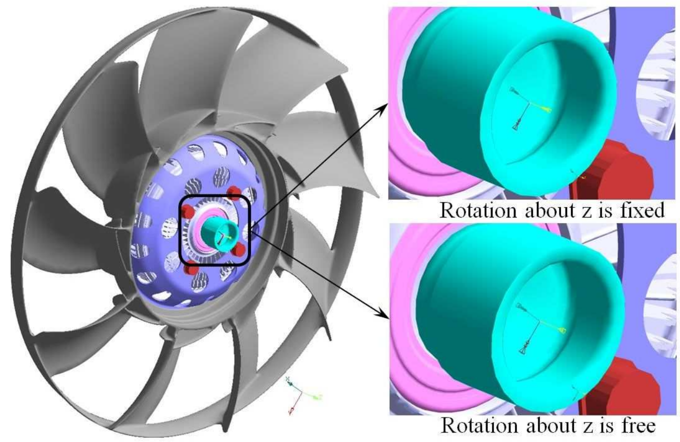
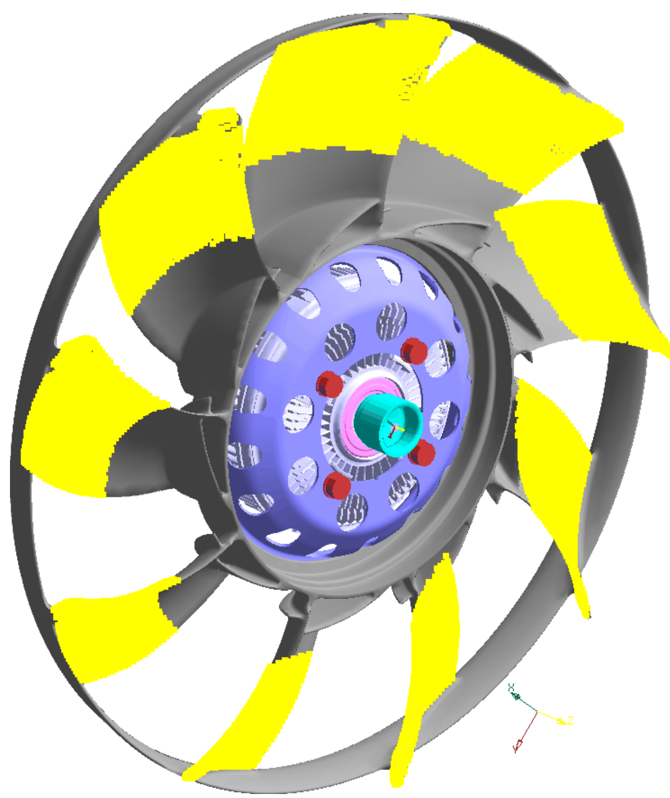


Fig.2.6 Constrains for static simulations

- Define the loadings.

In linear static analysis, centrifugal load due to its own weight and the thrust force due to air pushed by fan at N_{max} rpm are considered as load condition. After applying the boundary condition in the pre-processor the model is solved in the Permas. The results of solved model are evaluated in MEDINA post-processing.



Thrust is applied at yellow mark region of fan blade

Fig.2.7 Load for static simulations

- The preprocessing (model definition) step is critical.

2) Solution-:

During this solution phase, finite element software assembles the governing algebraic equations in matrix form and then using known parameters computes the unknown values of the primary field variable(s). The additional, derived variables, such as reaction forces, element stresses are computed with known results values using back substitution. Special solution techniques are used to reduce data storage requirements and computation time to solve the thousands of equations. Based on Gauss elimination, a wave front solver is commonly used for static linear problems.

3) Post processing

Analysis and evaluation of the solution results is referred to as post processing. Postprocessor software contains sophisticated routines used for sorting, printing, and plotting selected results from a finite element solution. Examples of operations that can be accomplished include-:

- Sort element stresses in order of magnitude.
- Check equilibrium.
- Calculate factors of safety.
- Plot deformed structural shape
- Animate dynamic model behavior.
- Produce color-coded temperature plots.
- While solution data can be manipulated many ways in post processing, the most important objective is to apply sound engineering judgment in determining whether the solution results are physically reasonable.

III.RESULTS AND DISCUSIONS

Static Analysis

Engine operating conditions are considered which have maximum rotational speed of N_{max} rpm is applied on the fan in linear static analysis. The maximum stress location due to centrifugal force does not match with failure in test whereas that is match with maximum stress location due to thrust. The maximum stress due to centrifugal force is (70%) less as compared to that of due to thrust force at N_{max} rpm.

