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Design and Analysis of Aerofoil Bladed Radial Fan Backward Impeller Using FEA

[1]P.C.Vijayan, [2]Dr.R.Rajappan,
[1]*Assistant Professor, Department of Mechanical Engineering, Mailam Engineering College, Mailam.*
[2]*Dean, Department of Mechanical Engineering, Mailam Engineering College, Mailam.*

Abstract: *These aerofoil bladed radial fans are mainly used in thermal power plants to supply sufficient quantity of air to the furners. In order to attain complete combustion. An analysis was carried out using the default thickness of the impeller of the radial fan, leading to large vibrations and one of the reasons for failure. Many researches have been carried out to reduce the thickness of the impeller part found for the safe stress and strain limits. The value analysis / Engineering results in material reduction, cost reduction with reduced vibrations for the desired design and operating conditions.*

To ensure the desired performance while considering the significance of physical operating situation for a radial fan a full-fledged finite element Analysis has been carried out for the prediction of natural frequency of the rote system. Stress distribution and strain energy distribution of the rotating impeller. Objective of this paper is to optimization of thickness without exceeding the allowable stress and keeping in consideration the operating restriction and design parameters.

Keyword: *Optimization, Impeller, Deflection, Stress.*

I. Introduction

A fan is a turbo machine used for energy transfer. It can be defined as a rotating machine with a bladed impeller, which maintains a continuous flow of air (or) gases. Fans usually consist of a single rotor with or without a stator element and cause a rise in pressure of the flowing fluid. The principle involved is that the mechanical energy owing to the rotation of the fan is converted into the fluid energy (in the form of pressure rise). Fans obviously consume power as they rotate with the help of prime mover and energize the flowing fluid. Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It can be used to analyze either small or large-scale deflection under loading or applied displacement. ANSYS is a general purpose finite element computer program for the solution of structural, heat transfer engineering analysis. ANSYS solution to capabilities includes: static analysis, elastic, plastic, thermal, stress, stress stiffened, large deflections, bilinear elements, dynamic analysis, model, harmonic response, linear time history, non-linear time history, heat transfer analysis: conduction,

Convection, radiation, coupled to fluid flow, coupled to electric flow, structures, magnetic, etc. Analysis can be made in one, two, or three dimensions, including axisymmetric and harmonic element options. ANSYS also contains a complete graphics package and extensive pre and post processing capabilities.

II. Literature Review

2.1 Noise and Vibration

The flow at the impeller outlet is non-uniform. The diffuser vanes or volute cutwaters are thus approached by an unsteady flow. The flow at the stator vanes acts back on the velocity field in the impeller. The related phenomena are called “rotor/stator interaction” (RSI). As a consequence of the RSI, hydraulic excitation forces are generated. These give rise to pressure pulsations, mechanical vibrations and alternating stresses in various pump components. The vibrations transmitted to the foundations spread as solid-borne noise throughout the building. The pressure pulsations excite the pump casing to vibrations. They also travel as fluid-borne noise through the piping system, where they generate vibrations of the pipe walls. The vibrating walls and structures radiate air-borne noise.

2.2 Smart materials and structures - a finite-element approach

This paper gives a bibliographical review of the finite-element methods (FEMs) applied to the analysis and simulation of smart materials and structures. The bibliography at the end of the paper contains references to papers, conference proceedings and theses/dissertations on the subject that were published between 1986-1997. The following topics are included: smart materials; smart components/structures; smart sensors and actuators; controlled structures technology; and other topics.

2.3 Finite element computational dynamic rotating systems

This bibliography lists references to papers, conference proceedings and theses /dissertations dealing with finite element analysis of rotor dynamics problems that were published in 1994–1998. It contains 319 citations. Also included, as separate subsections, are finite element analyses of rotor elements – discs, shafts, spindles, and blades. Topics dealing with fracture mechanics, contact and stability problems of rotating machinery are also considered in specific sections. The last part of the bibliography presents papers dealing with specific industrial applications.

2.4 Analysis of Turbo machine Blades

This literature review deals with the static and dynamic analysis of turbine blades and discs. The various formulations and solutions of linear and non linear vibrations of blades and discs are summarized. Experimental methods are also discussed.

