Design, Static Structural & Model Analysis of Water Ring Vacuum Pump Impeller

Ajay A. Mali[1] Harshalkumar N. Patel[2] Siddhi J. Patel[3] Mohd. Ammar M. Shaikh[4]
[1,2,3,4]B.Tech Student
[1,2,3,4]Department of Mechanical Engineering
[1,2,3,4]Indus University, Ahmedabad, India

Abstract— Water ring vacuum pump is mostly used device in industries to generate vacuum. Water ring vacuum pump is a specific form of rotary positive displacement pump utilizing water as the principle element in gas compression. It could be used as a compressor also. The present paper describes an improvement in the performance of vacuum pump impeller. Due to the damage in one of few blades of the impeller the whole impeller needs to be changed, which increases the maintenance and replacement cost. But due to the designing and implementation of the impeller with removable blades the maintenance and replacement cost could be reduced. The design of the impeller with the removable blades has been done using the PTC CREO 3.0 software and the performance of the impeller has been checked in the ANSYS software for static structural and model analysis. The standard VWS200 series single stage vacuum pump is used as the reference for dimensions.

Key words: Water Ring Vacuum Pump, Vacuum Pump Impeller, Static Structural Analysis, Model Analysis, VWS200 Series

I. Introduction

Working principle of single stage WRVP: A water ring vacuum pump has an impeller with blades attached to a center hub located in a cylindrical body but off-set from the center. The blades near the top of the pump are closer to the outside wall than at the sides and bottom of the pump. The impeller sits between two end plates (port plates) which have shaped holes cut into them called ports. The pump requires a liquid (also called the sealant) to create vacuum. Prior to starting the pump, it should be partially filled with the liquid sealant. The liquid can be water, oil or a solvent, depending upon the application. When the pump starts, the impeller slings the liquid sealant, by centrifugal force, to the outside walls of the body forming a ring of water. Because the impeller is off-set from the body, some of the blades are fully immersed in water, and some are almost out of the water. The area of void space without water, is sealed off between the water and between the impeller blades, called an "impeller cell". As we follow one impeller cell from the top of the pump, counter-clockwise, you can see the water recedes from the center hub, acting as a water piston to create a larger cell. This is the suction of the pump, drawing in air, gases, or vapors through the "inlet port" at the sides of the impeller. After impeller cell passes the inlet port and travels toward the discharge port, the sealant water is forced back toward the center hub of the impeller, creating the compression step. As the impeller cell passes the discharge port the compression is at its highest and the gases, along with some of the liquid sealant, are exhausted through the discharge port to atmosphere. Although the diagrams show a very smooth ring of water, in actuality the liquid sealant is highly turbulent. Resulting in some of the liquid sealant being discharged with the gases.

A. Water Ring Vacuum Pump Features

a) Reliable simple design which involves only one rotating part
b) Can handle condensable vapors or even slugs of liquid in entrained in the gas steam without damage to pump or affecting pump performance.
c) Produces a steady non-pulsating gas flow when it is used as either a vacuum pump or compressor.
d) Resistance to contaminants entering with the gas stream these will be diluted and washed through the pump by the seal liquid.

B. The Information Needed To Accurately Size a Water Ring Vacuum Pump Includes

- Inlet pressure, usually expressed in mm of Hg
- Inlet temperature
- Mass flow rate, usually expressed in LB/hr and the molecular weight of fluid components
- Vapor pressure data for each fluid components
- Seal fluid data, if other than water: specific gravity, specific heat, viscosity, thermal conductivity, molecular weight and vapor pressure data.
- Temperature of the seal fluid or cooling water
- Discharge pressure.

II. Causes of the Pump Impeller Blades

A. Cavitation

Entrained vapor can be caused by number of factors. Vortex in the tank, insufficient water source, steam injection or incorrect NPSH conditions. Entrained vapor causes cavitation. The cavitation could be the loss of performance, wear to the impeller blades.

B. Incorrect Tools for Installation or Repair

Using a hammer to install impeller or shafts. They are delicate machines that can crack if struck with a hammer and impeller blades could be damaged.