Static Analysis Results	Baseline	var0101	var0201
Centrifugale force @ N_{max} rpm	100%	98%	94%
Thrust force @ N_{max} rpm	100%	74%	25%

Table 3.1 Static analysis results

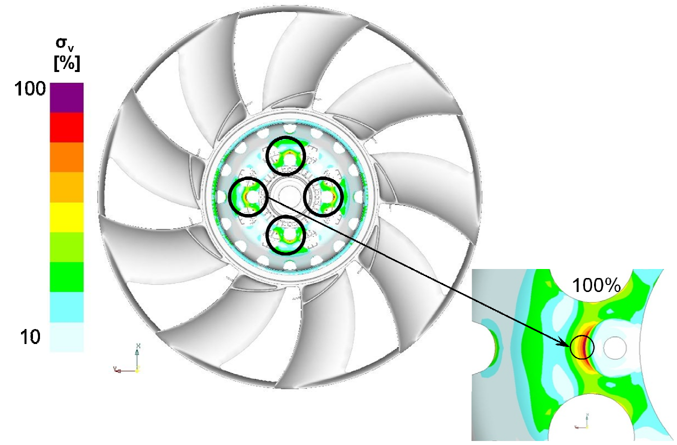


Fig.3.1 Stress plot for Baseline design

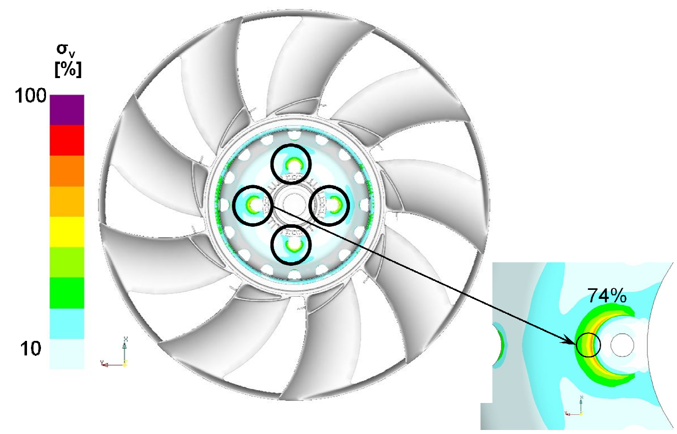


Fig.3.2 Stress plot for design var0101

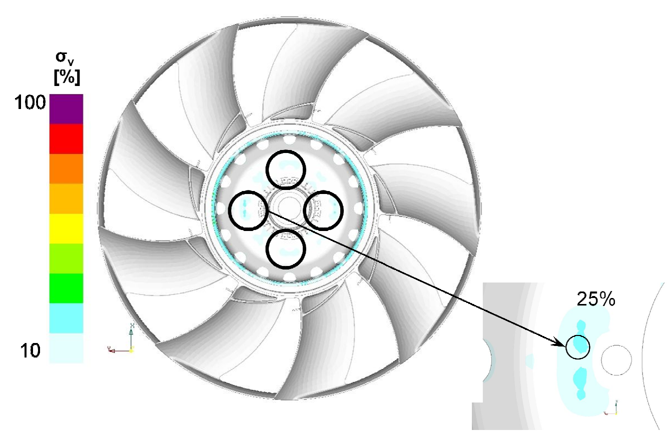


Fig.3.3 Stress plot for design var0201

From the static analysis results we concluded that the stress in the fan inserts are less as compared to baseline (failure) for var0101 & var0201.

Dynamic Analysis

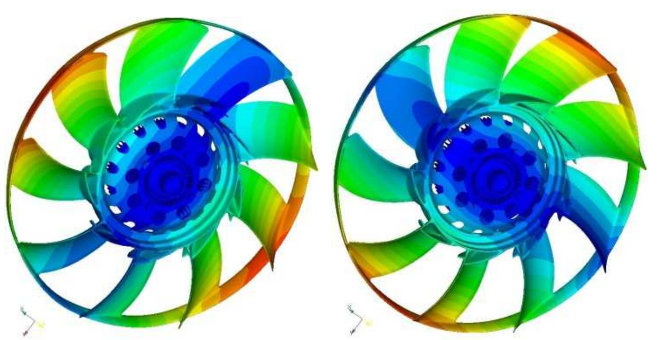
Structure's vibration characteristics such as natural frequencies, mode shapes, and mode participation factors can be determined by Modal analysis technique [4].

The Eigen (natural frequency) values and modes are calculated with rotations (N_{max} rpm) and without rotations. The Eigen values for both the design as follows.

Modes	Eigen Frequency					
	Baseline		Var0101		var0201	
	0 rpm	N_{max} rpm	0 rpm	N_{max} rpm	0 rpm	N_{max} rpm
1	100%	108%	107%	115%	121%	138%
2	100%	108%	107%	115%	130%	137%
3	100%	137%	101%	138%	109%	141%
4	100%	112%	100%	112%	106%	117%
5	100%	111%	101%	112%	106%	117%
6	100%	123%	101%	123%	103%	124%

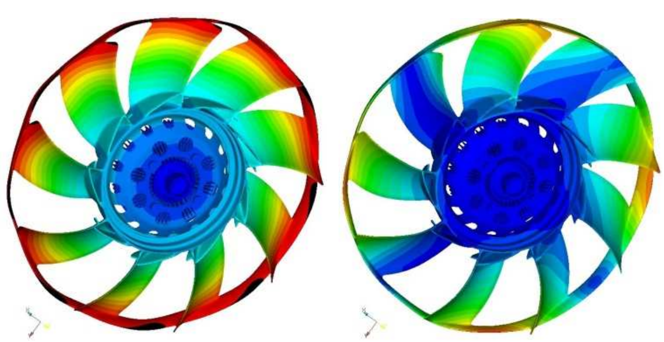
Table 3.1 Eigen/Natural Frequency at no rotation and at rpm

The modes for baseline without rotation (0 rpm) are as follows. The mode 3 will be responsible of fan insert bending.



