

# Optimization of Centrifugal Pump Impeller Outlet Vane Angle by Using Modal Analysis

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**Abstract:** A number of variety of centrifugal pump have been constructed and used in many different applications in domestics, Agricultural, industry and other technical sectors. Due to the great number of free geometric parameters, their design and performance prediction process is still a difficult task, mainly the effect of which cannot be directly evaluated. Centrifugal pumps consume huge amounts of energy in various industrial applications. Therefore for these pumps, the improvement of machine efficiency has become a major challenge. Since the hydraulic performance of a centrifugal pump strictly depends on its impeller shape, in the present work, an efficient and original approach has been developed and applied to the design of centrifugal pump impellers in order to achieve a higher efficiency. An overview of the different inlet and outlet volutes for radial impellers. In this paper vibration of pump minimize by changing the centrifugal pump impeller outlet vane angle. Initially published two paper shows designing the pump impeller with new angle system, CATIA part analysis in ANSYS workbench which finds out 6 mode of natural frequency of vibration. Here it is shown experimental Result and FFT analysis result of new pumping systems. Which shown Vibration minimize, Performance increasing and mathematically shown life improvement

**Keywords—** Centrifugal Pump, Centrifugal Impeller, Pump Vibration, FFT analysis, Impeller.

## I. INTRODUCTION

Centrifugal pump is a machine that imparts energy to a fluid. This energy can cause a liquid to flow or rise to a higher level. Centrifugal pump is an extremely simple machine which consists of two basic parts: The rotary element or impeller and the stationary element or casing. The centrifugal pumps are widely used in the world because the pump is robust, effective and inexpensive to produce. Centrifugal pumps are more economical to own, operate and maintain than other types of pumps. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power, come in many sizes, from microscopic for use in medical applications to large industrial pumps. Mechanical pumps serve in a wide range of applications such as pumping water from wells, aquarium filtering, pond filtering and aeration, in the car industry for water-cooling and fuel injection etc.

This paper detail study existing pump system and changing outlet vane angle create new systems. When design complete then these both systems experimentally studied and compare the result. What changess happens in new pumping system that's studied by experimentally, note down the vibration effect on performance and life of pump.

## II. IMPELLER DESIGN

Impellers directly connected with a balancing device were first patented in the 1990s, for instance (Korczak et al., 2005; Pavlenko, 2008). The distinctive feature of the design of the single-stage pump impeller described in the patent (Martsinkovsky et al., 1995) is the lack of a classic drive shaft linked to the rolling element bearings. Instead of a bearing node, there are longitudinal and lateral seal clearances of the impeller and the balancing device. The hydrodynamic forces and moments generated in these clearances position the impeller relative to the pump casing. The impeller is driven by a flexible shaft with a relatively small diameter. The small diameter of the shaft results from the torque passed from the motor via a ball joint to the impeller.

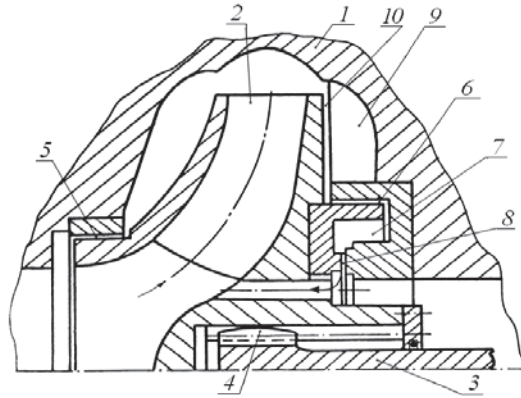


Fig.1. Pump impeller with a device:

1- pump casing, 2- impeller, 3- shaft; 4 – ball joint; 5, 6 –longitudinal seals of the impeller; 7 – annular chamber; 8- face seal; 9- radial vanes; 10 – lateral clearance of the impeller shroud.