C. Incorrect Impeller Adjustment

Incorrectly adjusting the impeller can lead to increased slippage in the pump, creating more turbulence inside the pump, lowering efficiency and increasing pressure inside the stuffing box which could be the reason of the damage of the impeller blades.

D. Using the Wrong Impeller

Using the wrong sized impeller for the pump causes the damage of the blades of the impeller.

E. Using Chemical Which Reacts with the Impeller

The utilization of the chemical in the pump which reacts chemically with the impeller blades can cause the damage of the impeller blades as shown in the figure 1.

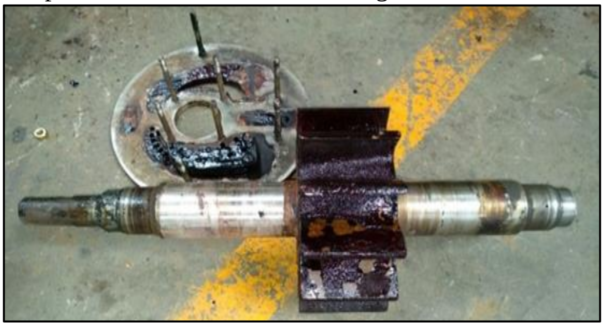

Fig. 1: (Damaged Impeller Blades by Chemical)

III. PURPOSE OF THE REMODELING

– Due to the reasons discussed above sometimes one or few blades of the impeller gets damaged. Because of that damage in one or few blades vacuum generation gets effected and reduced. For that damage, whole impeller needs to be removed. With the help of new design of the impeller with removable blades, the replacement cost of the impeller could be reduced.

– Most of the time after a long use of impeller, all the blades of the impeller get damaged. But the rotor and shaft remains undamaged. For the damage of blades the whole impeller setup needs to be removed. With the help of redesign that replacement cost could also be reduced.

IV. MODELING OF THE IMPELLER WITH REMOVABLE BLADES

Impeller is the important part of the vacuum pump as it displaces the water and force it to form water ring as the result of which air is trapped between the cavity of formed between two successive blade and drawing further rotation vacuum is created in pump as the expansion of trapped air takes place. Pump efficiency is more dependent on impeller of pump. The main design parameters of the impeller of this water ring vacuum pump are:

Number of blades	16
Rotational speed of impeller	1440
Flow rate	35LPM
Width of impeller	200 mm
Diameter of shaft	130 mm
Thickness of blade	15 mm

Table 1: Design Specification of Impeller

To study the effect of various parameters and the existing pump impeller has been remodeled using the CREO 3.0 software. The design specification of impeller is shown in the Table 1.

A. Redesign of the Removable Blade

The designing of the impeller blade is done with the reference of the original blades of the impeller of VWS200 series single stage water ring vacuum pump.

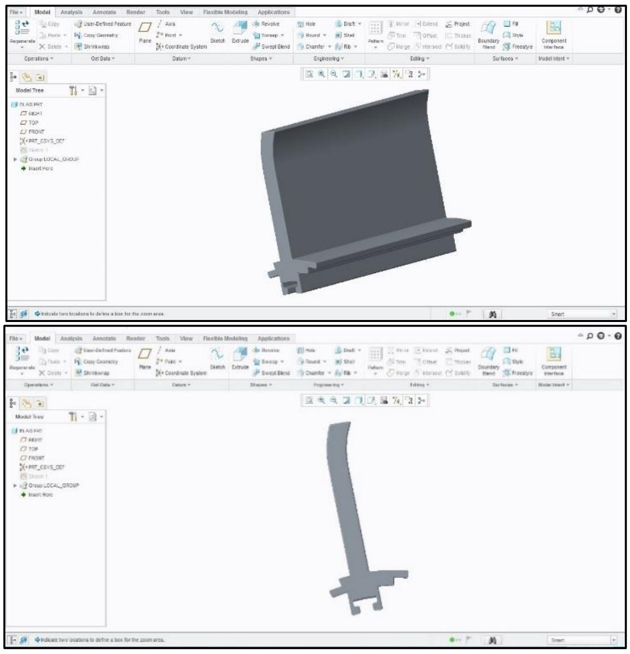

Fig. 2: (Remodeled Removable Blade)

The main feature of the blade is the T groove designed at the bottom of this blade. T shape section is designed on the rotor periphery. The T groove blade could be insert on the T section of the rotor. The blade is designed from the bottom for batter fitting in which upper part of the blade slot as shown is in the figure 2 will interact with the lower part of the other blade. With this kind of slot design vibration of the blades could be prevent.

