International Journal of Engineering, Science and Mathematics
Vol. 6 Issue 8, December 2017 (Special Issue)
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: ijesmj@gmail.com Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Material Evaluation for Manufacturing Impeller Blade of a Steam Exhauster in Visakhapatnam Steel Plant

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Abstract

The Steel Melt Shop (SMS) of Visakhapatnam steel plant is one of the core departments. The steel plant's productivity is entirely dependent on the performance of the steel melt shop. The hot metal from 'Blast Furnace' is converted into semi-finished product (Blooms) in the 'Tundish Machines'. For proper solidification, water is sprinkled over the liquid steel through the mould. This process generates steam which has to be exhausted to the atmosphere using steam exhauster.

The steam exhauster is placed in the connecting pipe which connects the bunker where solidification takes place and the chimney. The impeller blades of the steam exhauster are of complex shape and are made of AISI 904 L materials. These are subjected to various thrust forces and vibrations which cause various damages.

The present project is to study these damages and analyze the impeller blades due to the static loads. The modeling of the impeller blade assembly is carried through CATIA V12 R18 using "Part Design" and "Wire frame and surface design" module. The solid model of the blade is then imported to ANSYS software where static analysis is carried out. Various pressure loads and different materials and design optimization are considered to analyze the blade in the project.

Key Words:

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Steam exhauster;
Impeller;
AISI 904L;
Part Design;
wire frame and Surface Design;

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1. Introduction

Visakhapatnam steel plant [VSP], also known as Vizag Steel plant, is one of the public sector unit steel majors in India based in Visakhapatnam. The most and foremost important department is the Steel Melt Shop where the actual casting of the steel into "blooms" takes place. The liquid steel obtained from LD process is cast into blooms in the continuous casting machines(bloom casters). After blowing down the liquid steel with argon and obtaining the preset, the temperature should be 1570^0c-1575^0c. The mould should be filled with the liquid steel. The mould is applied with casting powder (Chlorine) for lubrication.

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The liquid metal here is cooled and solidified by supplying water at a brisk rate. The temperature at this particular point of the metal is around 1600^0C. Due to this temperature, water boils and steam is formed in the bunker (chamber). This steam from the bunker, to avoid clogging and many other adverse impacts has to be exhausted out of the bunker. Hence, steam exhausters are used. These exhausters, in VSP are placed in the casing pipe connected to the duct which links the bunker at datum height of 13metres from the ground level.The blades of the impeller are being broken consistently within a quick span. The point of interest lies in finding out the possible stresses induced and the deflections of the blade statically and suggesting better materials and designs.

Fig 1: The Impeller with broken blades

The geometric modeling of the impeller is carried out in CATIA V5 R18. Later the solid model is imported to ANSYS and is subjected to structural analysis of the blade (as only blades are being broken and the hub is retained, only blade is analyzed) is carried out for various pressure loads acting on the blade. The method is followed for various materials suited for the designed impeller blade.

2. Literature Review

Vui-Hong Wong [1] research involves the use of finite element analysis (FEA) to predict stress and deflection of impeller blades used on large (5m diameter) ducted axial flow impellers as the first step in the design process.

LiangweiZhong [2] presented the technique of three dimensional solid element model and assembly was used to determine the temperature field of radial-flow impeller. The FEM software Cosmos was applied to analyze model system, and the precise analytic results were obtained.

Shang Liang Chen [3] presented the CAD/CAM technologies for manufacturing centrifugal compressor impellers and turbine blades are investigated in this research. The control data points of an impeller or a blade were obtained by using the reverse engineering method. The obtained data were used as the input data for UG CAD/CAM software to construct the CAD model.

Yong Ling [4] discussed a large-scale, thin wall duplex stainless steel impeller with complex geometry was deformed severely and unpredictably during casting and heat treatment processes resulted in dimensional failure for the final part. In this paper, the distortion of the impeller during casting and heat treatment was calculated.

3. Design and Analysis

The modeling of the complete impeller along with the hub and the investigation for the maximum stresses induced in the blades (existing and modified) at the static load conditions is carried out using CATIA.

The solid model is created in the *partdesign* module of CATIA. Later it is analyzed in ANSYS. Solid tetrahedron element is considered in the analysis. The analysis is first carried out for the existing blade model to find out stress levels at static conditions and at maximum loads. Modified blade is also explored for the induced stresses. Further the investigation is carried out for higher loads, to find out the maximum load carrying capacity within the permissible stress of the material considered.

Material used for manufacturing of existing as well as modified solid blade is AISI 904L. The material properties of AISI 904L are taken from the following Table No.1.

Table 1: Mechanical properties of AISI 904L

Properties	
Density (×1000 kg/m^3)	7.7-8.03
Poisson's Ratio	0.27-0.30
Elastic Modulus (GPa)	190-210
Tensile Strength (MPa)	490
Yield Strength (MPa)	215
Elongation (%)	35
Hardness (HRB)	95max

a. Load Calculations

The pressure acting on the impeller is specified by the Visakhapatnam Steel Plant design department.