III. Specification of the problem

3.1. CLASSIFICATION OF FANS : ACCORDING TO PURPOSE :

1. Primary Air Fan : (PA FAN)

Primary air fans supply the air needed to dry and transport pulverized coal to the furnace of direct-fired boiler.

2. Forced Draught Fan: (FD FAN)

The forced draught fans supply the air-required for the combustion of fuel and normally handle stoichiometric plus excess air required for the satisfactory burning of fuel.

3. Induced Draught Fan: (ID FAN)

The induced draught fans draw the products of combustion from the boiler while creating sufficient draught (negative pressure) in the furnace for balanced draught operation.

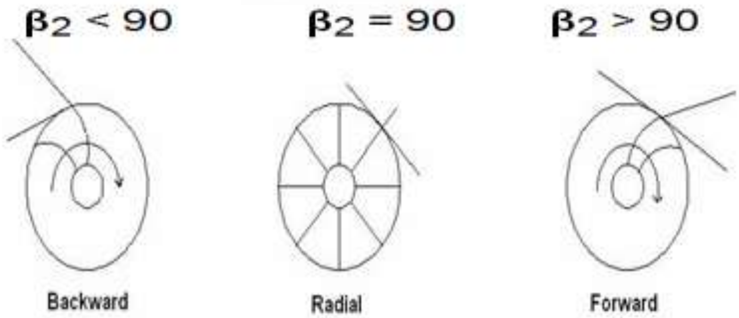
3.2 ACCORDING TO FLOW OF AIR:

1. Radial Fan:

A radial fan is a one in which the flow enters along the axis and leaves in the radial direction along the blades. It can be used for PA, FD and ID applications.

Based on the configuration of the blade with respect to the direction of rotation of the impeller (AS SHOWN IN THE FIG.) it is called backward curved, forward curved and radial bladed impeller

TYPES OF RADIAL FAN



BASED ON BLADE CONFIGURATION

2. Axial Fans:
An axial fan is a one in which the main flow is along the axis of rotation both at entry and exit.
Based on the profile these fans are mainly classified into two types namely,

I Axial Profile Impeller: (AP IMPELLER)

In this type, the impeller has a central hub which is spherical in nature and has blades with individual shafts located along the periphery. The hub is a high precision part which is ball turned to get a curved smooth profile. The individual blades of the impeller are driven with the help of hydraulic mechanism.

II Axial Non – Profile Impeller: (AN IMPELLER)

In this type, the impeller has a central hub, which is of hemispherical nature and has blades curved at a fixed angle and welded to the hub as in case of its radial counterpart.

Both the fans described above have an inlet guide vane (IGV) and an outlet guide vane (OGV) along with a diffuser at the exit.

3.3 FAN SPECIFICATIONS:

3.1. Backward Aerofoil Bladed Fan
3.2. Application- Primary Air Fan
3.3. Power- 1500 KW
3.4. Plant Capacity- 250 MW
3.5. Fan size- NDZV 20 BAB2
3.6. Speed- 1000 rpm
3.7. Head- 985m3
3.8. Pressure ~ 9850 Kg/m2
3.9. Volume – 50 m3/s
3.10. Material Used – Naxtra 70

IV. Element description

For this analysis 4-noded area element (SHELL 63) is used. SHELL 63 element is well suited for mapped meshing for this model. Usually for any area of a model can be meshed using 4-noded area element (SHELL 63) in a uniform manner (mapped meshing). It is a kind of mesh in which the points of the mesh are arranged in a regular way all through the continuum and can be stretched to fit a given geometry so that the results will be more accurate when compared to free mesh results.

4.1 Choosing the element type

4.1.1.The range of elements and testing the elements:

It is not possible to present a set of universal guidelines to develop any finite element model as such structural problem and element type have their own particular features. It is not even possible to give rules for what appears in packages to be identical element types since their formulation can be different. Quadratic elements, be they membrane or solid elements, give the best compromise between accuracy and efficiency for general use. When modeling a structural problem that can be classified, as having bending deformation and the geometry is either flat or curved, then the preferred choice of elements is always the general shell element.