B. Redesign of the Rotor

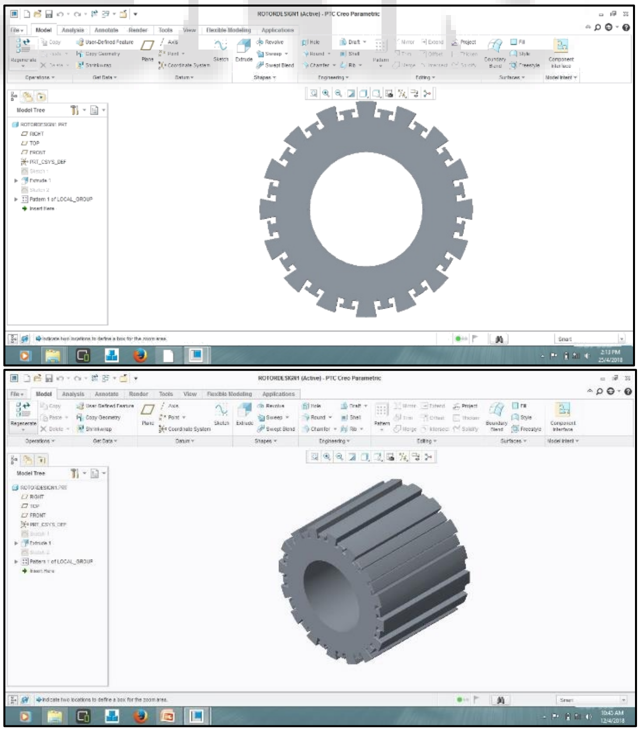

Fig. 3: (Remodeled Rotor)

The function and working of the redesigned rotor is similar to the original rotor. The main difference of the redesigned rotor is the T section on the periphery of the rotor. As discussed the function of the T section is to interact with the T groove of the blade and to support the blades. The redesigned rotor fits on the shaft of the impeller as the normal rotor of the vacuum pump.

C. Disassembly of the Redesign of the Impeller

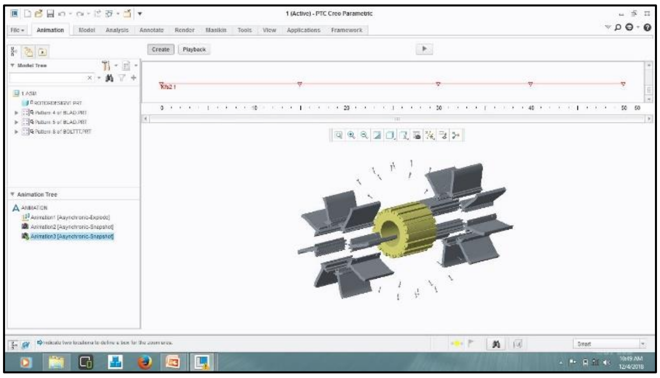

Fig. 4: (Remodeled Disassembly of the Impeller)

The disassembly of the impeller is shown in the figure 4. The blades will fit on the impeller as shown in the figure. Each and every blade could be removed or fitted separately. To make an interference fit between blades and rotor bolts are used in the design as shown in the figure.