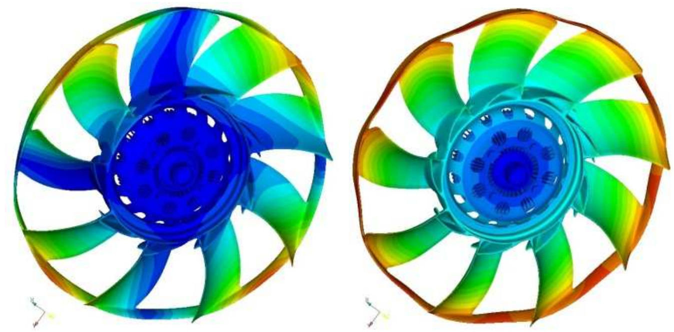
Mode 1 Mode 2

Fig.3.4 Modes 1 & 2 of baseline



Mode 3 Mode 4

Fig.3.5 Modes 3 & 4 of baseline



Mode 5 Mode 6

Fig.3.6 Modes 5 & 6 of baseline

The Campbell diagram gives us the information about the change in natural frequencies with rotational speed due to gyroscopic stiffness variation. The Campbell diagram for baseline design is calculated in PERMAS and it is as shown below.

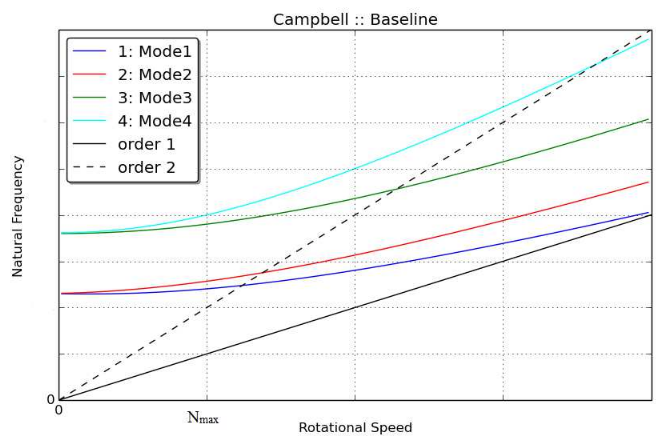


Fig.3.7 Campbell diagram of Baseline Design

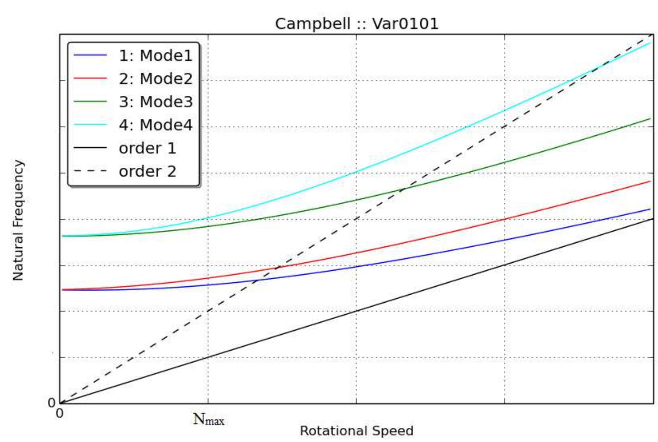


Fig.3.8 Campbell diagram of Design var0101

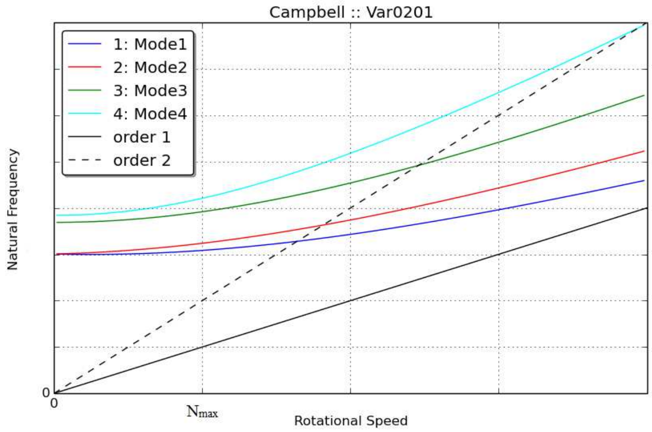


Fig.3.9 Campbell diagram of Design var0201

The design var0101 has small influence on the natural frequencies where as design var0201 has big influence. The first and second modes are shifted by 7% in design var0101 whereas those are shifted 21-30% in design var0201.It means the effect of natural frequency on operating speed range is more for baseline and it decreases with design var0101 and var0201.

IV.CONCLUSION

The New structure (design var0201) is performing better with satisfying loading conditions. The reduction in high stress will lead to performed better as compared to existing design. Overall stress concentration and deformation is less for var0101 & var0201.On safer side design var0201 is manufactured and tested which shows no failure at the end of test.