#### A. IMPELLER DESIGN DATA

All below data generated for required Head  $h_P = 12\text{m}$  (Considering 30% head loss in overall pump systems), required flow rate:  $Q = 10.4\text{ LPS}$  and Required speed  $N = 2600\text{ RPM}$  by using appropriate formulas

Diameter of suction flange, $D_{su}$ -----	66mm
Velocity in suction flange, $V_{su}$ -----	3 m/s
Shaft diameter, $D_s$ -----	25 mm
Impeller hub diameter, $D_H$ -----	35 mm
Impeller eye diameter, $D_0$ -----	75 mm
Velocity through impeller eye, $V_0$ -----	3.1 m/s
Diameter of inlet vane edge, $D_1$ -----	75 mm
Velocity at inlet vane edge, $V_1 = V_{f1}$ -----	3 m/s
Passage width at inlet, $b_1$ -----	15 mm per side
Tangential velocity of inlet vane edge, $u_1$ -----	10.21m/s
Vane angle at inlet, $\theta$ -----	16 <sup>0</sup>
Impeller outlet diameter, $D_2$ -----	140 mm
Radial component of outlet velocity, $V_{r2}$ -----	3 m/s
Vane angle at outlet, $\phi$ -----	24 <sup>0</sup>
Total passage width at outlet, $b_2$ -----	9 mm
Tangential velocity of outlet vane edge, $u_2$ -----	19.1 m/s
Absolute velocity leaving impeller, $V_2'$ -----	9.2 m/s
Tangential component of absolute leaving velocity, $V_{w2}'$ -----	8.65 m/s
Angle of water leaving impeller, $\alpha$ -----	19 <sup>0</sup>
Number of impeller vanes, $z$ -----	6

#### B. IMPELLER MODEL

Using above data for the software and experimental method. In this study we calculate the impeller blade inlet angle from given data and change the impeller blade outlet angle from standard angle i.e.  $16^\circ$  to  $35^\circ$  it means we modify pump system at outlet blade angle and check the effect of that change on the performance and also effect on model by changing blade angle what change will happen on the vibration of pump. Impeller Model for vane outlet angle  $20^\circ$ ,  $24^\circ$ ,  $30^\circ$  and  $35^\circ$ . Modeling of Impeller is done using 3D software CATIA V5 R17.

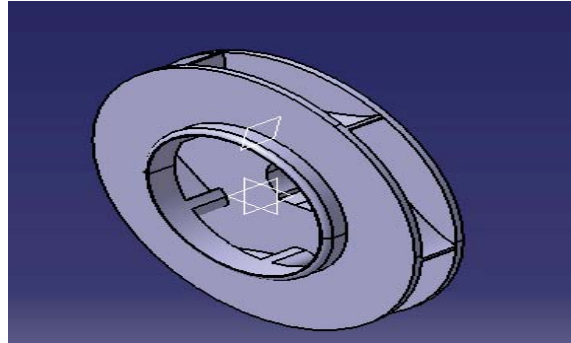


Fig 3: Centrifugal pump impeller catia part

### III. IMPELLER CHECK

As Impeller is made up by using Cast Iron and it is brittle material. When it is working condition that time load applied on the surface area of impeller is compressive in nature. So checking the impeller applying uniform compressive load and find out the maximum deformation of pump material. As deformation occurs it affect the performance of pump. Also considering pump work maximum allowable speed and find out vibration of pump and pump impeller. For the destruction of pump for vibration, when operating critical frequency of pump impeller match with the natural frequency of pump then destruction of pump occurs; so find out the natural frequency of pump impeller and our main aim is to keep the operating critical frequency below to natural frequency or always natural frequency greater than the operating critical frequency. This issue checks the pump using ANSYS V12 workbench for static structural load and modal analysis for vibration.

#### A. ANSYS V12 WORKBENCH FOR STATIC STRUCTURAL LOAD

In this case ANSYS V12 workbench used, in that case subpart static structural processor used for solution. In this case shaft hub used as fixed part and other loading condition used for all part of impeller uniform way. Rotation velocity of impeller is 2600 RPM; Hydrostatic pressure is  $16\text{m/s}^2$  and calculated bending moment  $277736\text{ N-m}$  is applying for find out the total deformation and Equivalent stress of pump impeller and in case of result section compared it for all four vane outlet angle  $20^\circ$ ,  $24^\circ$ ,  $30^\circ$  and  $35^\circ$ . Find out effect on impeller body when change in vane outlet angle  $20^\circ$ ,  $24^\circ$ ,  $30^\circ$  and  $35^\circ$ .