D. Assembly of the REDESIGN of the IMPELLER

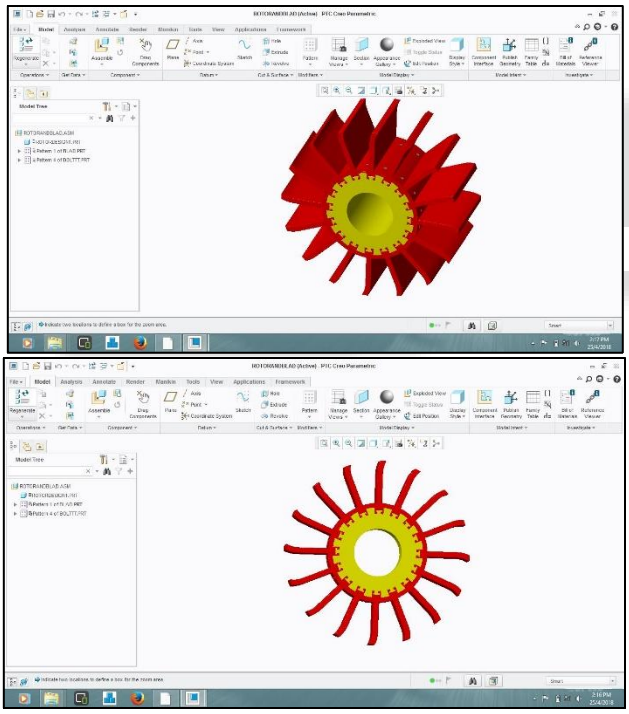

Fig. 5: (Remodeled Assembly of the Impeller)

The assembly of the impeller is shown in the figure 5. The redesigned impeller works as similar as the normal impeller. The blades fit on the rotor with the help of T slot design. Bolts make a strong fitting between rotor and blades. For any clearance between blades and rotor remaining which can cause vibration, there are many packing materials (for example champion sheet) could be used.

V. STATIC STRUCTURAL & MODEL ANALYSIS

The static structural and model analysis is the analysis of the stress, strain and displacement of the component. The ANSYS is used for the static structural analysis. As shown in the figure different types of color describes the level of stress and deformation on the component. Blue color describes the minimum stress area or the minimum deformation and red color describes the maximum stress area or the maximum deformation.

Force applied	1 KN
Pressure applied	1 MPa

Table 2

To study the effect of various forces and pressure the static structural and model analysis has done using ANSYS 14.0 software.

A. Static Structural Analysis of the Blade for Equivalent Stress (for 1KN Force):

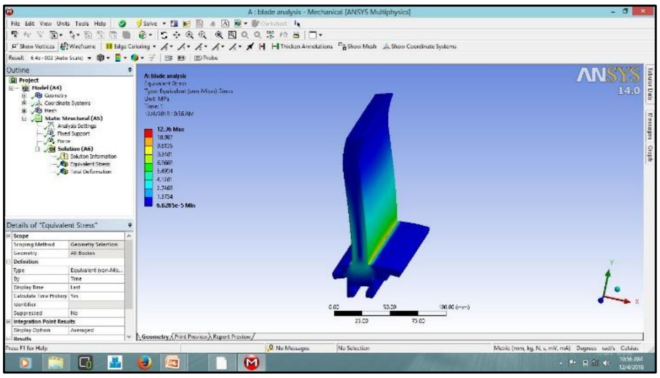

Figure 6 (Static Structural Analysis of the Blade For Stress)

The static structural analysis of the removable blade is shown in the figure 6. As discussed earlier the T shaped groove will fit in the rotor of the impeller. The figure shows the stress level in the blade. At the bottom side if the blade where the blade is connected, maximum stress is produced. And from the bottom of the blade to the top of the blade the level of stress gets decreased.

Highest stress	At the bottom of the blade	12.36 MPa
Medium stress	At the middle of the blade	4.1201 MPa
Lowest stress	At the top of the blade	$6*10^{-5}$ MPa

Table 3 (Static Structural Analysis of the Blade for Stress)