4.1.2. Using a Hierarchy of elements:

Analysts should develop a model using a step by step approach. This means that they should start with a simple approximation, say a beam model, and make it more precise as the finite element modeling progresses. Never tackle a real problem directly as this is likely to be time consuming and wasteful of resources. Remember, that more results that are generated the more effort that will be necessary to check that they are reliable and relevant.

4.1.3 Restricting the dimensions of a problem:

Avoid the use of solid elements to model a problem where the length in one of the spatial dimensions, for example the material thickness, is much less than the lengths in the other two dimension.

4.1.4 Plate and shell elements:

Plate and shell elements have historically been the most difficult to use in terms of achieving reliable and cost effective solutions. In particular these elements in a static analysis do not give an acceptable solution if the displacement of the nodes normal to the surface of the material is greater than the thickness of the material.

4.1.5 The role of compatibility:

Elements must have the same order, all though one can mix three sided and four sided elements. There must be connection between the corner nodes of neighboring elements and, if present, continuity between the edge nodes of adjacent elements.

4.1.6 Elements of model contact:

Before developing a three dimensioning model for a problem with contact between different parts, check that the package has three dimensional contact algorithms.

V. Static Analysis

The procedure for a static analysis consists of three main steps:

1. Build the model
2. Apply loads and obtain the solution
3. Review the results

The overall equilibrium equations for linear structural static analysis are:

$[K]\{u\} = \{F\}$

OR $[k]\{u\} = \{F^q\} + \{F^q\}N$

Where: $[K]$ = total stiffness matrix = $\sum [K_e]$ M=1

$\{u\}$ = nodal displacement vector

N = number of elements [Ke] = element stiffness matrix {Fq} = total applied load vector {Fr} = reaction load vector

5.1 Build the model:

To build the model, define the element types, element real constants, material properties, and the model geometry.

5.2 Apply loads and obtain the solution:

In this step, the loads (boundary conditions) are defined and the solution is obtained.

5.3 Review the results:

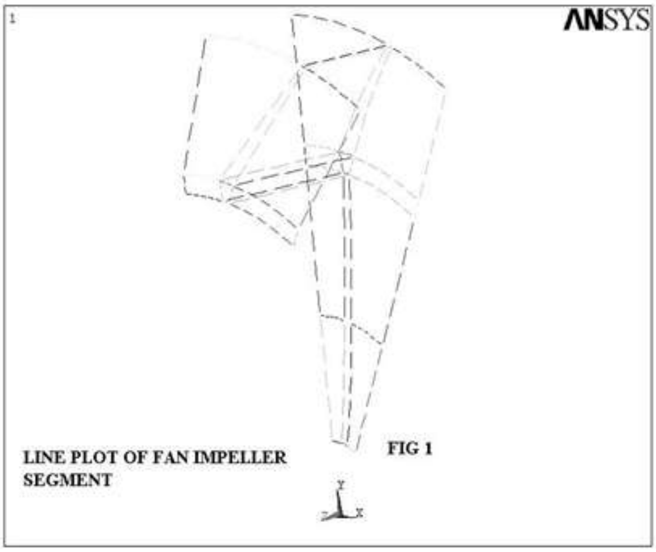
After the solution is completed, the post-processing step gives the results of the static analysis.

VI. Design Optimization

Design optimization is a technique that seeks to determine an optimum design. By “optimum design” all the specified requirements are met with a minimum expense of certain factors such as weight, surface area, volume, stress, cost, etc. in other words, the optimum design is usually one that is as effective as possible. Any aspect of the design can be optimized: dimensions (such as thickness), shape (such as fillet radii), placement of supports, and cost of fabrication, natural frequency, material property and so on. An optimum design can be defied as the best possible design satisfying a specific objective and a set of constraints imposed by the specifications or by the design problem itself.

VII. Segment Generation

First the segment of the radial fan impeller is created using ANSYS preprocessor. The created segment is shown below in fig 1.



VIII. Results And Discussions

STATIC ANALYSIS:

The stress distribution and the deflection of the impeller are found. The stress distribution and the deflection plot for the various components of the impeller are plotted in the table.