REFERENCES

1. M. Tauhiduzzaman, A. Yip, S. C. Veldhuis, "Form error in diamond turning", *Precision Engineering* , March 2015 42 (2015)22-36
2. Ebrahim Mustafa Abdallah , Danardono ,Triyono, "Finite Element Method for Analyzing Axial Fan Blade with Different Twist Angle and Chord Length", *International Journal of Engineering Research & Technology (IJERT)* ISSN: 2278-0181 IJERTV4IS030040 Vol. 4 Issue 03, March-2015
3. A.Guiral , A.Alonso a, J.G.Giménez, "Vehicle–track interaction at high frequencies – Modeling of a flexible rotating wheel set in non-inertial reference frames", *Journal of Sound and Vibration,* (June 2015) 355(2015)284–304
4. M. Varun Kumar, B. Ashiwini Kumar, "Model Analysis of Axially Symmetric Linear Rotating Structures", *International Journal of Engineering And Advanced Technology (IJEAT)* ISSN: 2249-8958, Volume-2, Issue-4, April 2013
5. Saad S. Alkhfaji, Seamus D. Garvey, "Modal correlation approaches for general second-order system: Matching mode pairs and an application to Campbell diagrams", *Journal of Sound and Vibration,* (June 2011) 330 (2011)5615-5627
6. R. S. Amano, E. K. Lee, C. Xu, Jianhui Xie, "Modal Investigation of the Unsteady Flow Generated by an Axial Fan: Experimental Testing and Simulations", *International Journal of Rotating Machinery* 2005:3, 256–263

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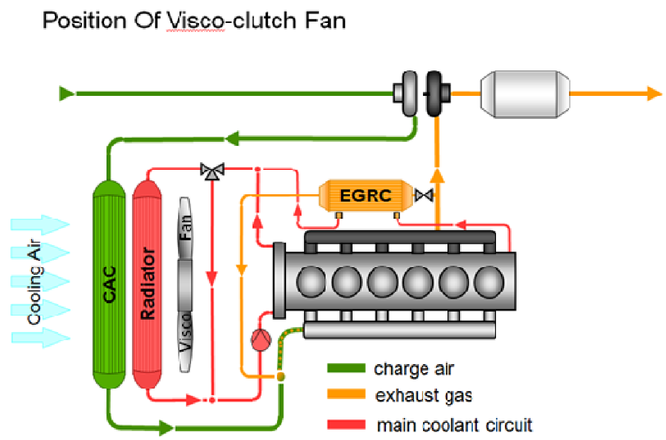

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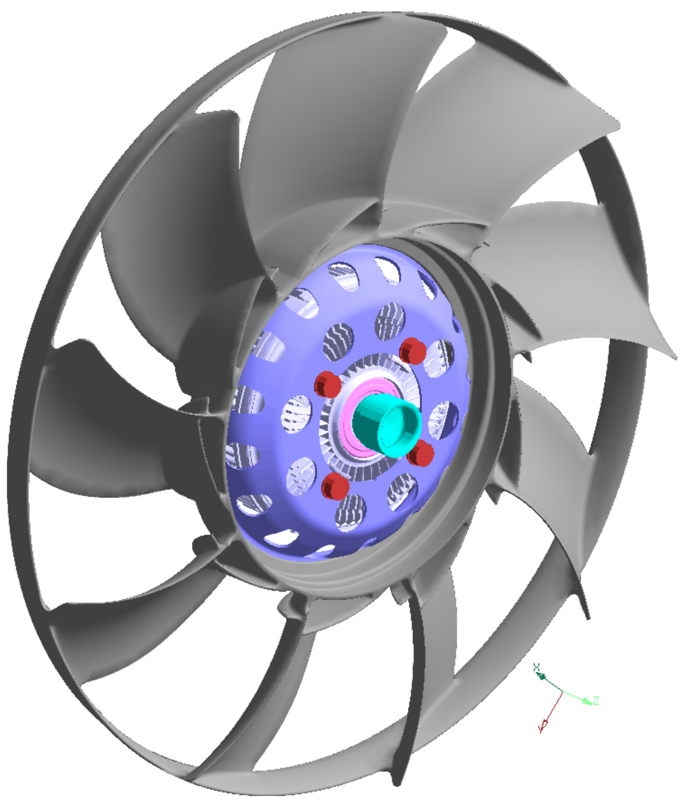

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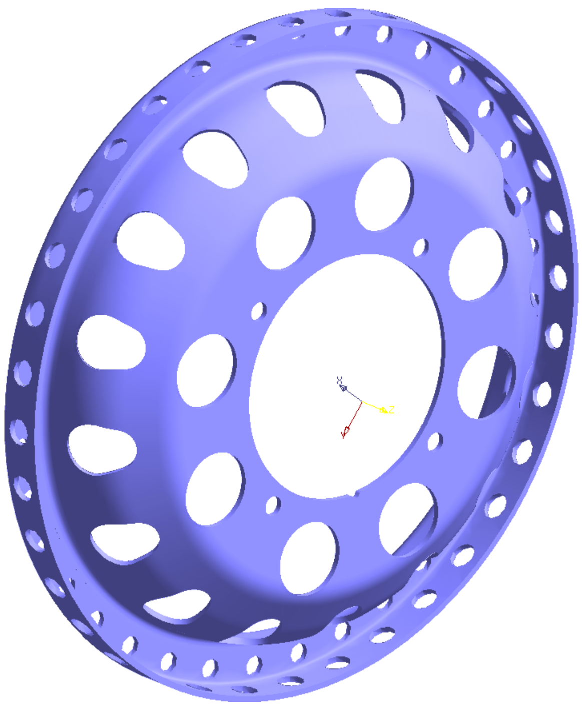