B. Static Structural Analysis of the Blade for Total Deformation (For 1KN Force):

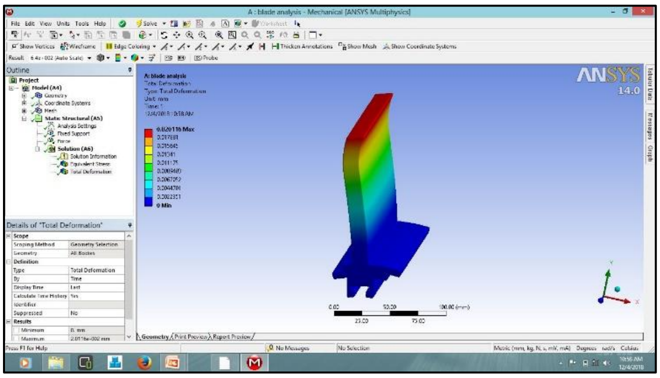

Fig. 7: (Static Structural Analysis of Blade for Total Deformation)

The given figure shows the deformation of the blade when force of water hits the blade. As shown in the figure 7 the maximum deformation occurs at the top of the blade, because when the deformation occurs the tip of the blade deflects maximum. At the bottom of the blade no deformation occurs because of the joint.

Highest deformation	At the top of the blade	0.020 mm
Medium deformation	At the middle of the blade	0.006 mm
Lowest deformation	At the bottom of the blade	0.000 mm

Table 4: (Static Structural Analysis of Blade for Total Deformation)

C. Static Structural Analysis of the Assembly of Impeller for Equivalent Stress (for 1 MPa pressure)

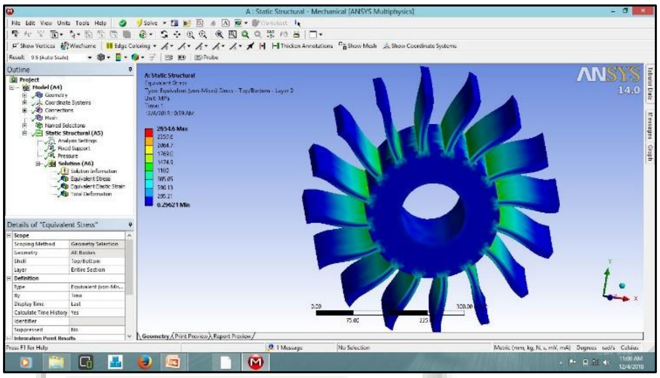

Fig. 8: (Static Structural Analysis of the Impeller Assembly for Stress)

The figure 8 shows the reaction of the impeller and the reaction of the removable blades when 1 MPa pressure is applied on the impeller. Maximum stress produces at the bottom of the blade where blade is in contact with the rotor. At the top of the blade minimum stress is produced.

Highest stress	At the bottom of the blades	1180 MPa
Medium stress	At the middle of the blades	295.21 MPa
Lowest stress	At the top of the blades	0.296 MPa

Table 5 (Static Structural Analysis of the Impeller Assembly for Stress)

D. Static structural analysis of the Assembly of Impeller for Total Deformation (for 1 MPa pressure)

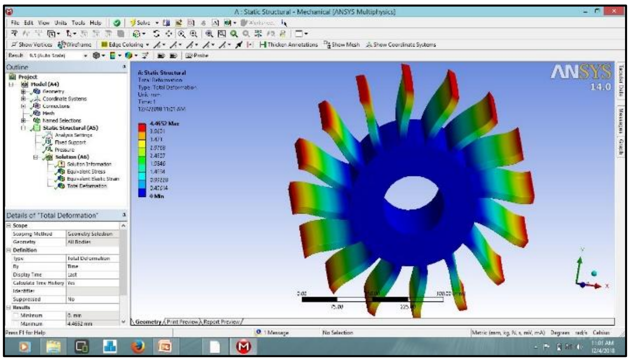

Fig. 9: (Static structural analysis of the impeller assembly for deformation)

The figure 9 shows the deformation of the impeller at 1 MPa pressure. As shown in the figure maximum deformation occurs at the tip of the blades. As pressure applied, all the blades react similarly. From the top of the blade to the bottom of the blade deformation gets reduce. And at the contact point of the blade and rotor, no deformation occurs.