OPTIMIZATION:

For the original fan impeller the stress value is 4.274kgf/mm^2 and deflection is .0678mm.

The blade in the impeller has the maximum stress of 4.274kgf/mm^2.

COMPONENTS	ORIGINAL FAN		OPTIMIZED FAN	
	STRESS Kgf/mm2	DEFLECTION mm	STRESS Kgf/mm2	DEFLECTION mm
FAN IMPELLER	4.274	0.0678	5.822	0.09945
BACKPLATE (BOTTOM)	1.284	0.0126	1.291	0.016396
BACKPLATE (TOP)	2.318	0.03426	2.593	0.041143
BLADE	4.274	0.0678	5.822	0.099455
COVER PLATE	2.852	0.0526	3.091	0.064076
RING	2.927	.04845	3.159	0.057363
FLANGE	.58453	.00198	.68138	.002394

RESULTS FOR FAN IMPELLER WITH ORIGINAL THICKNESS:

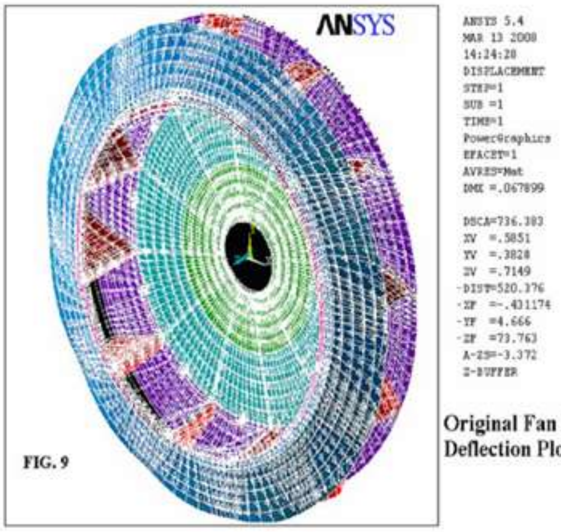


FIG. 9

Original Fan Impeller Deflection Plot

RESULTS FOR OPTIMIZED FAN IMPELLER:

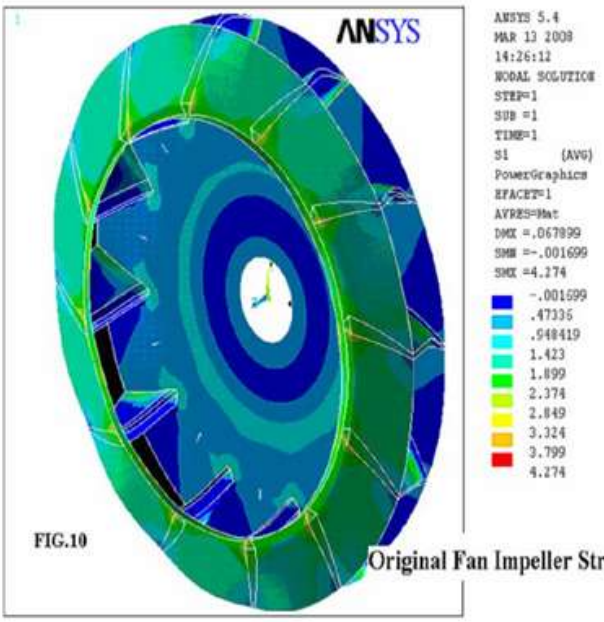


FIG.10

Original Fan Impeller Stress Plot

IX. Conclusion

In this work, an attempt has been made to increase the Fan efficiency by optimizing the thickness of the various components in the fan impeller, and analyzing the stress distributions in them. Optimization of the thickness of the parts of impeller leads to decrease in weight of the Fan Impeller, and in turn the power required for driving the fan decreases. Pre -stress conditions are applied to this model, therefore the strengthening and weakening of the impeller is predicted.

The overall power required drive the fan decreases by reducing into optimized thickness of an impeller fan, strengthening and weakening of the impeller is predicated by applying the pre stress conditions to this analysis. The comparison of original impeller size before optimization and the optimize thickness without compromising the performance. And also noticed that after optimized the thickness of the fan and weight of fan impeller has been reduced by 37.5%.

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