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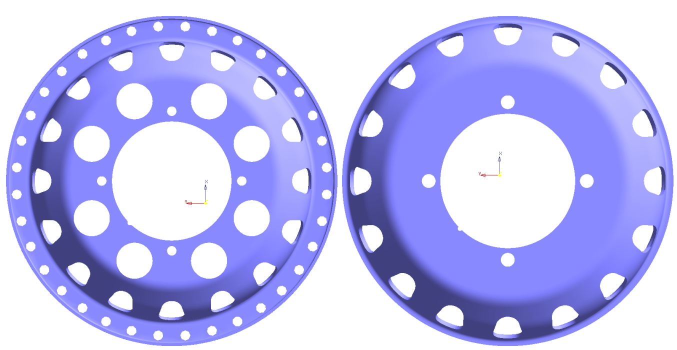

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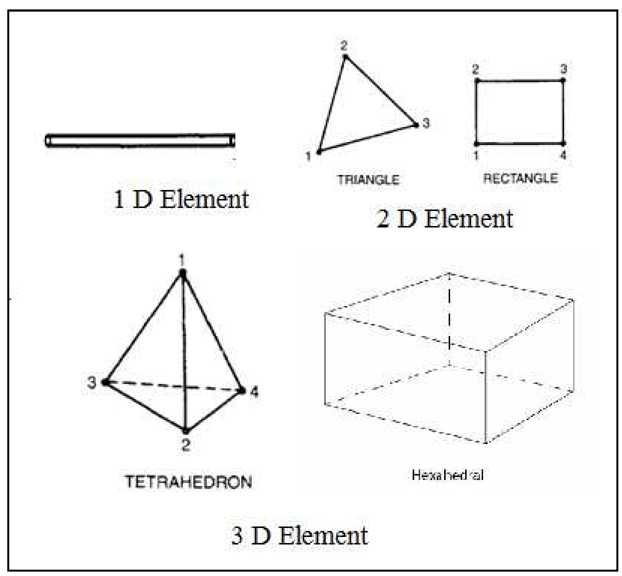

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Aluminum	70,000	0.33	2.8×10^{-9}

Table 2.1 Material and their properties of component

- Define the element connectivity's (mesh the model).

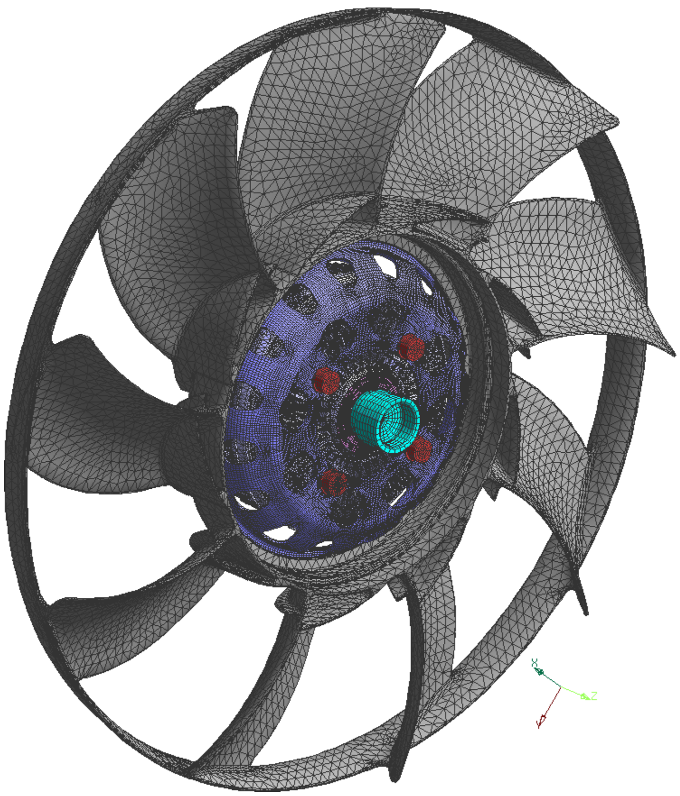


Fig.2.5 Mesh model of Visco fan

- Define the physical constraints (boundary conditions).

The shaft of the visco fan (shaft) is fixed in all directions except rotation about its own axis is free for centrifugal load and fixed for thrust load.

The thrust force is more (10-20%) at tip of the fan blade [6].