#### a. TOTAL DEFORMATION APPLYING STATIC LOAD

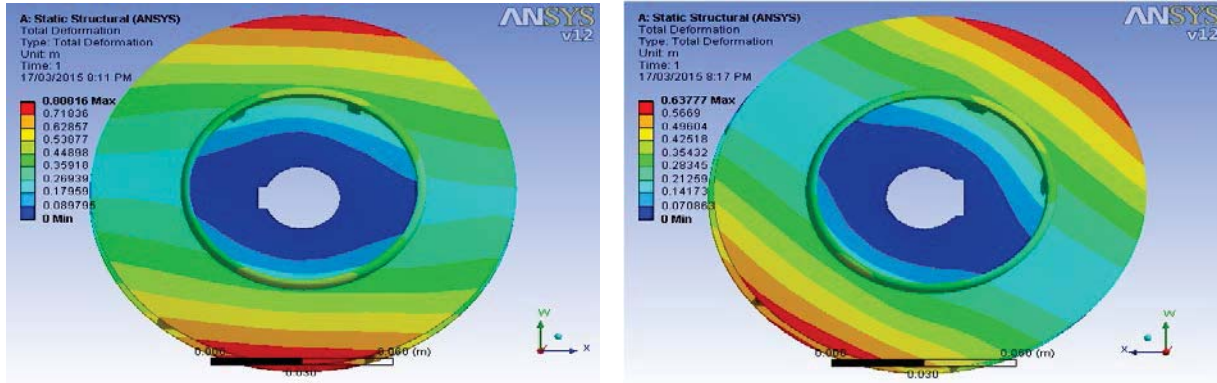


Fig 4: 24° and 30° outlet vane angle total deformation with static load condition

#### b. EQUIVALENT STRESS APPLYING STATIC LOAD

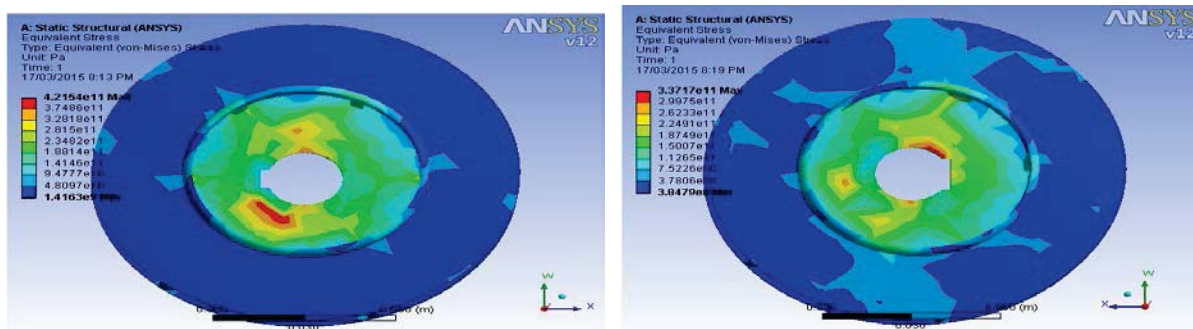


Fig 6: 24° and 30° outlet vane angle Equivalent stress with static load condition

### IV. VIBRATIONS IN CENTRIFUGAL PUMPS

It is necessary to be interested in vibration in centrifugal pumps because it has a major effect on the performance. Generally, increasing vibration levels indicate a premature failure, which always means that the equipment has started to destroy itself. It is so because excessive vibrations are the outcome of some system malfunction. It is expected that all pumps will vibrate due to response from excitation forces, such as residual rotor unbalance, turbulent liquid flow, pressure pulsations, cavitation, and/or pump wear. The magnitude of the vibration will be amplified if the vibration frequency approaches the resonant frequency of a major pump, foundation and/or piping component. Generally higher vibration levels (amplitudes) are indicative of faults developing in mechanical equipment.

#### A. MECHANICAL CAUSES OF VIBRATIONS

The mechanical causes of vibrations includes –

- Unbalanced rotating components,
- Damaged impellers and non concentric shaft sleeves
- Bent or warped shaft
- Pump and driver misalignment,
- Pipe strain (either by design or as a result of thermal growth),
- Inadequacy of foundations or poorly designed foundations
- Thermal growth of various components, especially shafts,
- Rubbing parts
- Worn or loose bearings, Loose parts,
- Loosely held holding down bolts

· Damaged parts.

### B. HYDRAULIC CAUSES OF VIBRATIONS

The hydraulic causes of vibrations includes –

- Operating pump at other than best efficiency point (BEP)
- Vaporization of the product
- Impeller vane running too close to the pump cutwater
- Internal recirculation
- Air entrapment into the system through vortexing etc.
- Turbulence in the system (non laminar flow),
- Water hammer.