Highest deformation	At the top of the blade tip	4.4652 mm
Medium deformation	At the middle of the blade	1.9846 mm
Lowest deformation	At the bottom of the blade	0.00 mm

Table 6: (Static Structural Analysis of the Impeller Assembly for Deformation)

E. Modal Analysis of the Impeller

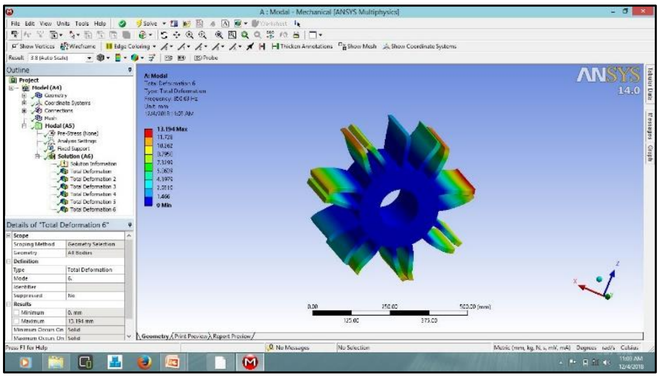

Fig. 10: (Model Analysis of the Impeller for Vibration)

The given figure 10 shows the model analysis of the impeller. When vibration occurs, the blades of impeller reacts in different way as shown in the figure. The frequency of the vibration is 850.63 Hz. On that frequency blades deform in different direction with each other.

Highest deformation	At the top of the tip of blade	13.194 mm
Medium deformation	At the middle of the blade	4.3979 mm
Lowest deformation	At the bottom of the blade	0.00 mm

Table 7 (Model Analysis of the Impeller for Vibration)

F. Static Structural Analysis of the Bolt (For 1 KN Shear Force)

Major diameter	5 mm
Minor diameter	4.2 mm
Pitch	1.5 mm
Length	30 mm
Thread tipe	V thread

Table 8: (Specification of Bolt)

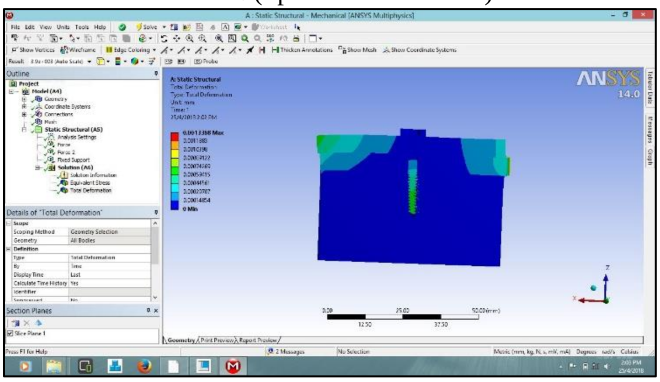

Fig. 11: (Static Structural Analysis of the Bolt)

The static structural analysis of the bolt is shown in the figure 11. The shear stress occurs on the bolt due to shear force of the upper and lower plate. The force is taken 1 KN for both the plates. Due to the shear force minor deformation occurs on the bolt as shown in the figure.

VI. CONCLUSION

A water ring vacuum pump which is used for purpose of creating vacuum. In WRVP all parts of that pump are very important for performance of pump and affect directly to the performance of vacuum pump. But most critical part of pump is impeller and impeller is heart of pump and its function needed very properly to get higher performance. In WRVP it is very difficult task to improve design of pump impeller by experimental study. So, the new design of the impeller is done in the CREO software. Also, to examine the effect of force and pressure on the remodeled impeller and to examine the reaction of the impeller on the vibration the static structural and model analysis is done in the ANSYS software.

In the WRVP impeller is most critical and important part so choose it for modification to improve performance and to reduce cost. We have seen that the change in the design will improve the performance of the impeller. But the main function of the remodeled impeller is removable blades. Due to the utilization of removable blades the cost of replacement and maintenance could be reduced. For the damage of one or few blades only those blades need to be removed and replaced. On the damage of all blades of the impeller only blades need to be removed, the rotor and the shaft on which rotor is attached are not to be removed. The new design will directly effect on the maintenance and replacement cost, which could be reduced in huge amount.

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