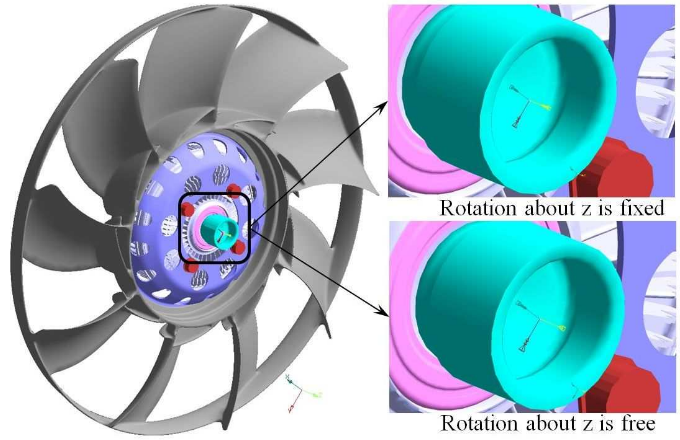
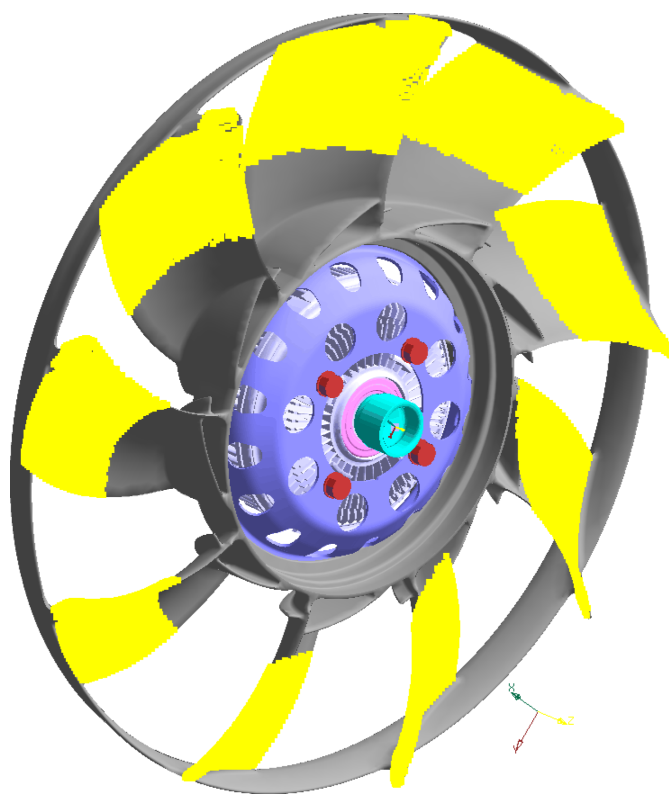


Fig.2.6 Constrains for static simulations

- Define the loadings.

In linear static analysis, centrifugal load due to its own weight and the thrust force due to air pushed by fan at N_{max} rpm are considered as load condition. After applying the boundary condition in the pre-processor the model is solved in the Permas. The results of solved model are evaluated in MEDINA post-processing.



Thrust is applied at yellow mark region of fan blade

Fig.2.7 Load for static simulations

- The preprocessing (model definition) step is critical.

2) Solution-:

During this solution phase, finite element software assembles the governing algebraic equations in matrix form and then using known parameters computes the unknown values of the primary field variable(s). The additional, derived variables, such as reaction forces, element stresses are computed with known results values using back substitution. Special solution techniques are used to reduce data storage requirements and computation time to solve the thousands of equations. Based on Gauss elimination, a wave front solver is commonly used for static linear problems.

3) Post processing

Analysis and evaluation of the solution results is referred to as post processing. Postprocessor software contains sophisticated routines used for sorting, printing, and plotting selected results from a finite element solution. Examples of operations that can be accomplished include-:

- Sort element stresses in order of magnitude.
- Check equilibrium.
- Calculate factors of safety.
- Plot deformed structural shape
- Animate dynamic model behavior.
- Produce color-coded temperature plots.
- While solution data can be manipulated many ways in post processing, the most important objective is to apply sound engineering judgment in determining whether the solution results are physically reasonable.

III.RESULTS AND DISCUSIONS

Static Analysis

Engine operating conditions are considered which have maximum rotational speed of N_{max} rpm is applied on the fan in linear static analysis. The maximum stress location due to centrifugal force does not match with failure in test whereas that is match with maximum stress location due to thrust. The maximum stress due to centrifugal force is (70%) less as compared to that of due to thrust force at N_{max} rpm.

Static Analysis Results	Baseline	var0101	var0201
Centrifugale force @ N_{max} rpm	100%	98%	94%
Thrust force @ N_{max} rpm	100%	74%	25%