### C. PERIPHERAL CAUSES OF VIBRATIONS

The peripheral causes of vibrations includes –

- Harmonic vibration from nearby equipment or drivers.
- Operating the pump at a critical speed
- Temporary seizing of seal faces

## V. ANSYS V12 WORKBENCH FOR MODAL ANALYSIS FOR VIBRATION

In this case ANSYS V12 workbench used, in that case subpart modal processor used for solution vibration check. In this case shaft hub used as fixed part and find out 6 mode of natural frequency of vibration. Find out the total deformation of pump impeller for lowest natural frequency of vibration and in case of result section compared it for all four vane outlet angle  $20^\circ$ ,  $24^\circ$ ,  $30^\circ$  and  $35^\circ$ . Find out effect on impeller body when change in vane outlet angle  $20^\circ$ ,  $24^\circ$ ,  $30^\circ$  and  $35^\circ$ .

### A. TOTAL DEFORMATION OF IMPELLER WHEN IT VIBRATES IN NATURAL FREQUENCY

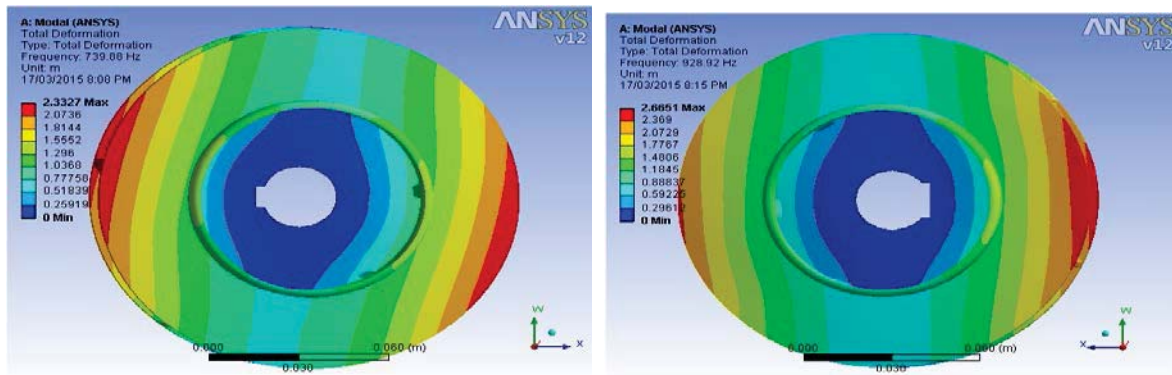


Fig 8:  $24^\circ$  and  $30^\circ$  outlet vane angle Total Deformation when it vibrates its natural frequency

### Experimentally Find Out Efficiency

The efficiency for 300 blade vane angle is find out 41.2%, for 240 it was found that 42.4%. This indicate that just changing the centrifugal pump outlet vane angle increase the performance. From this experimental result of performance and FFT result it is predict that resonance reduces and because of that efficiency goes on increasing. This is because of change the shock wave generation from 300 to 240. In 240 water discharge occurs was smooth as compare to 300 water discharge, this effect total performance of pump and also reduce vibration generation of pump. Hence assume when 5Hp pump run for 8Hr per day, as a vibration reduction increasing 1.2% efficiency of pump it save 1.2% power of 5Hp input power i.e.359Watt for a day, hence when it consider for 365days it save 131035 watt power save for one year. This type of saving occurs only changing the outlet vane angle, without any major change.

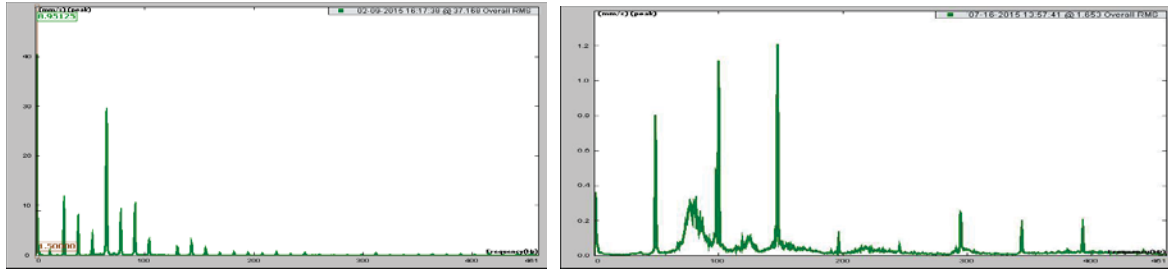


Fig. 10 : FFT result for old and new pumping systems

### Vibration Effect on Pump Life

When Pump is in working condition that time vibration of pump occurs certain limit. In our old pump system impeller outlet vane angle are 300 that time first natural frequency 0Hz and exciting frequency 60Hz are close to each other because of that vibration resonance occurs. Because of resonance NPSC and bearing life minimize. When NPSH is minimize as compare to required NPSH it increase the cavitation problem of centrifugal pump impeller which reduce H & Q generation by pump which directly effect on the efficiency of pump. For old pump system, i.e. 300 operating frequency from FFT result is 60 Hz For this speed NPSH is 7.7 m of water