Pressure Head h = 45 mm Hg

For Mercury (Hg),Density ρ = 13600 kg

Acceleration Due To Gravity g = 9.81 m/s^2

Pressure = ρgh

P = (13600*9.81*45)/1000

P = 6003.72 N/m^2

P = 6003.72*10^{-6}N/mm^2

3.2 Idealization of Impeller

The impeller is of complex shape, and cannot be idealized in 1-D, or 2-D modeling. For a clear understanding of the geometry of the blade, 3-D solid model of the entire propeller with seven blades is idealized in CATIA part design module. The 3-D solid model provides the complete information about the impeller to facilitate the engineering analysis program such as Finite Element Analysis for stress and strain predictions, which require properties such as weight, volume and moment of inertia, which in turn cannot be derived from other modeling techniques such as "Wire frame modeling" or "surface modeling". The idealized 3-D solid model of the complete propeller with seven blades is shown in figure.

Fig 2: Idealization of impeller

3.3 Solid Modeling of the Impeller

The impeller blades are designed in the CATIA *part design* module and are shown in (Fig4a) existing impeller and (Fig4b) modified impeller. The design variation is shown at the stiffener.

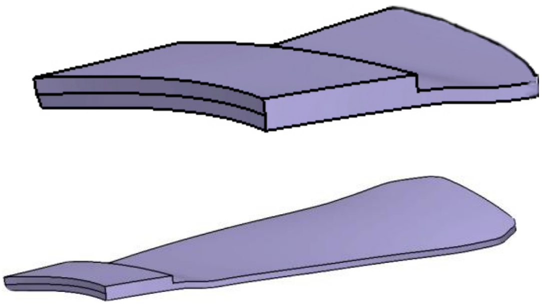

Fig 3(a) Existing impeller blade

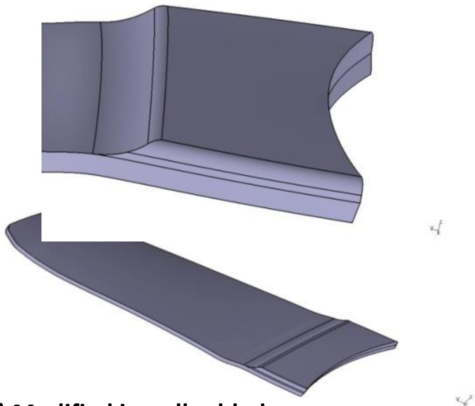

Fig 3(b) Modified impeller blade

The analysis is carried out in ANSYS. The load is applied on the surface of the blade of the impeller uniformly. The root of the blades is arrested in all degrees of freedom as it is fixed to the rim. The loaded blades are meshed using solid tetrahedron element.

3.4.1 Static Analysis with Material Variation

Initially, the blades are analyzed for three different materials to obtain the deformations and stress contours.

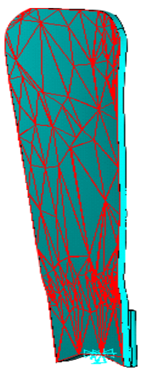

Fig 4: Meshed model

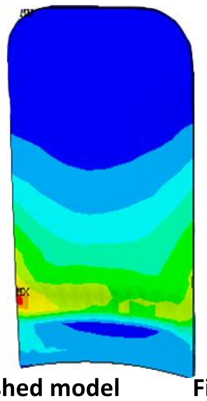

Fig 5: Stress Contours

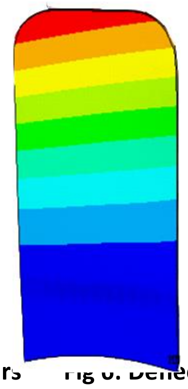

Fig 6: Deflection Contours

3.4.2 Static Analysis with Design Variation

Pressure is applied uniformly on the surface of the blade. The loaded blades (fig 7) are meshed with solid tetrahedron element and analyzed to obtain the stress contours (fig 8).

Fig 7: Boundary Conditions

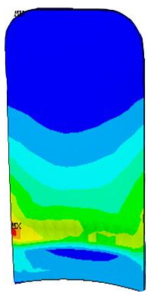

Fig 8: Existing Design

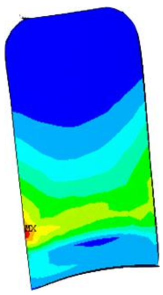

Fig 9: Modified Design

4. Result Analysis for Material Variation

The maximum induced stresses and deformations are obtained and presented in Table No.2 and Table 3 for the three materials. The maximum stress induced in all the three materials is 74.499 N/mm^2 since all the three belong to the stainless steel grade with no appreciable variation in their Young's Moduli. AISI 330 and AISI 904L fail when the load is increased by 40% and 50% of the maximum loads respectively. But for

Duplex Stainless Steel, even at higher loads at 150% of existing maximum load, the induced stresses are well below safe stress (i.e. 117.5 Mpa considering a factor of safety 2). It has the minimum deflections at all load variations when compared to the AISI330 and AISI 904L. It can be concluded that the Duplex Stainless Steel can safely withstand the existing maximum loads.