Table 3.1 Static analysis results

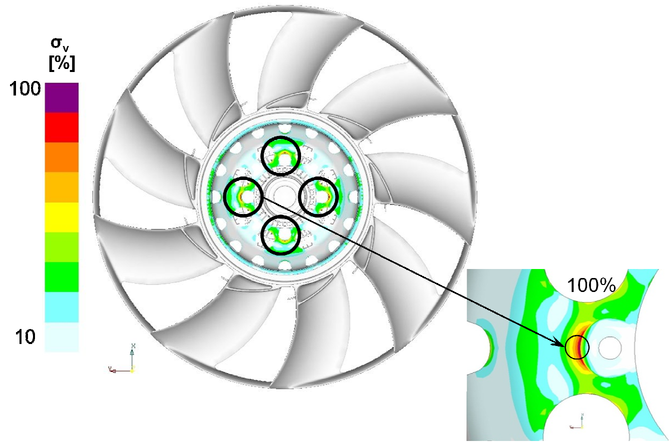


Fig.3.1 Stress plot for Baseline design

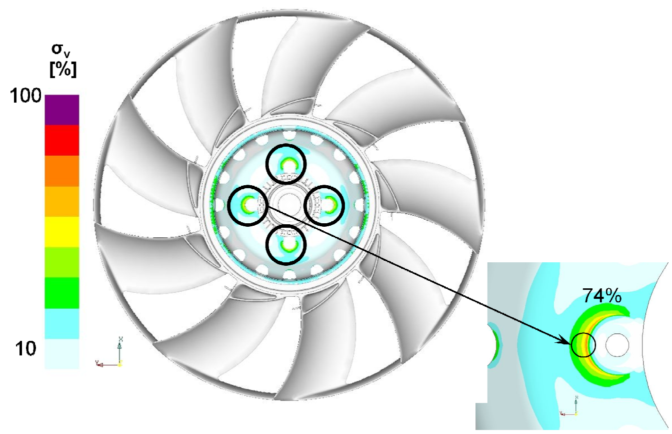


Fig.3.2 Stress plot for design var0101

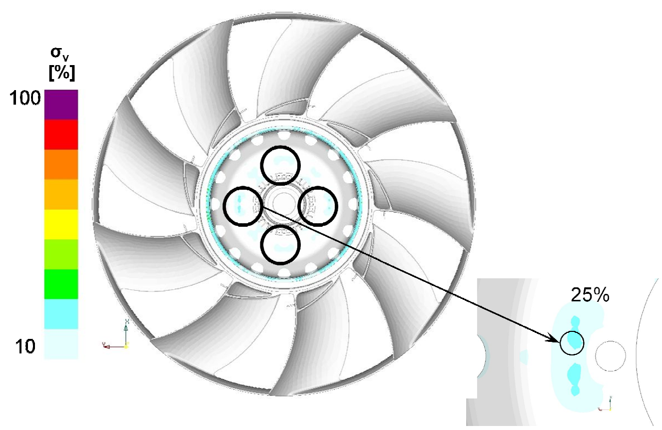


Fig.3.3 Stress plot for design var0201

From the static analysis results we concluded that the stress in the fan inserts are less as compared to baseline (failure) for var0101 & var0201.

Dynamic Analysis

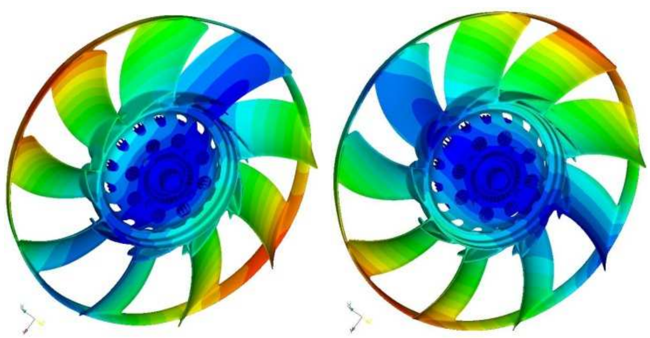
Structure's vibration characteristics such as natural frequencies, mode shapes, and mode participation factors can be determined by Modal analysis technique [4].

The Eigen (natural frequency) values and modes are calculated with rotations (N_{max} rpm) and without rotations. The Eigen values for both the design as follows.

Modes	Eigen Frequency					
	Baseline		Var0101		var0201	
	0 rpm	N_{max} rpm	0 rpm	N_{max} rpm	0 rpm	N_{max} rpm
1	100%	108%	107%	115%	121%	138%
2	100%	108%	107%	115%	130%	137%
3	100%	137%	101%	138%	109%	141%
4	100%	112%	100%	112%	106%	117%
5	100%	111%	101%	112%	106%	117%
6	100%	123%	101%	123%	103%	124%

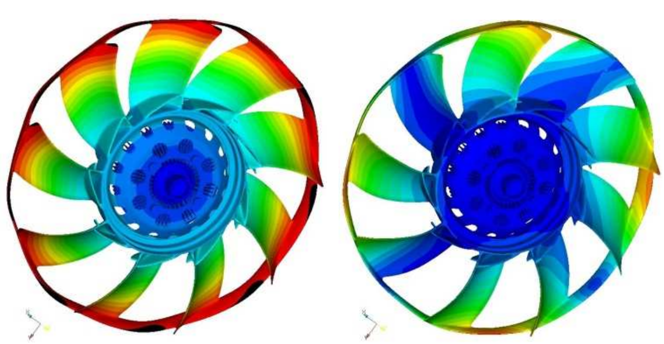
Table 3.1 Eigen/Natural Frequency at no rotation and at rpm

The modes for baseline without rotation (0 rpm) are as follows. The mode 3 will be responsible of fan insert bending.



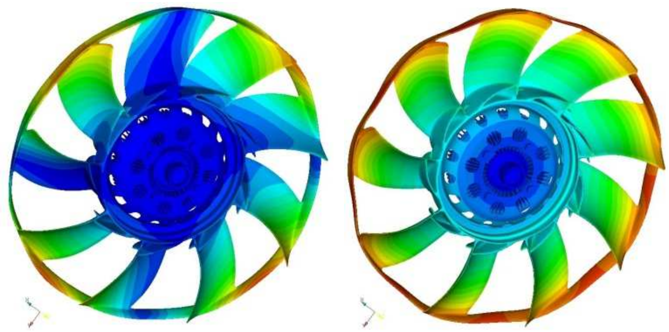
Mode 1 Mode 2

Fig.3.4 Modes 1 & 2 of baseline



Mode 3 Mode 4

Fig.3.5 Modes 3 & 4 of baseline



Mode 5 Mode 6

Fig.3.6 Modes 5 & 6 of baseline

The Campbell diagram gives us the information about the change in natural frequencies with rotational speed due to gyroscopic stiffness variation. The Campbell diagram for baseline design is calculated in PERMAS and it is as shown below.