Similarly for new pump system i.e. 240 N=1500Rpm For this speed NPSH is 10m of water head

Cavitation of impeller reduce the life of impeller and increase the noise and unbalance force on all parts. This unbalance force reduce the bearing life of pump and bearing failure occurs. Because of bearing failure Prime mover i.e. Electric motor failure occurs Vibration Forces are Vibration is a dynamic response to a dynamic force, and an increase in force is extremely detrimental to bearing life, then, we also know that an increase in vibration (which results from an increase in forces) produces a corresponding decrease in bearing life which can be calculated. Also, if we know the source of the vibration and can reduce or eliminate this force, then a subsequent increase in bearing life can be expected.

**Rule:** Excessive vibration = excessive force = a reduction in bearing life

## VI. RESULT DISCUSSION

In this study finally we analysis that vane outlet angle  $20^\circ$ ,  $24^\circ$ ,  $30^\circ$  and  $35^\circ$  changes then in case statical load applying we found that total deformation and Equivalent stress are also changes. Total deformation of impeller goes on changes when vane angle increase total deformation up to  $30^\circ$  goes on decreasing and then again increasing for vane angle  $35^\circ$ . Similarly Equivalent stress of impeller goes on changes when vane angle increase stress up to  $30^\circ$  goes on decreasing and then again increasing for vane angle  $35^\circ$ .

Similarly when vane outlet angle  $20^\circ$ ,  $24^\circ$ ,  $30^\circ$  and  $35^\circ$  changes then natural frequency of vibration changes in modal analysis when vane outlet angle  $20^\circ$  high natural frequency but it decrease for  $24^\circ$  again it increase for  $30^\circ$  and again it decrease for  $35^\circ$  but all natural frequency is greater than critical frequency of vibration which is 260Hz for 2600 RPM and 6 vanes by calculation hence all vane angle are best to sustain for vibration state.

Above all case we check the mechanical property for various vane outlet angles i.e.  $20^\circ$ ,  $24^\circ$ ,  $30^\circ$  and  $35^\circ$ . All cases are not affect the mechanical property of impeller material so this cannot use for selection of pump Impeller. We check the performance pump impeller by mathematical form then we obtained as vane angle change  $20^\circ$  to  $35^\circ$  then overall efficiency is same for all vane angle but mechanical efficiency goes on decreasing and manometric efficiency goes on increasing. But for vane outlet angle  $23^\circ$  to  $25^\circ$  mechanical as well as manometric efficiency are in selection condition so we prefer vane outlet angle  $24^\circ$  for 5HP pump to give high performance. From software result and Theoretical result it is conclude that 240 pump impeller is most suitable for avoiding structural deformation of pump impeller. Experimentation result of 240 pump impeller shows efficiency goes on increasing 1.2% and it considering comparatively efficiency increase 29.1%. Optimization of pump outlet vane angle is from 300 to 240 occurs that is 20% optimization of outlet vane angle possible

## VII. CONCLUSION

In this paper we have tried to emphasize the static load condition and vibrations in centrifugal pumps, its causes / sources and the diagnosis methods. It is shown how total deformation and vibration in centrifugal pump could be diagnosed and its remedies can be worked out on the basis of diagnosis.

- 1) We modify pump system by changing only impeller dimension without changing material properties
- 2) Developing Optimize Outlet vane angle of Centrifugal pump impeller improve overall efficiency as well as Manometric efficiency with considerable minimizing pump vibration
- 3) Saving Electric power
- 4) Increasing Life of pump by minimization of cavitation and also increase the life of prime mover by reducing bearing failure

#### FUTURE SCOPE OF STUDY

Minimization of Cost of manufacturing of 240 pump impeller by changing Iron casting material as a plasticreinforced material using which completely reduce corrosion problem and also with minimization of vibration problem and cavitation

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