Table 2: Comparison of Stresses with Material and load Variations

Material	**Yield Stress Mpa**	**Permissible yield stress(FS=2) Mpa**	**Stress MPa**				
			At 100% pressure load	At 110% pressure load	At 130% pressure load	At 140% pressure load	At 150% pressure load
AISI 330	205	102.5	74.4999	81.949	96.849	104.299	111.749
AISI 904 L	215	107.5	74.4999	81.949	96.849	104.299	111.749
DUPLEX SS	**235**	**117.5**	**74.4999**	**81.949**	**96.849**	**104.299**	**111.749**

Table 3: Comparison of Deflections with Material and load Variations

Material	**Displacement mm**				
	At 100% pressure load	At 110% pressure load	At 130% pressure load	At 140% pressure load	At 150% pressure load
AISI 330	0.001923	0.002115	0.0025	0.002692	0.002885
AISI 904 L	0.001827	0.00201	0.002375	0.002558	0.00274
DUPLEXSS	**0.00161**	**0.001827**	**0.002325**	**0.002159**	**0.0024941**

Since the usage of Duplex Stainless Steel involves additional material costs, modification in design with the same material is the best suited alternative.

5. Result Analysis for Design Variation

The maximum induced stresses and deformations are obtained and presented in Table No.4 for both existing and modified designs. For existing blade, maximum stress induced is of 74.499 N/mm^2 and for modified blade, the maximum stress is only 69.379 N/mm^2, which is less than the induced stress of the existing blade. Even at higher loads at 150% of existing maximum load, the induced stresses are well below safe stress (i.e107.5 Mpa considering a factor of safety2). From Fig.11 and Fig 12, it can be concluded that the modified blade can safely withstand the existing maximum loads better than the existing design.

Table 5: Comparison of Stresses for Design Variation

Design	Yield Stress MPa	Permissible Stress MPa	At 100% pressure load	At 110% pressure load	At 130% pressure load	At 140% pressure load	At 150% pressure load
Existing Design	215	107.5	74.4999	81.949	96.849	104.299	111.749
Modified Design	**215**	**107.5**	**69.379**	**76.317**	**90.193**	**97.131**	**104.069**

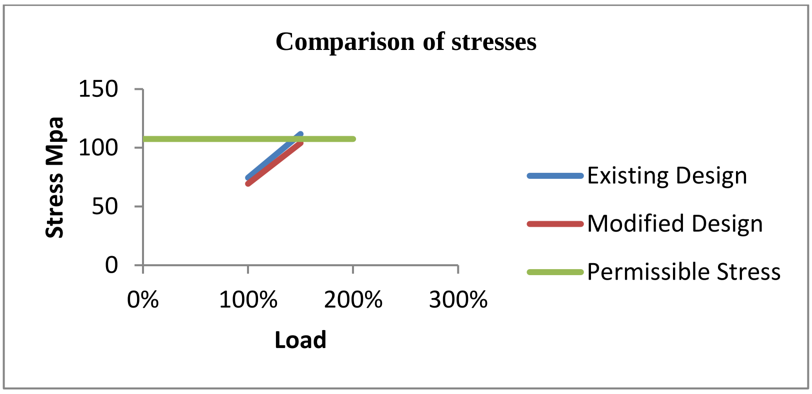

Fig 10: Comparison of Stresses with Design Variation

Table 6: Comparison of Deflections with Design Variation

Material	**Displacement mm**				
	At 100% pressure load	At 110% pressure load	At 130% pressure load	At 140% pressure load	At 150% pressure load
Existing Design	0.001827	0.00201	0.002375	0.002558	0.002748
Modified Design	0.001763	0.00194	0.002292	0.002469	0.002645

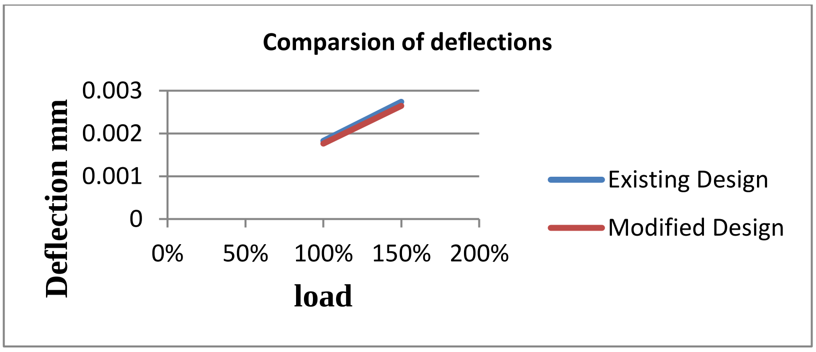

Fig 11: Comparison of Deflections with Design Variation

6. Acknowledgements

The authors are thankful to the Visakhapatnam Steel Plant, Design department, Visakhapatnam, INDIA for permitting and providing the necessary technical data related to Impeller to execute this project successfully.

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