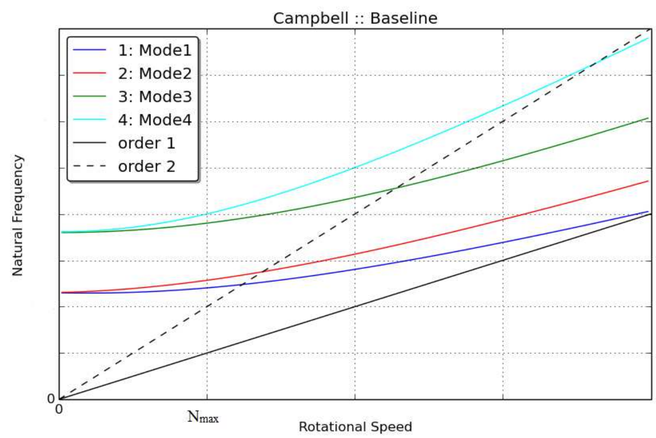


Fig.3.7 Campbell diagram of Baseline Design

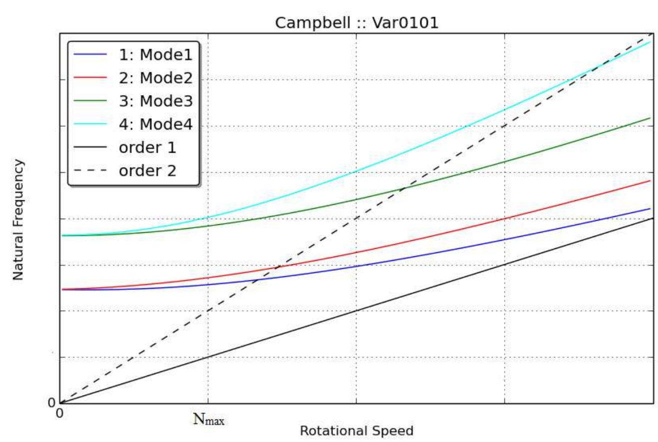


Fig.3.8 Campbell diagram of Design var0101

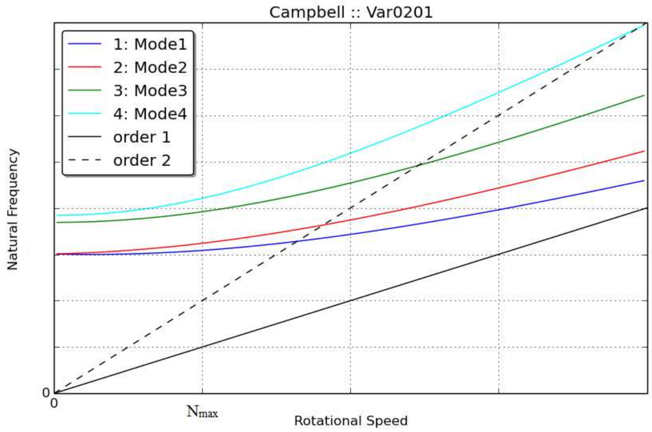


Fig.3.9 Campbell diagram of Design var0201

The design var0101 has small influence on the natural frequencies where as design var0201 has big influence. The first and second modes are shifted by 7% in design var0101 whereas those are shifted 21-30% in design var0201.It means the effect of natural frequency on operating speed range is more for baseline and it decreases with design var0101 and var0201.

IV.CONCLUSION

The New structure (design var0201) is performing better with satisfying loading conditions. The reduction in high stress will lead to performed better as compared to existing design. Overall stress concentration and deformation is less for var0101 & var0201.On safer side design var0201 is manufactured and tested which shows no failure at the end of test.

REFERENCES

1. M. Tauhiduzzaman, A. Yip, S. C. Veldhuis, “Form error in diamond turning”, *Precision Engineering* , March 2015 42 (2015)22-36
2. Ebrahim Mustafa Abdallah , Danardono ,Triyono, “Finite Element Method for Analyzing Axial Fan Blade with Different Twist Angle and Chord Length”, *International Journal of Engineering Research & Technology (IJERT)* ISSN: 2278-0181 IJERTV4IS030040 Vol. 4 Issue 03, March-2015
3. A.Guiral , A.Alonso a, J.G.Giménez, “Vehicle–track interaction at high frequencies – Modeling of a flexible rotating wheel set in non-inertial reference frames”, *Journal of Sound and Vibration,* (June 2015) 355(2015)284–304
4. M. Varun Kumar, B. Ashiwini Kumar, “Model Analysis of Axially Symmetric Linear Rotating Structures”, *International Journal of Engineering And Advanced Technology (IJEAT)* ISSN: 2249-8958, Volume-2, Issue-4, April 2013
5. Saad S. Alkhfaji, Seamus D. Garvey, “Modal correlation approaches for general second-order system: Matching mode pairs and an application to Campbell diagrams”, *Journal of Sound and Vibration,* (June 2011) 330 (2011)5615-5627
6. R. S. Amano, E. K. Lee, C. Xu, Jianhui Xie, “Modal Investigation of the Unsteady Flow Generated by an Axial Fan: Experimental Testing and Simulations”, *International Journal of Rotating Machinery* 2005:3, 256–263